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Original article

REGULATION OF THE PROCESS OF SOCIAL REPRODUCTION OF RURAL TERRITORIES UNDER DEPOPULATION CONDITIONS

D.V. Khripkova, K.A. Khripkov,
S.A. Vangorodskaya, G.N. Gaidukova

Abstract

Background. The article is devoted to the study of the problem of social reproduction of rural territories under depopulation conditions complicated with consequences of the COVID-19 pandemic. The study also includes the effect of the special military operation on country's rural border territories. According to authors, social reproduction is necessary to consider as self-regulated and regulated process of renewal of quantitative and qualitative resources of rural areas for stabilization of the rural socio-territorial community, overcoming of degradation processes and further sustainable growth. The aim of this article is to analyze modern reality regarding demographic processes taking place in rural territories and to identify the main directions in the regulation of the social reproduction process in rural areas. The paper has implemented the dispositions of rural residents regarding demographic potential and demographic trends, as well as the expert community in the regard of risks and threats to socio-demographic security of rural territories of the Central Black Earth Economic Region. It is noted that the statistics of Russian rural population' demographic development clearly shows the trend of depopulation of these areas which is determined not only with a combination of demographic factors, including the demographic transition, but also, perhaps to a greater extent, by socio-political and economic conditions.

Purpose. The objective of the present investigation is to study of the problem of social reproduction of rural territories under depopulation conditions complicated with consequences of the COVID-19 pandemic.

Materials and methods. When considering the process of social reproduction of rural areas, we will rely on the concept of rural networks developed by a team of authors led by Dutch economist Frederick Van der J.D Ploeg. Dutch scientists have

combined numerous theoretical concepts and ideas regarding rural development, rural networks, in their opinion, appear to be multidimensional, multifunctional with a multitude of intrasectoral interactions. In the framework of the proposed concept, scientists identify several conceptual blocks in the structure of rural networks (among them: endogeneity, sustainability, social structure of the population, social capital, etc.), which are in dynamic interaction.

The empirical basis of the study is made up of: 1) statistical data characterizing the birth rate, mortality rate, migration of the population; 2) complex of sociological investigations of the demographic potential and demographic trends in rural areas conducted un the Belgorod region in 2021-2024 by a team of scientists from the National Research Institute "Belgorod State University" which include the mass sociological questionnaire survey N=1000 (2021), series of focus-group interviews and expert surveys (N=50, annually).

Results. Our theoretical and empirical analyses allow us to formulate a number of practical recommendations to the authorities of various levels, business community and public structures, etc., aimed at improving the main parameters of demographic development of rural areas:

1. Formation of regional expert groups in the sphere of demographic development. "The problem of the efficiency and effectiveness of demographic processes and measures to regulate them affects the interests not only of civil servants and politicians making certain attempts to respond to demographic crises, but also of scientists engaged in the study of demographic challenges" – N.P. Goncharova writes.

The solution to the problem of strengthening the principle of scientific validity of demographic policy in rural areas requires large-scale involvement of experts in the development and implementation of demographic development programmes and projects. In our opinion, the selection of experts should be differentiated and involve scientists specialising in different fields of knowledge, in particular, experts in demography, sociology of management, sociology of family, sociology of youth, social gerontology. This will allow for a targeted and more concentrated approach to the development of projects and programmes for demographic development.

Modern digital technologies make it possible to search for experts throughout the country and ensure their inclusion in the working process. It is promising to create an electronic database of experts in the field of demographic development, which in parallel functions as an interactive platform for discussing issues and problems of demographic development, and which in the future can be used to organise open online conferences, forums and symposia.

2. Development of science-based comprehensive monitoring of the regional demographic policy performance. The objectively demanded tendency to search for new

tools and technologies of demographic development of rural areas implies the development and implementation of systems of indicators for assessing regulatory impacts.

In a turbulent and highly dynamic society, the problem of indicators and indicators with the help of which it is possible to assess the effectiveness/efficiency of the demographic policy is of great importance. Today it is necessary to scientifically substantiate and develop indicators that will allow us to assess the sociodynamics of demographic processes. They should reflect their objective and subjective sides.

Based on the analysis and synthesis of state and regional documents in the field of demography, generalisation of information sources, including the Federal State Statistics Service data, we propose a set of indicators, which should be monitored and allow to assess the effectiveness of demographic policy in rural areas: a) monitoring of the reproduction plans of the population; b) monitoring of population' incomes and participation in social programs; c) monitoring of population' state of health; d) monitoring of the quality and accessibility of services in such spheres as education, healthcare and social services, promotion of employment; e) monitoring of infrastructure' quality; f) sociological survey "Demographic wellbeing of the population of rural territories".

The proposed indicators are assessed using a set of methods, such as: evaluation of information in official sources, data on adopted and existing legislative acts and program documents in the field of the demography and family policy; official statistical data describing the demographic and socio-economic situation available on the website of the Federal State Statistics Service, as well as in the Unified Interdepartmental Information Statistical System; data from periodic sample surveys of the Federal State Statistics Service on demographic problems; and data on the demographic and socio-economic situation in the Russian Federation.

3. Creation of regional and municipal Centers for the support of social practices of active longevity. The methodology of preserving and developing the resource potential of the older generation is proposed to be used more widely, which allows for a differentiated approach to the formation of an active longevity strategy, taking into account the capabilities and motivation of different groups of elderly and old people.

Conclusion. In the conditions of modern dynamically changing reality, the prospects of demographic development of rural areas are ambiguous, and forecasting the situation regarding demographic development is difficult. At present, in the era of turbulence of socio-economic processes, there is no agreement in the demographic forecasts of researchers.

In modern conditions, scientific and methodological support and systematic monitoring of demographic processes in rural areas become the key to prompt and adequate response to demographic challenges.

Keywords: depopulation; rural territories; demographic development; social reproduction; socio-demographic security

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Научная статья

РЕГУЛИРОВАНИЕ ПРОЦЕССА СОЦИАЛЬНОГО ВОСПРОИЗВОДСТВА СЕЛЬСКИХ ТЕРРИТОРИЙ В УСЛОВИЯХ ДЕПОПУЛЯЦИИ

Д.В. Хрипкова, К.А. Хрипков,
С.А. Вангородская, Г.Н. Гайдукова

Аннотация

Обоснование. Статья посвящена изучению проблемы социального воспроизводства сельских территорий в условиях депопуляции, осложненной последствиями пандемии COVID-19. Исследуется также влияние специальной военной операции на сельские приграничные территории страны. По мнению авторов, социальное воспроизводство необходимо рассматривать как саморегулируемый и регулируемый процесс обновления количественных и качественных ресурсов сельских территорий для стабилизации сельского социально-территориального сообщества, преодоления деградационных процессов и дальнейшего устойчивого роста. Целью данной статьи является анализ современных реалий в отношении демографических процессов, происходящих на сельских территориях, и выявление основных направлений в регулировании процесса общественного воспроизводства на селе. В работе реализованы диспозиции сельских жителей относительно демографического потенциала и демографических тенденций, а также экспертного сообщества в отношении рисков и угроз социально-демографической безопасности сельских территорий Центрально-Черноземного экономического района. Отмечается, что статистика демографического развития сельского населения России наглядно демонстрирует тенденцию депопуляции этих территорий, которая определяется не только совокупностью демографических факторов, включая демографический переход, но и, возможно, в большей степени, социально-политическими и экономическими условиями.

Цель. Целью данного исследования является изучение проблемы социального воспроизводства сельских территорий в условиях депопуляции, осложненной последствиями пандемии COVID-19.

Материалы и методы. Рассматривая процесс социального воспроизводства сельских территорий, мы будем опираться на концепцию сельских сетей, разработанную коллективом авторов под руководством голландского экономиста Фредерика Ван дер Дж.Д Плоэга. Голландские ученые объединили множество теоретических концепций и идей, касающихся развития сельских территорий, сельские сети, по их мнению, представляются многомерными, многофункциональными с множеством внутриотраслевых взаимодействий. В рамках предложенной концепции ученые выделяют несколько концептуальных блоков в структуре сельских сетей (среди них: эндогенность, устойчивость, социальная структура населения, социальный капитал и т.д.), которые находятся в динамическом взаимодействии.

Эмпирическую базу исследования составляют: 1) статистические данные, характеризующие рождаемость, смертность, миграцию населения; 2) комплекс социологических исследований демографического потенциала и демографических тенденций в сельской местности, проведенных в Белгородской области в 2021-2024 гг. коллективом ученых НИУ «БелГУ», включающий массовый социологический анкетный опрос N=1000 (2021 г.), серию фокус-групповых интервью и экспертных опросов (N=50, ежегодно).

Результаты. Проведенный нами теоретический и эмпирический анализ позволяет сформулировать ряд практических рекомендаций для органов власти различных уровней, бизнес-сообщества, общественных структур и т.д., направленных на улучшение основных параметров демографического развития сельских территорий:

1. Формирование региональных экспертных групп в сфере демографического развития. «Проблема эффективности и результативности демографических процессов и мер по их регулированию затрагивает интересы не только государственных служащих и политиков, предпринимающих определенные попытки реагирования на демографические кризисы, но и ученых, занимающихся изучением демографических вызовов».

Решение проблемы усиления принципа научной обоснованности демографической политики на селе требует масштабного привлечения экспертов к разработке и реализации программ и проектов демографического развития. На наш взгляд, отбор экспертов должен быть дифференцированным и включать ученых, специализирующихся в разных областях знаний, в частности, экспертов в области демографии, социологии управления, социологии семьи, социологии молодежи, социальной геронтологии. Это позволит обеспечить адресный и более концентрированный подход к разработке проектов и программ демографического развития.

Современные цифровые технологии позволяют искать экспертов по всей стране и обеспечивать их включение в рабочий процесс. Перспективным представляется создание электронной базы данных экспертов в области демографического развития, которая параллельно функционирует как интерактивная площадка для обсуждения вопросов и проблем демографического развития, и которая в дальнейшем может быть использована для организации открытых онлайн-конференций, форумов и симпозиумов.

2. Развитие научно обоснованного комплексного мониторинга эффективности региональной демографической политики. Объективно востребованная тенденция поиска новых инструментов и технологий демографического развития сельских территорий предполагает разработку и внедрение систем индикаторов для оценки регулирующих воздействий.

В условиях турбулентного и высокодинамичного общества проблема индикаторов и показателей, с помощью которых можно оценить результативность/эффективность демографической политики, имеет большое значение. Сегодня необходимо научно обосновать и разработать показатели, которые позволят оценить социодинамику демографических процессов. Они должны отражать их объективные и субъективные стороны.

На основе анализа и обобщения государственных и региональных документов в области демографии, обобщения источников информации, в том числе данных Федеральной службы государственной статистики, мы предлагаем набор показателей, мониторинг которых позволит оценить эффективность демографической политики в сельской местности: а) мониторинг планов воспроизводства населения; б) мониторинг доходов населения и участия в социальных программах; в) мониторинг состояния здоровья населения; г) мониторинг качества и доступности услуг в таких сферах, как образование, здравоохранение и социальное обслуживание, содействие занятости; д) мониторинг качества инфраструктуры; е) социологическое исследование «Демографическое благополучие населения сельских территорий».

Для оценки предлагаемых показателей используется комплекс методов, таких как: оценка информации в официальных источниках, данные о принятых и действующих законодательных актах и программных документах в области демографии и семейной политики; официальные статистические данные, характеризующие демографическую и социально-экономическую ситуацию, размещенные на сайте Федеральной службы государственной статистики, а также в Единой межведомственной информационной статистической системе; данные периодических выборочных обследований Федеральной службы государственной статистики по демографическим проблемам; данные о демографической и социально-экономической ситуации в Российской Федерации.

3. Создание региональных и муниципальных Центров поддержки социальных практик активного долголетия. Предлагается более широкое использование методологии сохранения и развития ресурсного потенциала старшего поколения, что позволяет дифференцированно подходить к формированию стратегии активного долголетия с учетом возможностей и мотивации различных групп пожилых и старых людей.

Заключение. В условиях современной динамично меняющейся действительности перспективы демографического развития сельских территорий неоднозначны, а прогнозирование ситуации с демографическим развитием затруднено. В настоящее время, в эпоху турбулентности социально-экономических процессов, в демографических прогнозах исследователей нет согласия.

В современных условиях научно-методическое обеспечение и систематический мониторинг демографических процессов в сельской местности становятся залогом быстрого и адекватного ответа на демографические вызовы.

Ключевые слова: депопуляция; сельские территории; демографическое развитие; социальное воспроизводство; социально-демографическая безопасность

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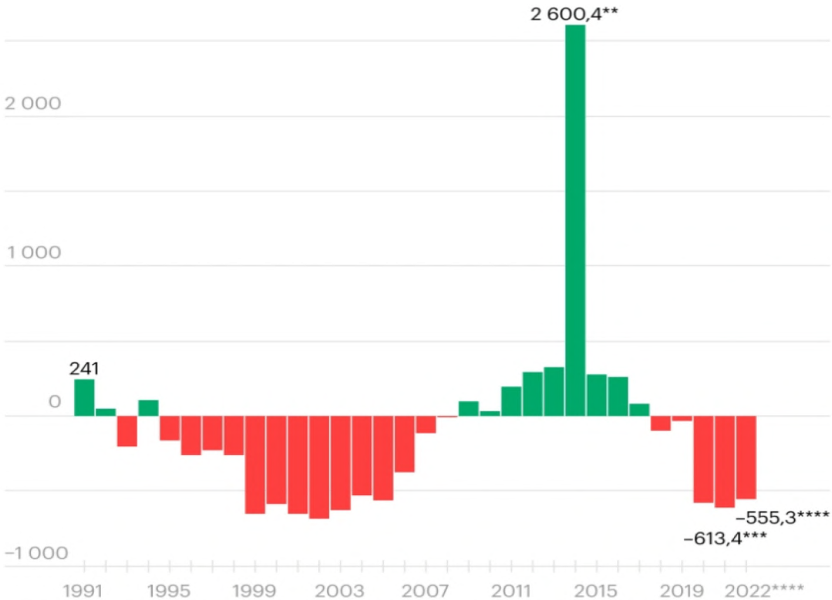
Introduction

One of the strategic objectives of the Russian State Policy is the solvation of urgent problems in the sphere of demography. The abovementioned goal is particularly relevant in modern conditions of significant changes, both in their characteristic and possible consequences, composition and size of the population. Investigations of the Human Capital Multidisciplinary Research Centre state that "demographic waves are typical for Russia – fluctuations in the number of births and individual age groups due to both demographic and socio-economic natures. In some years they soften, for instance, in Russia in 2000-s, and in others, such as in the 2020-s, on the contrary, they intensify these trends" [1]. Official data from the Federal State Statistics Service attests that "constant number of Russian residents as of the 1st January 2023 was 146.425 million people and was down 555 thousand (minus 0.38%) over the year. This follows from the preliminary estimate of the resident population posted by the Federal State Statistics Service on 31 January" [2] – Fig.1.

Population size of the RSFSR* as of the 1st January 1991 – 148.27 million.

Population size of Russia* as of the 1st January 2023 – 146.425 million.



**Data about the change of Russia's population size in 2014 included Crimea's residents for the first time

***Changes for 2021 excluding census

****Changes for 2022 including census

Fig. 1. Dynamic of the population size of the Russian Federation, thousands of people [2]

Modern processes of rural depopulation represent one of the key socio-economic problems that have a significant impact on the sustainability and development of agricultural regions. Population decline, increased migration processes, as well as a decrease in the birth rate and aging of the population lead to transformations of the social potential of rural communities and, as a result, to disruption of the mechanisms of social reproduction. In these conditions, it becomes critically important to develop and implement effective regulatory strategies aimed at stabilizing and replenishing the social capital of rural areas.

The process of social reproduction in rural areas encompasses the formation and maintenance of socio-demographic, cultural and economic conditions that ensure the qualitative and quantitative renewal of the population and labor resources. Depopulation, acting as a systemic factor, reduces the level of accessibility of social benefits, complicates the functioning of infrastructure and undermines traditional social ties, which dictates the need for an integrated approach to managing the reproduction process.

In common, the relevance of the topic is due to the contradiction between the need to preserve and develop rural areas as the most important elements of the national socio-economic system and the increasing demographic risks caused by depopulation.

Demographic processes are currently undergoing significant changes under the influence of several key factors. First, the COVID-19 pandemic, which has made significant adjustments to the dynamics of population development. The impact of the spread of the virus and related restrictive measures has affected not only the reproduction rates of the population, but also the psychological attitudes and life strategies of citizens, thereby exacerbating a number of existing socio-economic difficulties.

Secondly, the processes of accelerated automation and digitalization of the economic sphere have an important impact, which transform the structure of labor activity and social relationships, having an indirect impact on the demographic situation and social behavior of the population. I.E. Kalabikhina emphasizes that «under the influence of digitalization the preconditions for inequality of different demographic groups in the near future are being formed. Digitalization of the economy can affect different socio-demographic groups in different ways: women and men, young and old, households with and without children, urban and rural dwellers. <…> It is crucial today to systematize the directions of possible mutual influences of demographic development and digitalization” [3, p. 149].

The third factor is the increased risks and uncertainty caused by the Special military operation and its economic and geopolitical consequences. This has the greatest impact on the border areas – Belgorod, Kursk and Voronezh regions. As a result of the special operation, there is a massive outflow of the economically active population from Russia, while an increase in the birth rate is not noted and is not predicted. According to experts, “the main impact on the birth rate in Russia will be indirect, because families will not be able to plan for the birth of children. The longer the mobilization lasts, the greater the impact. The Russian economy is already experiencing a shortage of young workers and is in danger of stagnation, which may last a long time after the special operation" [4]. As I. Yefremov notes, "if hostilities continue in the coming months, as expected, less than 1.2 million people may be born in Russia next year, which is the lowest figure in modern history" [4]. Thus, experts agree that the consequences of the pandemic, as well as "the consequences of the February and especially September events, will be perhaps the most serious demographic challenge for Russia in recent history" [5], including because "the anxiety level has jumped higher now than at the beginning of the special military operation and at the peak of the pandemic" [5].

All three of the above factors have a complex impact on the demographic situation. On the one hand, they pose significant challenges: increased risks and uncertainty reduce the attractiveness of living in border regions, lead to an outflow of economically active population and exacerbate demographic decline, especially in terms of fertility. On the other hand, such conditions can stimulate government support measures, resource mobilization, and social programs aimed at stabilizing and developing regions, which can potentially mitigate negative trends. Thus, the influence of factors is ambiguous and requires a comprehensive analysis to develop an effective demographic policy.

Insufficient development of infrastructure, especially social infrastructure, relatively low-income levels, and limited employment opportunities exacerbate the process of rural depopulation. This demographic trend is observed in most developed countries of the world, including Russia, and is characterized by a demographic imbalance, when rural areas become donors of population for agglomerations.

The researchers note that "the rural population in Russia is rapidly declining both in absolute and relative terms. Long-term trends towards a progressive (without returning to the indicators of previous years) decline in the rural population began to take shape in the RSFSR by the end of the 50s of the XX century" [6, p. 152]. In turn, A.A. Vyalshina emphasizes that "in parallel with the desertification of significant territories in part of the population, there is also a so-called 'desertification in terms of services' (for example, 'medical desertification', lack of banking services, poor-quality Internet). Rural areas located near urban centers are involved (actively involved) in the processes of economic, transport and infrastructural development due to counter-urbanization, labor migration or secondary residence. While in remote areas, the gap between urban and rural areas turns many residents into a kind of 'second-class citizens', as its consequences increase internal social inequality and worsen the situation of the most vulnerable groups of the population" [7].

Currently, ensuring the sustainable development of rural areas and, as a result, their social reproduction is of particular importance in demographic policy.

Considering the concept of social reproduction, we will rely on the methodological principles of population reproduction, however, we will take into account not only the quantitative change in the population, but also the transformation of its qualitative characteristics. In this regard, we consider the social reproduction of rural territories as a self-regulated and regulated process of renewing the quantitative and qualitative resources of rural territories necessary to stabilize rural socio-territorial communities, overcome degradation processes and ensure its sustainable further growth.

The purpose of the article is to identify the main directions of regulating the social reproduction of rural areas based on the analysis of demographic processes taking place in them.

Purpose. The aim of the article is to analyze the current reality regarding the demographic processes occurring in rural areas and to identify the main directions of regulating the process of social reproduction of rural areas.

Materials and methods

When considering the process of social reproduction of rural areas, we will rely on the concept of rural networks developed by a team of authors led by Dutch economist Frederick Van der J.D Ploeg [8]. Dutch scientists have combined numerous theoretical concepts and ideas regarding rural development, rural networks, in their opinion, appear to be multidimensional, multifunctional with a multitude of intersectoral interactions. In the framework of the proposed concept, scientists identify several conceptual blocks in the structure of rural networks (among them: endogeneity, sustainability, social structure of the population, social capital, etc.), which are in dynamic interaction.

In addition, the work is based on the concept of sustainable development. This concept considers rural development through the prism of a balanced interaction of economic, social and environmental factors, which makes it possible to ensure the long-term viability of rural communities. Within the framework of sustainable development, the emphasis is on preserving natural resources, strengthening the social structure, developing the local economy and improving the quality of life. The work of Teresa de Noronha Vaz and Peter Neukamp "Multitasking in rural areas: Technological change and sustainable development" is of methodological interest. The study pays special attention to the demographic characteristics of rural regions, which affect the employment structure and the possibilities of using technology. The authors show that the introduction of technology and the ability to perform several types of activities simultaneously (multitasking) make it possible to maintain employment and involve a wider age range of the population, including youth and the elderly. Technological changes are contributing to the creation of jobs that do not require a permanent presence in the city center. This reduces the level of migration from rural areas and contributes to demographic stabilization [15, p. 111].

The empirical basis of the study was:

Statistical indicators reflecting the levels of fertility, mortality and migration of the population;

The results of comprehensive sociological studies of the demographic potential and trends in the development of rural areas of the Belgorod region, conducted by a team of scientists from the National Research University "Belgorod State University" in the period from 2021 to 2024. This includes a massive questionnaire survey with a sample of 1,000 people conducted in 2021, as well as a series of focus group interviews and expert surveys with 50 participants, which were conducted annually.

Results

The demographic situation in rural areas of Russia is characterized by an ageing population, low birth rate, high mortality and active migration outflow, which causes a pronounced demographic trend of rural population loss.

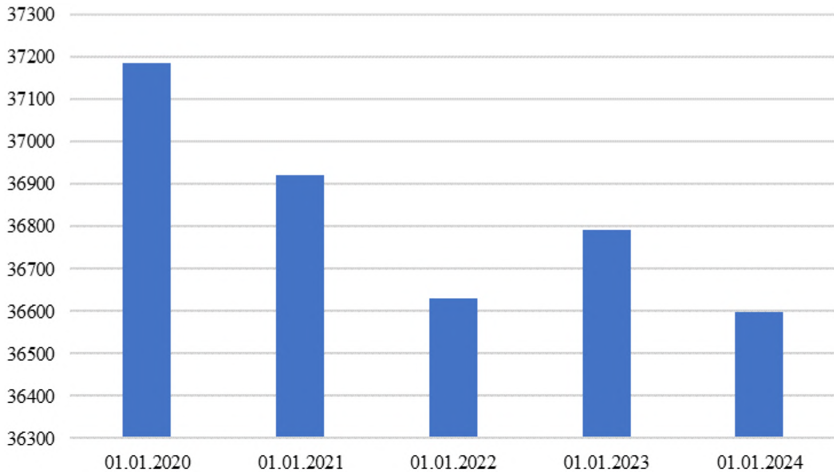


Fig. 2. Change in the rural population in the Russian Federation in 2020-2024, thousands of people

The processes of rural population loss continue to increase due to both natural population decline and migration outflow. The analysis of changes in the rural population of the Russian Federation has shown that over the last five years it has decreased by 588.2 thousand people – Fig. 2. When extending the time range and comparing 2024 with 2010, the reduction in the rural population of the country will amount to more than 3 million people or 8.6%.

The citizens living in rural areas surveyed by us in the course of sociological research noted the negative dynamics of mortality, fertility and migration rates and expressed their conviction that "the situation will not change" in the near future (94%).

As for the representatives of the expert community, most of them noted that "the current reality regarding demographic processes in rural areas can be described as 'risky'" (74%). Experts have identified the main threats to the socio-demographic security of rural areas of the Central Black Earth region: a decrease in the birth rate to a critically low level – less than 1.3 children per 1 woman of reproductive age (38.7%), an increase in imbalances in the sex and age structure of the population, in particular, population aging, gender imbalance (77.4%), as well as increased migration outflow, and as a result, a decrease in human capital (83.9%) – Fig. 3.

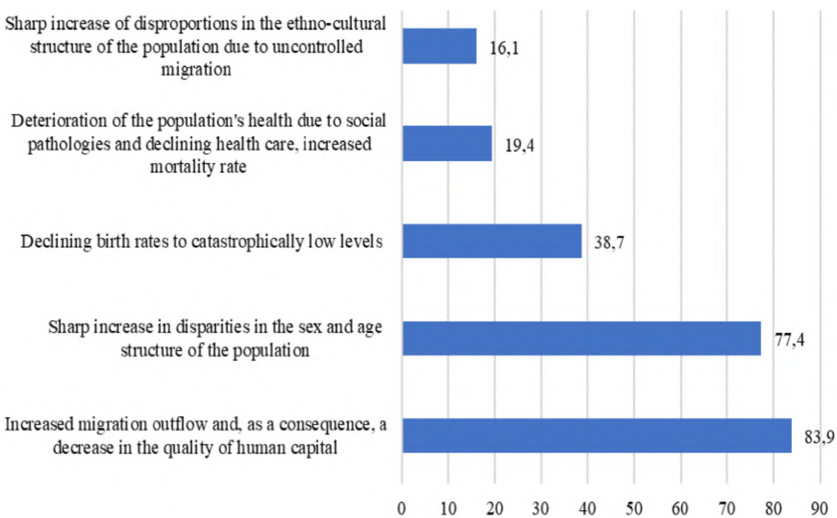


Fig. 3. Distribution of experts' answers to the question: "What threats to socio-demographic security in rural areas of the Central Black Earth Region, from your point of view, are most likely to materialize in the next 10 years? (specify up to 3 answer options)", %

According to experts, most of these threats can be realized in the next 10 years, while the greatest concern is the increased migration outflow and the associated decrease in the quality of human capital, as indicated by 83.9% of respondents. This indicates a critical problem of leakage of labor and intellectual resources from rural areas, which negatively affects its development. The second most important factor is the sharp increase in imbalances in the gender and age structure of the population, selected by 77.4% of experts, which indicates a demographic imbalance with a predominance of elderly residents and a shortage of young people. A decrease in the birth rate to a catastrophically low level was noted by 38.7% of respondents, which exacerbates the long-term problems of population reproduction. The deterioration of public health, as well as a sharp increase in imbalances in the ethno-cultural structure of the population, are assessed as less likely, but still significant threats, with indicators of 19.4% and 16.1%, respectively.

Indeed, in today's unstable and rapidly changing social and economic environment, demographic prospects seem ambiguous. As V.G. Dobrokhleb notes, "for the third year, the Russian population has been in a situation of a 'perfect storm': in the context of the COVID-19 pandemic, rapid technological changes associated with the digitalization of the entire living space, and increasing international tensions taking place against the background of the aging of the country's population" [9, p. 67]. This creates additional challenges for ensuring demographic sustainability, especially in rural regions of the Central Black Earth region. In the current era of turbulence of socio-economic processes, "there is no agreement in the demographic forecasts of researchers" [10, p. 86], which underlines the complexity and ambiguity of forecasting the demographic development of territories.

Experts suggest using a range of technologies to overcome the current demographic and social situation. First of all, digitalization of healthcare and the introduction of telemedicine have great potential to reduce mortality from chronic diseases by 15-20% in five years, which is important in the context of an aging population. Automation and robotization of agriculture can increase the productivity of the Central Black Earth regions by 25-30%, creating economic incentives to retain the young population. Digital educational platforms and retraining programs will reduce youth unemployment to 10% in 3-4 years, improving employment in remote and rural areas. The development of smart cities with modern infrastructure is designed to improve the quality of life and attractiveness of the regions, contributing to population growth by 5-7% in the long term. Also, the introduction of digital services to support young families –

unified social assistance portals and mortgage programs – will help increase the birth rate by 10-15% in the target territories. With investments of about 1-2% of GDP annually, the integrated implementation of these technologies will help stabilize the demographic situation and ensure socio-economic development in the region.

Experts unanimously recognize regional authorities as the main subject of demographic policy, since they are the ones closest to the real problems and needs of the local population. It is the regional authorities that have the necessary resources and powers to adapt federal programs to the specifics of specific territories, taking into account their socio-economic and cultural characteristics. In addition, they effectively interact with the local community, businesses and social institutions, which allows them to quickly respond to changes in the demographic situation and implement targeted support measures. This approach contributes to a more accurate allocation of funds and an increase in the effectiveness of demographic initiatives, which is critical for the sustainable development of the regions.

According to 95.7% of experts, today there is an objective need to improve the tools used by government authorities to manage the demographic development of rural areas. Our theoretical and empirical analysis allows us to formulate a number of practical recommendations designed to improve the indicators of social reproduction of rural areas in conditions of depopulation.

1. *Formation of regional expert groups in the field of demographic development*. As N.P. Goncharova notes, “the problem of the effectiveness and efficiency of demographic processes and their regulatory measures affects the interests of not only civil servants and politicians who are making certain attempts to respond to demographic crises, but also scientists involved in the study of demographic challenges” [11, p.14]. The formation of regional expert groups in the field of demographic development is one of the key measures aimed at improving the effectiveness of demographic process management at the local level. Such groups should consist of qualified specialists from various fields: demographers, sociologists, economists, representatives of government authorities and public organizations, as well as experts working directly with rural areas. The main task of these teams is a comprehensive analysis of the socio-demographic situation, taking into account regional and local characteristics, which makes it possible to identify the causes of depopulation and develop adaptive strategies to reduce it. Regional expert groups ensure regular monitoring of key indicators of demographic potential, as well as evaluate the effectiveness of existing programs and initiatives. Based on the data obtained, they form

practical recommendations that promote sustainable social reproduction and create conditions for improving the quality of life in rural areas. An important aspect of their work is the organization of interaction between different levels of government and stakeholders, which contributes to the coordination of actions and the formation of integrated approaches to solving demographic problems. The creation of such groups helps to reduce the risks of errors in decision-making, accelerate the implementation of innovative solutions and social initiatives aimed at stabilizing the population. However, for the effective implementation of this recommendation, it is necessary that the initiative comes from regional authorities with the involvement of federal resources and ensures a constant exchange of information with local communities. Financial and institutional support for expert groups is important for their long-term activities and achieving sustainable results. Thus, the formation of regional expert groups becomes the foundation for the development of an adaptive management system for demographic processes, which is especially important in the context of increasing depopulation of rural areas.

2. *The development and implementation of adapted social programs* is one of the key strategies aimed at the stabilization and development of rural areas, taking into account their unique characteristics and needs. Authorities are required to develop a set of targeted support measures that take into account the specifics of local conditions and affect the main aspects of the population's life – housing conditions, quality and accessibility of medical services, education, as well as infrastructure that directly affects the comfort level and prospects of residents. Improving housing conditions is not only the construction of new housing, but also the modernization of existing ones, increasing the energy efficiency of houses, providing utilities, which creates a stable basis for living and significantly increases the attractiveness of rural settlements. An important component is the modernization of the healthcare system, including the development of primary health care, equipping paramedic and obstetric centers with modern equipment, attracting qualified personnel and using telemedicine technologies, which is especially important due to the remoteness of many rural areas from large medical centers. The improvement of the education system involves the introduction of teacher training programs, the creation of conditions for distance learning and additional education, which contributes to the formation of competitive human capital and reducing the educational gap between urban and rural areas. The central effect of such programs is a significant improvement in the quality of life, which helps to retain young people and stimulates migration back from cities, thereby reducing the level of regional extinction. Special attention

should be paid to an integrated approach, when social measures are integrated with economic initiatives that create jobs and opportunities for self-realization. For the successful implementation of these programs, constant feedback from the local population and the expert community is needed, allowing timely adjustment of support measures to meet changing conditions. Thus, adapted social programs become the foundation for sustainable rural development, reducing social tensions and increasing the demographic stability of the region.

3. *Active cooperation with public and religious organizations* is an important element of an integrated approach to social development and strengthening of civil society. Public and religious structures act as intermediaries between State institutions and the population, having a deep understanding of local traditions, values and needs. Effective cooperation with them allows authorities to more accurately identify the problems of human settlements, respond to social challenges in a timely manner and create conditions for the sustainable development of communities. Interaction with public organizations promotes the involvement of citizens in decision-making processes, increases the level of social activity, and creates an environment of trust and mutual assistance. Religious organizations, in turn, play an important role in strengthening the moral foundations of society, supporting family values and providing psychological assistance, especially in times of crisis. Joint projects implemented with the participation of these organizations cover a wide range of areas, from social services for vulnerable groups to educational programs and cultural initiatives, which contribute to the harmonious development of society. It is important to emphasize that in order to maximize the effectiveness of such interaction, it is necessary to establish a permanent dialogue and partnership based on mutual respect and consideration of the interests of all parties. Government agencies should create conditions for the creation of advisory councils and working groups with the participation of representatives of public and religious associations, as well as ensure transparency and openness of joint actions. This approach not only improves the quality of implemented measures, but also strengthens social stability, reduces the level of conflict, and helps to form civic identity and responsibility. Ultimately, active cooperation with public and religious organizations contributes to the formation of a more cohesive, sustainable and harmonious society.

Conclusion

In the context of rural depopulation, comprehensive regulation aimed at preserving and reproducing the social potential of the region is becoming important. The main problem is the decline in the number and aging of the population, which exacerbates the demographic and economic situation, reducing the quality of life and social activity. To stabilize the situation, it is necessary to strengthen the role of state institutions and activate local communities, including public and religious organizations, in order to create a sustainable system of social support and motivation for living in rural areas. An important area is infrastructure development, improvement of employment conditions and social protection, which helps to retain and attract residents. Regulation should take into account measures to strengthen family values and support young families, which increases fertility and contributes to demographic stabilization. In general, a successful solution to the problem of depopulation requires a comprehensive multi-level approach, taking into account the specifics of rural areas and their socio-economic context.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

ASSESSMENT OF ANTHROPOGENIC LOAD BY THE LEVEL OF FLUCTUATING ASYMMETRY OF *BETULA PENDULA* LEAVES (USING THE EXAMPLE OF THE DON STATE TECHNICAL UNIVERSITY TRAINING AND EXPERIMENTAL SITE)

D.A. Kozyrev, E.A. Mun, P.A. Dubnitskaya, V.S. Ligacheva, M.Y. Odabashyan, A.A. Eroshenko, O.V. Gordiets

Abstract

Background. This study aimed to assess the level of anthropogenic stress on the territory of the Don State Technical University training and experimental site (Rassvet, Rostov Oblast) using the fluctuating asymmetry method of *Betula pendula* Roth. A comparative analysis of the integral index of fluctuating asymmetry was conducted between zones with different levels of expected impact (“Site 1” and “Site 3”) and a conventional background zone (“Roshcha”). The level of fluctuating asymmetry in the anthropogenic impact groups was significantly higher than in the background zone, and the overall environmental condition of the study area corresponded to the “alarm” category. The most stress-sensitive traits were the length of the second vein and the angle between the veins. The fluctuating asymmetry method has proven its effectiveness for bioindicating complex anthropogenic stress in urban ecosystems.

Purpose. The aim of the study was to quantitatively assess the level of anthropogenic stress on the territory of the Don State Technical University training and experimental site by analyzing the fluctuating asymmetry of the leaves of *Betula pendula* Roth and identifying the most sensitive morphological features.

Materials and methods. The study focused on *Betula pendula* Roth growing in anthropogenically altered habitats, with special attention to the fluctuating asymmetry of its leaf morphological traits in the leaf blade of *Betula pendula* as an indicator of developmental instability. A method for assessing fluctuating asymmetry of the leaf blade was employed. Standard biometric methods were used to measure five leaf blade traits, followed by calculation of the relative asymmetry value for each trait and the integral fluctuating asymmetry index for each leaf. Statistical data processing included descriptive statistics, testing for normality (Shapiro-Wilk test), and homogeneity of variance (Levene’s test). One-way analysis of variance (ANOVA) with Tukey’s post hoc test was used to compare groups.

Results. The integral fluctuating asymmetry index (IIFA) for the combined sample was 0.093, which corresponds to the "alarm" zone according to Zakharov's scale. Statistical analysis revealed significant differences ($p < 0.001$) between the conventional background zone "Roshcha" (IIFA = 0.065 ± 0.004) and the impact zones "Site 1" (0.110 ± 0.007) and "Site 3" (0.104 ± 0.006). At the same time, no significant differences were found between the two sites ($p = 0.721$). Analysis of the contribution of individual traits showed that the "Length of the second vein" (0.152) and "Angle between veins" (0.095) exhibit the greatest sensitivity to anthropogenic stress.

Conclusion. The study demonstrates that fluctuating asymmetry in *Betula pendula* leaves is an effective tool for diagnosing complex anthropogenic stress. The data indicate an unfavorable environmental situation within the Don State Technical University training and experimental site, where developmental disturbances reach alarming levels. Spatial differentiation of FA values confirms the hypothesis of higher stress in areas immediately adjacent to infrastructure. Identifying the most sensitive morphological features allows for the optimization of bioindication monitoring programs for such urbanized areas.

Keywords: fluctuating asymmetry; bioindication; *Betula pendula*; anthropogenic stress; urban ecosystems

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Научная статья

ОЦЕНКА АНТРОПОГЕННОЙ НАГРУЗКИ ПО УРОВНЮ ФЛУКТУИРУЮЩЕЙ АСИММЕТРИИ ЛИСТЬЕВ *BETULA PENDULA* (НА ПРИМЕРЕ УЧЕБНО-ОПЫТНОГО ПОЛИГОНА ДГТУ)

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Аннотация

Обоснование. Исследование направлено на оценку уровня антропогенной нагрузки на территории учебно-опытного полигона ДГТУ (п. Рассвет, Ростовская область) методом флуктуирующей асимметрии листовой пластинки берёзы повислой (*Betula pendula* Roth). Проведён сравнительный анализ интегрального показателя флуктуирующей асимметрии между зонами с предполагаемой разной степенью воздействия («Полигон 1», «Полигон 3») и условно-фоновой зоной («Роща»). Установлено, что уровень флуктуирующей асимметрии в группах антропогенного воздействия достоверно выше, чем в фоновой зоне, а состояние среды на всей исследованной территории соответствует зоне «тревоги». Наиболее чувствительными к стрессу признаками являются длина второй жилки и угол между жилками. Метод флуктуирующей асимметрии подтвердил свою эффективность для биоиндикации комплексной антропогенной нагрузки в урбоэкосистемах.

Цель. Целью исследования была количественная оценка уровня антропогенного стресса на территории учебно-опытного полигона ДГТУ путём анализа флуктуирующей асимметрии листьев берёзы повислой и выявления наиболее чувствительных морфологических признаков.

Материалы и методы. Объект данного исследования берёза повислая (*Betula pendula* Roth) в условиях антропогенно-преобразованных территорий. Предметом исследования выступила флуктуирующая асимметрия морфологических признаков листовой пластинки *Betula pendula* как показатель нарушения стабильности развития. В работе применялся метод оценки флуктуирующей асимметрии листовой пластинки. Использовались стандартные биометрические методы измерения пяти пластинчатых признаков листа с последующим расчётом относительной величины асимметрии для каждого признака и интегрального показателя флуктуирующей асимметрии для каждого листа. Статистическая обработка данных включала описательную статистику, проверку распределения на нормальность (критерий Шапиро-Уилка) и однородность дисперсий (тест Левена), для сравнения групп применялся однофакторный дисперсионный анализ (ANOVA) с последующим пост-хок тестом Тьюки.

Результаты. Интегральный показатель флуктуирующей асимметрии (ИП ФА) для объединённой выборки составил 0,093, что соответствует зоне «тревоги» по шкале Захарова. Статистический анализ выявил достоверные различия ($p < 0{,}001$) между условно-фоновой зоной «Роща» (ИП ФА = 0,065 ± 0,004) и зонами воздействия «Полигон 1» (0,110 ± 0,007) и «Полигон 3» (0,104 ± 0,006). При этом значимых различий между двумя полигонами не обнаружено (p = 0,721). Анализ вклада отдельных признаков показал, что наибольшую чувствительность к антропогенному стрессу проявляют «Длина второй жилки» (0,152) и «Угол между жилками» (0,095).

Заключение. Проведённое исследование демонстрирует эффективность метода флуктуирующей асимметрии листьев берёзы повислой для диагностики комплексной антропогенной нагрузки. Полученные данные свидетельствуют о напряжённой экологической обстановке на территории учебно-опытного полигона ДГТУ, где уровень нарушений развития достигает уровня «тревоги». Пространственная дифференциация значений ФА подтверждает гипотезу о более высоком стрессе в зонах непосредственной близости к инфраструктуре. Выявление наиболее чувствительных морфологических признаков позволяет оптимизировать программы биоиндикационного мониторинга для подобных урбанизированных территорий.

Ключевые слова: флуктуирующая асимметрия; биоиндикация; *Betula pendula;* антропогенный стресс; урбоэкосистемы

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Introduction

Urban tree stands are a critical component of urban ecosystems, providing a wide range of ecosystem services, including carbon sequestration, improved air quality, microclimate regulation, and biodiversity conservation. However, the viability and functionality of these stands are threatened by the chronic impact of a complex array of anthropogenic stressors. These include chemical pollution of the soil and atmosphere, physical degradation and compression of soil cover, disruption of symbiotic interactions in soil biota, and specific microclimatic conditions [1; 5].

The cumulative effect of these factors is reflected in fundamental disturbances in the physiology and ontogenesis of woody plants. Research has documented accelerated development, leading to a two- to threefold reduction in lifespan, premature senescence and leaf shedding, as well as the activation of compensatory mechanisms at the molecular and cellular levels [2]. Therefore, monitoring the condition of urban dendropopulations requires the development of integrated diagnostic methods sensitive to the overall stress response of the organism, as opposed to traditional approaches that measure the concentrations of individual pollutants.

A promising tool in this area is assessing developmental stability based on the magnitude of fluctuating asymmetry (FA) of bilateral organs. FA, defined as small, non-directional deviations from ideal symmetry, is a consequence of the organism's inability to buffer disturbances during ontogenesis [4]. Its level correlates with the intensity of stress – both genetic and environmental – making FA a universal indicator of environmental conditions [9]. The effectiveness of this approach has been confirmed for a wide range of stress factors: from heavy metal pollution [6] and thermal stress to the impact of radical changes in environmental conditions at the boundaries of habitats [10].

Thus, given the complex nature of anthropogenic stress in urbanized environments, fluctuating leaf asymmetry represents a theoretically sound and methodologically robust bioindicator parameter. However, under optimal conditions, low levels of fluctuating asymmetry will be observed as a manifestation of ontogenetic noise [8].

Purpose

The aim of the study was to assess the level of anthropogenic load on the territory of the educational and experimental site of the Don State Technical University (Rassvet, Rostov Region) based on the analysis of fluctuating asymmetry of the leaf blade of the *Betula pendula* Roth. To achieve this goal, *Betula pendula* leaf material was sampled in areas with expected varying degrees of anthropogenic impact ("Site 1", "Site 3") and in the conditional background zone "Roshcha". The integrated index of fluctuating asymmetry (IIFA) was calculated for each study group based on five lamellar leaf traits. To qualitatively process the obtained data, a comparative statistical analysis of the obtained IIFA values was conducted between the groups to identify significant differences. Based on the statistical analysis data, the morphological leaf traits most sensitive to anthropogenic stress were determined. As a result of the study, the state of the environment in the study area was evaluated according to the Zakharov scale.

Materials and methods

The study was conducted using a model species, *Betula pendula* Roth. This species was chosen as a bioindicator due to its widespread distribution, high sensitivity to anthropogenic impact, and ease of leaf sampling.

The study was conducted at the Don State Technical University training and experimental site in the village of Rassvet, Aksay District, Rostov Region. The site represents an anthropogenically transformed ecosystem typical of the southern European part of Russia and includes areas with varying levels of recreational and anthropogenic pressure. Three groups of *Betula pendula* trees, growing 100–200 meters apart, were selected for the study. This allowed us to cover areas with differentiated anthropogenic pressure: zones in the immediate vicinity of educational and laboratory buildings and infrastructure ("Site 1" and "Site 3") and a background zone, remote from the main sources of pressure (Roshcha). The climate of the area is temperate continental with arid features, characterized by hot summers with frequent dry winds and moderately cold, low-snow winters. Average annual precipitation is approximately 500-600 mm, with high interannual variability and a pronounced summer minimum [3].

To ensure representativeness of the data and allow for comparative analysis, material was collected at three sites with different expected levels of anthropogenic load:

1. "Site 1": A site in close proximity to the landfill infrastructure, characterized by potentially high recreational load.
2. "Site 3": A site adjacent to technological zones or utility lines, where anthropogenic impacts are expected.
3. "Roshcha": A site consisting of a forest belt or natural tree stand within the landfill, remote from the main sources of impact and considered a background (control) site.

Leaf collection for the study subject was carried out uniformly from the middle canopy layer (at a height of 1,5–2 m) to minimize the influence of age-related and microclimatic gradients.

To assess developmental stability, the fluctuating asymmetry method – small, non-directional deviations from strict bilateral symmetry – was used. Five lamellar features were measured on each leaf (Fig. 1) on the left and right halves of the leaf blade:

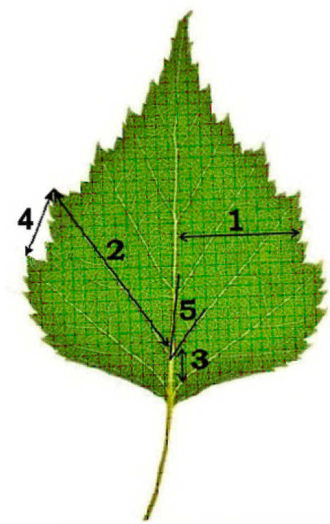

Fig. 1. Measured leaf parameters [7]

1. Width of leaf half.
2. Length of second vein from base.
3. Distance between bases of first and second veins.
4. Distance between ends of first and second veins.
5. Angle between main and second veins.

Measurements were taken using a digital caliper and a protractor with an accuracy of 0,1 mm and 1°, respectively.

For each trait on each leaf, the relative asymmetry value was calculated using the formula:

$$\text{FA val} = \frac{|R - L|}{|R + L|}$$

where *R* and *L* are the values of the trait on the right and left sides of the leaf, respectively.

The integral index of fluctuating asymmetry for each leaf was calculated as the arithmetic mean of the asymmetry values for all five characteristics:

$$\text{IIFA leaf} = \frac{\sum \text{FA val}}{5}$$

To describe the data for each group, the arithmetic mean (M), standard error of the mean (±m), standard deviation (SD), minimum, maximum, and coefficient of variation (CV, %) were calculated (Table 1).

Data distribution was tested for normality using the Shapiro-Wilk test, and homogeneity of variances was tested using Levene's test. Since the basic assumptions for using parametric tests (normality and homogeneity of variances) were not violated, a one-way analysis of variance (ANOVA) was used to compare mean values of the IIFA between the three groups. If statistically significant differences were identified, pairwise comparisons between groups were performed using Tukey's post-hoc test for multiple comparisons. The level of statistical significance was set at $p < 0{,}05$.

To rank the features based on their contribution to overall asymmetry, the mean asymmetry value for each feature was calculated across the entire pooled sample.

Environmental conditions were assessed based on the IIFA using the generally accepted Zakharov scale.

Results of the research

The integral index of fluctuating asymmetry (IIFA) for the combined sample of 30 leaves was 0,093, which, according to Zakharov's scale, corresponds to the “alarm” zone and indicates the presence of moderate anthropogenic stress.

To further clarify this conclusion, a comparative analysis of three groups of trees was conducted: two from the hypothetical impact zone (“Site 1” and “Site 3”) and one from the conventional background zone “Roshcha.”

The initial data analysis revealed that the IIFA distribution in the “Site 1” and “Site 3” groups deviated slightly from normality (Shapiro-Wilk test, $p > 0{,}05$), while in the “Roshcha” group, the distribution was normal. The group variances were homogeneous (Levene’s test, $p = 0{,}152$). Given that the parametric assumptions were met, a one-way analysis of variance was used to compare the groups.

Table 1.

Descriptive statistics of the integral index of fluctuating asymmetry of birch leaves in different groups

Group	n	Average (M)	Standard error (±m)	Standard deviation (SD)	Min	Max	CV, %
Site 3	10	0,104	0,006	0,020	0,074	0,134	19,2
Site 1	10	0,110	0,007	0,023	0,080	0,152	20,9
Roshcha	10	0,065	0,004	0,012	0,047	0,082	18,5

Descriptive statistics (Table 1) demonstrate that the lowest values of the IIFA were found in the “Roshcha” group (0,065 ± 0,004), while in the “Site” groups, the values were significantly higher and approximately the same (0,104 ± 0,006 and 0,110 ± 0,007). The coefficient of variation in all groups was below 25%, indicating acceptable homogeneity of the samples.

The results of the analysis of variance revealed statistically significant differences between at least one pair of groups (ANOVA: $F\ (2, 27) = 21{,}45$, $p < 0{,}001$).

Table 2.

Results of pairwise comparison of IIFA groups using Tukey’s post-hoc test (p-value)

Comparison groups	p-value
Site 3 — Roshcha	<0,001
Site 1 — Roshcha	<0,001
Site 3 — Site 1	0,721

Pairwise comparison using Tukey’s test (Table 2) confirmed that both “Site” groups differed significantly ($p < 0{,}001$) from the “Roshcha” background group. However, no statistically significant differences were found between the “Site

1" and "Site 3" groups (p = 0,721). A box plot (Fig. 2) was constructed to visualize these differences.

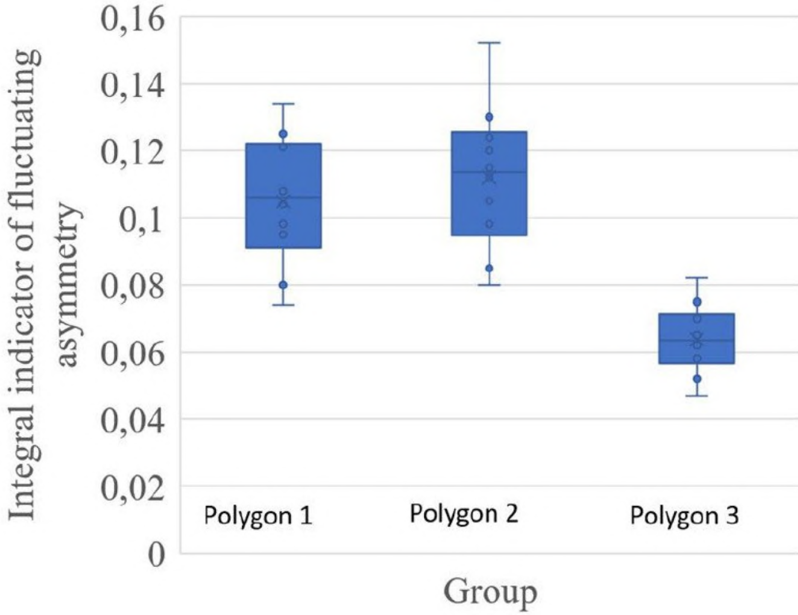

Fig. 2. Distribution of the integral index of fluctuating asymmetry in groups of *Betula pendula* leaves

Note: The figure shows the median, quartiles, and range of values. The "Site 1" and "Site 3" groups are not statistically different from each other (p> 0.05), but both significantly exceed the "Roshcha" group (p < 0,001).

To identify the most sensitive impact markers, an analysis of the mean asymmetry values for each of the five measured traits across the entire sample was conducted. Traits were ranked in descending order of contribution to the overall asymmetry:

1. Vein 2 Length: 0,152
2. Vein Angle: 0,095
3. Vein Tip Distance: 0,088
4. Leaf Halves Width: 0,057
5. Vein Base Distance: 0,037

The traits "Vein 2 Length" and "Vein Angle" make the greatest contributions to the overall asymmetry. This is consistent with literature data indicating that meristematic traits (such as vein length) and traits dependent on complex growth processes throughout the season (vein angles) often exhibit greater plasticity and, therefore, greater sensitivity to stress factors compared to more stable traits such as leaf width.

Conclusion

Thus, the conducted analysis allows us to draw a number of important conclusions. First, it has been confirmed that the level of fluctuating asymmetry in silver birch is an informative indicator of environmental conditions. The average IIFA value obtained (0,093) corresponds to the “alarm” zone on Zakharov’s scale (values ≥ 0,055 indicate a critical level of disturbance), indicating the presence of persistent anthropogenic pressure in the sampling area from the testing sites.

Second, a comparative analysis of the groups revealed clear spatial differentiation. Significantly lower IIFA values in the “Roshcha” group compared to the “Site” groups convincingly demonstrate that the trees in the grove experience less stress, allowing us to consider this area as a conditionally background zone. The absence of significant differences between the two testing sites may indicate a similar level of impact in these areas, both in strength and nature.

The identified structure of the contribution of traits to asymmetry has important methodological implications. For future research and comprehensive monitoring, it is advisable to focus on the most sensitive traits (vein length and intervein angle), which may improve the effectiveness of the study.

In our study, the sample size was 10 leaves per tree, which is sufficient to detect gross differences. To conduct a more detailed analysis of the influence of microclimatic and soil variations, a comprehensive monitoring study will be conducted, collecting larger samples and including a larger number of trees in each group.

Based on the integral fluctuating asymmetry index (0,093), the environmental condition in the studied areas is assessed as unsatisfactory and corresponds to the “alarm” zone. The study revealed significant differences between the “Roshcha” background zone and the impact zones (“Site 1” and “Site 3”), confirming the reliability of FA as a bioindication method. The most sensitive characteristics of the silver birch leaf blade to anthropogenic impact are the length of the second vein and the angle between the main and second veins, which make the greatest contribution to the overall asymmetry.

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All authors made an equivalent contribution to the preparation of the article for publication.

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Научная статья

ВЛИЯНИЕ ПРОБИОТИКОВ В СОСТАВЕ КОРМА НА РЫБОВОДНО-БИОЛОГИЧЕСКИЕ ПОКАЗАТЕЛИ ФОРЕЛИ *ONCORHYNCHUS MYKISS* (WALBAUM, 1792) В ПЕРИОД РАННЕГО ОНТОГЕНЕЗА

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Аннотация

Обоснование. Вопросы повышения продуктивности в различных отраслях сельского хозяйства, в особенности сектора аквакультуры, в настоящее время является приоритетной задачей многих научных коллективов в России и в других странах. Интенсификация производства неизбежно приводит к снижению резистентности объектов аквакультуры, что делает их восприимчивыми к различным патогенным агентам, в результате чего снижается общая продуктивность производства. Применение пробиотиков в биотехнологическом цикле выращивания позволяет снизить негативные эффекты интенсификации.

Неоднократно было высказано мнение, что наибольший эффект на организм рыб оказывают штаммы бактерий с пробиотическими свойствами, которые изначально были характерны для рассматриваемого организма и среды его обитания. В настоящей работе рассмотрены эффекты пробиотических штаммов бактерий, выделенных из донных отложений в местах постоянного обитания рыб.

Цель исследования заключалась в изучении влияния пробиотиков в составе корма на рыбоводно-биологические показатели форели *Oncorhynchus mykiss* (Walbaum, 1792) в период раннего онтогенеза.

Материалы и методы. Площадкой для проведения эксперимента послужило рыбоводное предприятие индустриального типа, расположенное в Ростовской области. Объектом исследования являлись 100 000 экз. личинок радужной форели *O. mykiss* в возрасте 29 суток, которые в случайном порядке были распределены на 2 группы (контроль и опыт).

Продолжительность эксперимента составила 30 суток. Рацион особей включал стартовые комбикорма для молоди лососевых рыб с размером крупки 0,2 мм с содержанием сырого протеина 58,0%.

Опытная группа в составе рациона получала пробиотическую добавку с 2 штаммами бактерии *Bacillus subtilis* (штамм МТ48 и МТ74). Содержание бактериальных клеток в готовом корме составляло $7{,}3 \cdot 10^6$ КОЕ/г. Бонитировку, в ходе которой оценивали морфометрические показатели рыб, проводили 2 раза за период эксперимента: в начале и по завершению. Для оценки эффективности введения пробиотика в состав рациона проводился расчет рыбоводных коэффициентов: коэффициент упитанности по Фультону, индивидуальный прирост массы, общий прирост биомассы, коэффициент конверсии корма и выживаемость.

Результаты. Добавление пробиотиков на основе *B. subtilis* (штаммы МТ48 и МТ74) в корм личинок *O. mykiss* привело к значительному улучшению рыбоводно-биологических показателей. В опытной группе наблюдалось увеличение средней индивидуальной массы рыб на 12,68% и длины тела по сравнению с контрольной группой.

Выживаемость личинок в опытной группе была выше на 19,41%, а общий прирост биомассы увеличился на 38,31%. Коэффициент конверсии корма снизился с 1,69 кг/кг в контрольной группе до 1,04 кг/кг в опытной группе, что свидетельствует о более эффективном использовании корма. Статистический анализ подтвердил достоверность различий между группами ($p < 0{,}05$).

Заключение. Проведённое исследование подтвердило эффективность применения пробиотиков на основе *B. subtilis* (штаммы МТ48 и МТ74) в кормлении личинок *O. mykiss*.

Включение пробиотической добавки в рацион способствовало значительному улучшению ключевых рыбоводно-биологических показателей: увеличению массы и длины тела, повышению выживаемости и снижению коэффициента конверсии корма.

Ключевые слова: *Oncorhynchus mykiss*; *Bacillus subtilis*; аквакультура; форель; пробиотики; рыбоводство; интенсификация

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Original article

THE EFFECT OF PROBIOTIC-ENRICHED FEED ON AQUACULTURE-BIOLOGICAL PARAMETERS OF RAINBOW TROUT *ONCORHYNCHUS MYKISS* (WALBAUM, 1792) DURING EARLY ONTOGENY

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Abstract

Background. The issues of increasing productivity in various sectors of agriculture, especially the aquaculture sector, are currently a priority for many research teams in Russia and other countries. The production intensification inevitably leads to a decrease in the resistance of aquaculture objects, which makes them susceptible to various pathogenic agents, resulting in a decrease in overall production efficiency. The use of probiotics in the biotechnological farming cycle can reduce the negative effects of intensification. It has been repeatedly suggested that bacterial strains with probiotic properties, which were originally characteristic of the organism in question and its habitat, have the greatest effect on the fish body. In this paper, the effects of probiotic bacterial strains isolated from bottom sediments in fish habitats are considered.

Purpose. The aim of the study was to study the effect of probiotics in the feed on the fish-breeding and biological parameters of trout *Oncorhynchus mykiss* (Walbaum, 1792) during the early ontogenesis.

Materials and methods. The experimental site was an industrial-type fish hatchery located in the Rostov region. The object of the study was 100,000 species of *O. mykiss* rainbow trout larvae aged 29 days, which were randomly divided into 2 groups (control and experiment). The duration of the experiment was 30 days. The diet of the individuals included starter feeds for juvenile salmon with a grain size of 0.2 mm and a crude protein content of 58.0%. The experimental group received a probiotic supplement with 2 strains of the bacterium *Bacillus subtilis* (strains MT48 and MT74) as a part of the diet. The content of bacterial cells in the finished feed was $7.3 \cdot 10^6$ CFU/g. The valuation, during which the morphometric parameters of the fish were evaluated, was carried out 2 times during the experiment period: at the beginning and at the end. To assess the effectiveness of probiotic implementation in the diet, fish farming coefficients were calculated: Fulton's fatness coefficient, individual weight gain, total biomass gain, feed conversion rate and survival rate.

Results. The addition of probiotics based on *B. subtilis* (strains MT48 and MT 74) to the feed of *O. mykiss* larvae led to a significant improvement in fish biological parameters. In the experimental group, there was an increase in the average individual fish weight by 12.68% and body length compared with the control group. The survival rate of larvae in the experimental group was higher by 19.41%, and the total increase in biomass increased by 38.31%. The feed conversion rate decreased from 1.69 kg/kg in the control group to 1.04 kg/kg in the experimental group, indicating a more efficient use of feed. The statistical analysis confirmed the significance of the differences between the groups (p<0.05).

Conclusion. The study confirmed the effectiveness of probiotics based on *B. subtilis* (strains MT48 and MT 74) in feeding *O. mykiss* larvae. The inclusion of probiotic supplements in the diet contributed to a significant improvement in key fish-breeding and biological parameters: an increase in body weight, length and survival rate and a decrease in feed conversion rate.

Keywords: *Oncorhynchus mykiss*; *Bacillus subtilis*; aquaculture; trout; probiotics; fish farming; intensification

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Введение

Увеличение численности населения и связанные с этим продовольственные потребности заставили многие страны обратить взгляд на аквакультуру как на важный источник пополнения своих продовольственных ресурсов. Более того, высокое качество продуктов аквакультуры для питания человека сделало аквакультуру быстрорастущим сектором пищевой промышленности, ежегодно увеличивающимся на 8% [1]. Фермеры стремятся увеличить плотность посадки некоторых видов, таких как радужная форель (*Oncorhynchus mykiss*), чтобы повысить производство рыбы. Однако высокая плотность негативно влияет на здоровье, выживаемость, показатели роста и качество продукции радужной форели [2; 3]. Одним из наиболее негативных последствий высокой плотности является увеличение популяции патогенных микроорганизмов. В последние десятилетия безответственное использование антибиотиков для уничтожения этих микроорганизмов привело к появлению многочисленных устойчивых бактерий [4; 5]. В этом смысле добавление в рацион рыбы некоторых альтернативных иммуностимуляторов, таких как пробиотики для укрепления иммунной системы, является подходящей заменой. Пробиотики могут помочь заменить или минимизировать применение антибиотиков и химиотерапевтических препаратов в рыбоводстве [6-8]. Включение пробиотиков в рацион является ключевым шагом для защиты выращиваемой рыбы от стресса или инфекций в условиях рыбоводства [9]. Пробиотики приносят пользу организму, улучшая устойчивость к болезням, состояние здоровья, показатели роста, усвоение корма и реакцию на стресс при добавлении в корм или воду для выращивания [10].

Радужная форель *Oncorhynchus mykiss* (Walbaum, 1792) является одним из ключевых объектов современной аквакультуры благодаря быстрому росту и востребованности на мировом рынке. В 2019 г. глобальное производство этого вида достигло 940 000 тонн, что подтверждает его экономическую значимость [11]. Однако интенсивные методы выращивания сопряжены с рядом проблем, включая стрессовые факторы, повышенную заболеваемость и снижение продуктивности, особенно на критически важных ранних этапах онтогенеза.

В последние годы особое внимание исследователей привлекает применение пробиотиков как экологически безопасной альтернативы антибиотикам. Многочисленные исследования подтвердили их положительное воздействие на объекты аквакультуры, включая улучшение микробиоценоза кишечника, модулирование иммунной системы, повышение эффективности потребления корма [13].

Особый интерес представляют «автохтонные» штаммы, например, как *Carnobacterium* sp. (штамм K1), выделенные из кишечника лососевых. Доказано, что их применение значительно повышает выживаемость молоди при бактериальных инфекциях (вызванных *Aeromonas salmonicida*, *Vibrio ordalii*, *Yersinia ruckeri*) [14].

Несмотря на значительный объем накопленных данных, большинство работ посвящено изучению влияния пробиотиков на взрослых особей, тогда как их роль в оптимизации рыбоводно-биологических показателей на ранних стадиях развития (личиночный и мальковый периоды) изучена недостаточно. Этот пробел в знаниях особенно значим, учитывая, что именно ранний онтогенез является критическим периодом для формирования устойчивости и дальнейшего роста рыбы.

Важность применения пробиотиков и их положительное влияние на здоровье широко обсуждаются в научной литературе. В обзоре van Doan с соавторами [15], посвященном пробиотикам, авторы отмечают, что бактерии, изначально выделенные из воды или желудочно-кишечного тракта (ЖКТ), имеют определенные преимущества, среди которых наиболее значимыми являются увеличение темпов роста, повышение ферментативной активности в ЖКТ, подавление адгезии и колонизации патогенов в ЖКТ, улучшение гематологических показателей и иммунного ответа.

Цель. Изучение влияния пробиотиков в составе корма на рыбоводно-биологические показатели форели *Oncorhynchus mykiss* (Walbaum, 1792) в период раннего онтогенеза.

Материалы и методы

Исследование одобрено Локальным независимым этическим комитетом Донского государственного технического университета (г. Ростов-на-Дону, Российская Федерация). В ходе экспериментов соблюдались рекомендации по гуманному и этичному обращению с лабораторными животными, в том числе, в соответствии с Директивой 2010/63/ЕС Европейского парламента и совета от 22.09.2010 «О защите животных, используемых в научных целях».

Эксперимент проводили в условиях индустриального рыбоводного предприятия, расположенного в Красносулинском районе Ростовской области. В качестве объекта исследования была выбрана радужная форель *O. mykiss* в возрасте 29 суток с момента выклева. Всего в эксперименте было задействовано 100 000 экз. личинок (группа 1 – контроль, группа 2 - опыт), которые были распределены в случайном порядке на 2 экспериментальные рыбоводные емкости (лотки) прямоугольной формы, изготовленные из полипропилена. Плотность посадки в лотках составляла 10 000 экз./м^2. Водоснабжение экспериментальных лотков осуществлялось по прямоточному типу, водоисточником являлись подземные воды. Продолжительность эксперимента составила 30 суток (31.05.2024 - 30.06.2024). В ходе эксперимента ежедневно проводили измерения концентрации растворенного в воде кислорода (O_2, мг/л), а также температуры воды (°С) с помощью портативного термооксиметра Анион-7040 («НПП Инфраспак-Аналит», г. Новосибирск, Российская Федерация).

Рацион особей включал стартовые комбикорма для молоди лососевых рыб с размером частицы 0,2 мм. Изготовление кормов производилось в лаборатории «Технологическая линия производства кормов» Донского государственного технического университета (г. Ростов-на-Дону, Российская Федерация). Производство экспериментальных кормов состояло из следующих этапов: взвешивание компонентов в соответствии с рецептурой, смешивание сухих компонентов кормов, увлажнение до массовой доли влаги 12%, гранулирование, охлаждение и просеивание гранул, обмасливание гранул под вакуумом, измельчение гранул, просеивание полученной крупки на наборе сит, повторное измельчение и просеивание крупной фракции.

Изготовленные корма характеризовались следующими показателями: сырой протеин – 58,0%, сырой жир – 13,0%, клетчатка – 0,30%, зола – 9,20%, кальций – 1,67%, фосфор – 1,25%, натрий – 0,57%. 2 группа рыб (опыт) дополнительно в составе корма получала пробиотическую добавку (0,1% от массы корма), полученную путем твердофазной ферментации соевых бобов. Пробиотический препарат содержал 2 штамма бактерии *Bacillus subtilis* (МТ48 и МТ74) с антиоксидантными свойствами с концентрацией $7{,}3 \cdot 10^9$ КОЕ/г. Содержание бактериальных клеток в корме составляло $7{,}3 \cdot 10^6$ КОЕ/г.

Кормление рыб выполнялось ежедневно, с интервалом через каждые 2 часа (12 раз в сутки). Суточная норма составляла 10% от предполагаемой биомассы рыб.

Для снижения хэндлинга контрольные измерения рыб (бонитировки) проводились 2 раза за период эксперимента: в начале и по завершению. В ходе бонитировки оценивали массу рыб (m, г) с использованием лабораторных весов II класса точности BEL LG- 2202i с дискретностью 0,01 г (ChangZhou XingYun Electronic Equipment Co., Китай), а также проводили измерения длины тела до конца чешуйного покрова (L, мм) при помощи штангенциркуля.

Для оценки эффективности кормления производили расчет следующих показателей:

– коэффициент упитанности по Фультону (QF, усл. ед.) согласно формуле:

$$Q_F = \frac{m * 100}{l^3}$$

– индивидуальный прирост биомассы (WGi, г) с применением формулы:

$$WGi = m_1 - m_0$$

– общий прирост биомассы (WGt, кг) согласно:

$$WGt = M_1 - M_0$$

– коэффициент конверсии корма (FCR, кг/кг) на основании формулы:

$$FCR = {}^{M_f}/_{WGt}$$

– выживаемость рыб (S, %) оценивали с применением формулы:

$$S = 100 * \frac{N_1}{N_0}$$

где t – продолжительность эксперимента, суток; l_1 – длина в конце эксперимента, см; l_0 – длина в начале эксперимента, см; m_1 – масса в конце эксперимента, г; m_0 – масса в начале эксперимента, г; N_1 – количество рыб в конце эксперимента, экз.; N_0 – количество рыб в начале эксперимента, экз.; M_f – масса корма, затраченного в ходе проведения эксперимента, кг; M_1 – биомасса рыб в конце эксперимента кг; M_0 – биомасса рыб в начале эксперимента, кг; m – масса, г; l – длина, см.

Статистическую обработку данных выполняли с использованием пакета Statistica 10.0 (StatSoft Inc., США). Первичный анализ включал проверку нормальности распределения с применением критериев Шапиро-Уилка и Колмогорова-Смирнова при уровне значимости $\alpha=0,05$. Визуальную оценку распределения проводили по гистограммам с наложением кривой нормального распределения и Q-Q графикам. Для сравнительного анализа групп использовали непараметрический U-критерий Манна-Уитни с коррекцией на непрерывность, что обусловлено особенностями распределения биометрических показателей. Расчет включал определение суммы рангов, U-статистики, Z-критерия с вычислением точного уровня значимости (p-value) и размера эффекта ($r=Z/\sqrt{n}$). Визуализацию результатов осуществляли посредством диаграмм размаха (box-plot), отображающих медиану, межквартильный размах (25-75 процентили) и диапазон нормальных значений (1,5 IQR). Особое внимание уделяли контролю качества данных, включавшему двойной ввод 10% случайной выборки, визуальную верификацию распределений и перекрестную проверку результатов альтернативными методами в пакете R 4.0.2. Мощность исследования при объеме выборки n=50 в каждой группе составляла 85% для обнаружения эффекта среднего размера (d=0,5) при $\alpha=0,05$.

Результаты исследования

В период проведения эксперимента гидробионты находились в схожих условиях: температура воды в лотках с контрольной и опытной группами рыб составляла в среднем 12,9±0,16 °С. Концентрация растворенного в воде O_2 в лотках за период эксперимента в среднем составила 12,0±0,22 мг/л (рисунок 1). pH воды составляла 7,5-7,6 (7,57±0,04). Создание подобных схожих условий поспособствовало проведению эксперимента, в ходе которого получены репрезентативные данные об изменении морфометрических и рыбоводно-биологических характеристик рыб при введении в рацион мультиштаммового пробиотического препарата на основе *B. subtilis* (штаммы МТ48, МТ74).

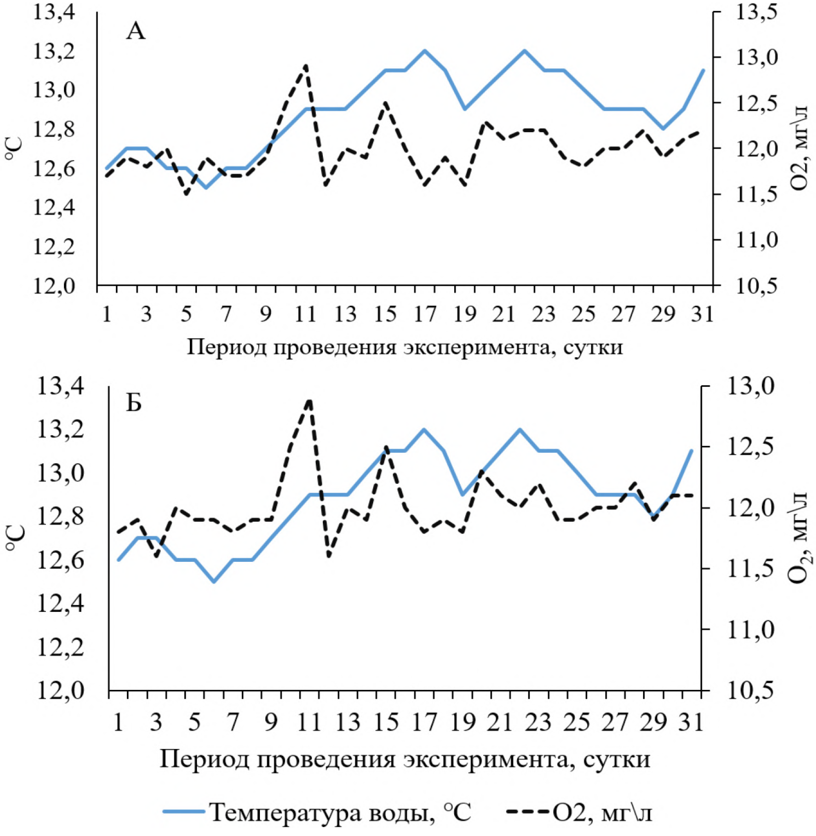

Рис. 1. Температура воды (°С) и концентрация растворенного в воде кислорода (O_2, мг/л) в период проведения эксперимента

На протяжении экспериментального периода в контрольной и опытной группах отсутствовали случаи заболеваний, все особи сохраняли клиническое здоровье. Наблюдалась стабильная пищевая активность, проявляющаяся в латентном периоде реакции на корм менее 3 секунд. В таблице 1 представлены морфометрические и основные рыбоводно-биологические параметры *O. mykiss*, задействованных в эксперименте.

Таблица 1.

Изменение морфометрических характеристик личинок форели *O. mykiss* в ходе эксперимента

Параметр, ед. изм.	Начало эксперимента (1 сутки)		Окончание эксперимента (30 сутки)	
	контрольная группа	опытная группа	контрольная группа	опытная группа
морфометрические характеристики				
Средняя индивидуальная масса рыб, г	0,111±0,032	0,101±0,022	0,799±0,170	0,915±0,155
min, г	0,057	0,050	0,447	0,605
max, г	0,191	0,161	1,402	1,836
Средняя индивидуальная длина рыб, см	2,314±0,135	2,304±0,097	3,664±0,197	3,824±0,185
min, см	2,000	2,000	3,1	3,3
max, см	2,600	2,500	4,5	4,4
Коэффициент упитанности по Фультону, усл. ед.	0,875±0,157	0,813±0,111	1,661±0,427	1,664±0,371
основные рыбоводно-биологические характеристики				
Индивидуальный прирост биомассы (WGi), г	-	-	0,688	0,814
Общий прирост биомассы (WGt), кг	-	-	14,185	22,994
Коэффициент конверсии корма (FCR), кг/кг	-	-	1,69	1,04
Выживаемость (S), %	-	-	49,4	61,3

Статистический анализ данных 30-суточного эксперимента по оценке влияния пробиотической кормовой добавки на рост личинок форели выявил значимые изменения ключевых морфометрических показателей. Исследование включало комплексный анализ распределения данных и сравнение групп с использованием современных методов визуализации и статистических критериев.

Анализ нормальности распределения показателя массы тела, представленный на гистограммах (рисунок 2.2 – контрольная группа, рисунок 2.4 – опытная группа) и подтвержденный Q-Q графиками (рисунок 2.5, рисунок 2.3), показал соответствие нормальному закону распределения (критерий Шапиро-Уилка: $p > 0,05$; критерий Колмогорова-Смирнова: $p > 0,05$ для обеих групп). Диаграмма размаха (рисунок 2.1) наглядно демонстрирует различия между группами: в опытной группе наблюдается смещение медианы в область более высоких значений при одновременном уменьшении межквартильного размаха, что свидетельствует не только об увеличении средней массы, но и о большей однородности показателей в группе, получавшей пробиотик.

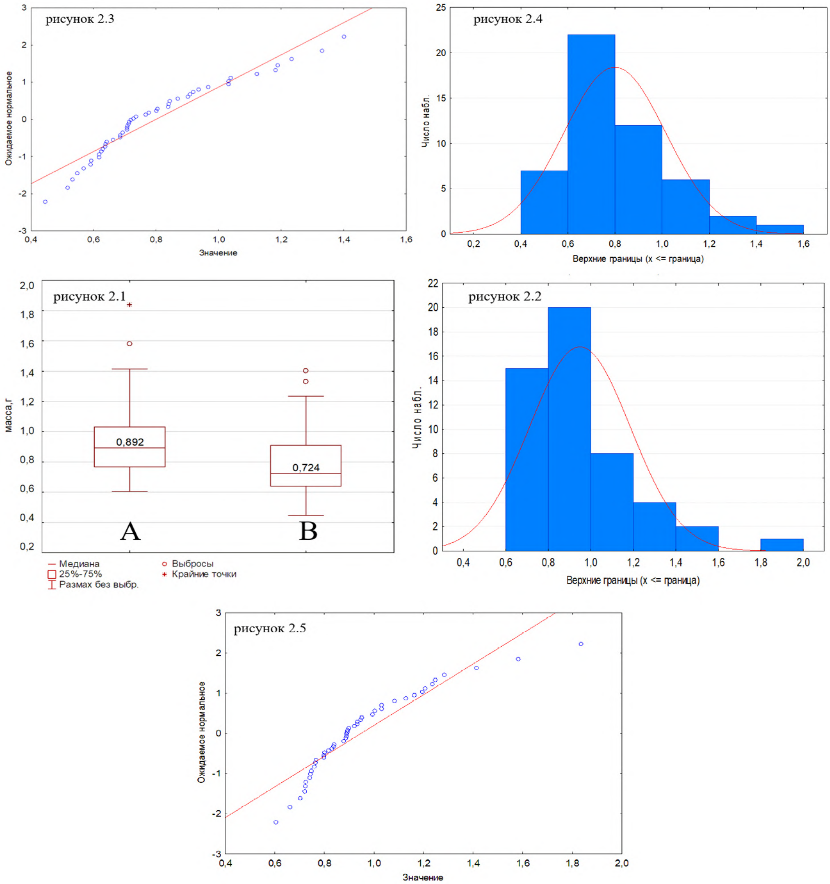

Рис. 2. 2.1. Диаграмма размаха для средней индивидуальной массы рыб в группах «контроль» (А) и «опыт» (В); 2.2 – гистограмма нормальности распределения данных для средней индивидуальной массы рыб в группе «контроль»; 2.3 – график нормальности распределения данных для средней индивидуальной массы рыб для группы «опыт»; 2.4 – гистограмма нормальности распределения данных для средней индивидуальной массы рыб в группе «опыт»; 2.5 – график нормальности распределения данных для средней индивидуальной массы рыб для группы «контроль»

Аналогичные закономерности выявлены для показателя длины тела. Гистограммы распределения (рисунок 3.2, рисунок 3.4) и соответствующие Q-Q графики (рисунок 3.3, рисунок 3.5) подтверждают нормальность распределения данных. Диаграмма размаха (рисунок 3.1) визуализирует достоверное увеличение медианных значений длины в опытной группе при сохранении нормального характера распределения.

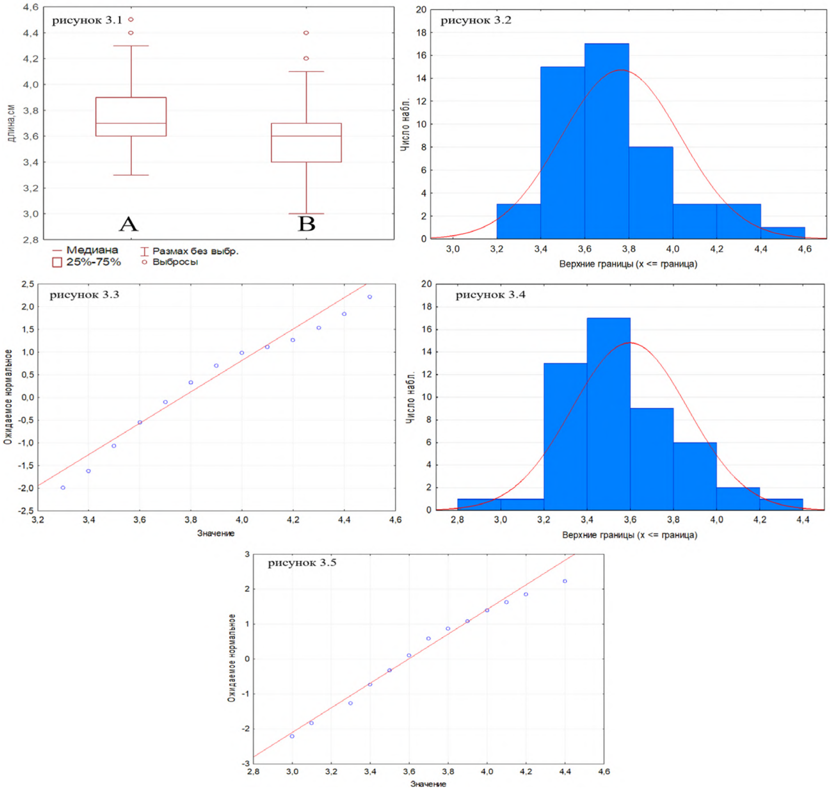

Рис. 3.3.1. Диаграмма размаха для средней индивидуальной длины рыб в группах «контроль» (А) и «опыт» (В); 3.2 – гистограмма нормальности распределения данных для средней индивидуальной длины рыб в группе «контроль»; 3.3 – график нормальности распределения данных для средней индивидуальной длины рыб для группы «контроль»; 3.4 – гистограмма нормальности распределения данных для средней индивидуальной длины рыб в группе «опыт»; 3.5 – график нормальности распределения данных для средней индивидуальной длины рыб для группы «опыт»

Результаты статистического анализа с использованием U-критерия Манна-Уитни показали высокую значимость различий между группами. Для показателя массы тела зафиксированы следующие значения: сумма рангов 3045,50 (контроль) против 2004,50 (пробиотик), U = 729,50 (Z = 3,58; p = 0,000337). Для показателя длины тела: сумма рангов 2969,00 (контроль) против 2081,00 (пробиотик), U=806,00 (Z=3,06; p=0,002). Размер эффекта для обоих показателей соответствовал средней величине (r=0,36 и r=0,31 соответственно), что подтверждает не только статистическую, но и практическую значимость полученных результатов.

Обсуждение и заключение

В ходе исследования установлены различия в морфометрических и основных рыбоводно-биологических характеристиках у младших возрастных групп радужной форели *O. mykiss* между контрольной и опытной группами. Особи, получавшие в рационе мультиштаммовый пробиотик на основе бактерий *B. subtilis* (штаммы MT48 и MT74) с антиоксидантными свойствами, продемонстрировали высокую выживаемость одновременно со снижением коэффициента конверсии корма. Выживаемость в опытной группе была выше, чем в контрольной на 19,41%. Личинки представляют наиболее уязвимую стадию развития, в связи с чем снижение смертности напрямую увеличивает выход товарной продукции и окупаемость затрат на корма.

Результаты исследования демонстрируют увеличение продуктивности в опытной группе, где было зафиксировано повышение выживаемости, а также увеличение средней индивидуальной массы особей (на 12,68%). Совокупное влияние этих факторов привело к значительному (на 38,31%) возрастанию общего прироста биомассы по сравнению с контрольной группой.

Полученные результаты согласуются с данными других исследований, демонстрирующих положительное влияние пробиотических добавок на продуктивность в аквакультуре. В частности, Gołaś I. с соавторами [12] наблюдали увеличение удельной скорости роста молоди *O. mykiss* на 15% при введении в рацион пробиотического штамма *Carnobacterium maltaromaticum* по сравнению с контрольной группой, получавшей стандартный корм. Эти данные подтверждают эффективность применения пробиотиков для оптимизации роста и развития объектов аквакультуры. В исследовании Wang и соавторов [16] продемонстрировано, что добавление пробиотического штамма *B. subtilis* RT-BS07 в рацион молоди *O. mykiss* повышало массонакопление до 118,2% от контрольных значений. Кроме того, было установлено увеличение устойчивости рыб к *Aeromonas* *hydrophila*, что свидетельствует об иммуномодулирующем свойстве данного пробиотического препарата.

Проведённое исследование подтвердило эффективность применения пробиотиков на основе *B. subtilis* (штаммы МТ48 и МТ74) в кормлении личинок *O. mykiss*. Включение пробиотической добавки в рацион способствовало значительному улучшению ключевых рыбоводно-биологических показателей: увеличению массы и длины тела, повышению выживаемости и снижению коэффициента конверсии корма.

Полученные результаты демонстрируют, что использование пробиотиков в раннем онтогенезе форели имеет важное значение для интенсификации аквакультуры. Данный подход может быть рекомендован для внедрения в рыбоводных хозяйствах с целью повышения продуктивности и экономической эффективности производства.

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Original article

MODULAR ROBOTIC PLATFORM FOR AN AUTOMATED SOIL MONITORING SYSTEM

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Abstract

Background. The modular robotic platform is implemented using the "robot-constructor" principle. The basic platform includes standardized interfaces for connecting various modules – specialized chassis for different types of surfaces, manipulators for cargo handling, and sensor systems for navigation and environmental monitoring. This architecture allows the robotic platform to be quickly adapted to specific customer needs without the need to develop a completely new solution. The platform demonstrates particular practical value in agro-ecological monitoring, where the modular architecture allows for the rapid adaptation of sensor equipment for analyzing key soil parameters.

Purpose. To present the architectural and functional design of a modular robotic platform implementing the "robot-constructor" principle and to justify its effectiveness as a basis for creating adaptive ground systems within the national aerospace infrastructure.

Materials and methods. The development of a modular self-propelled robotic platform was carried out within the framework of system engineering: conceptual design → synthesis of architecture → selection of components → integration of subsystems → verification on a physical layout. The design is based on a lightweight and rigid metal frame that allows quick replacement of modules (chassis, manipulators, sensors). For work in the agricultural sector, it is possible to switch from a wheeled to a tracked base.

Localization and orientation are implemented using visual odometry and simplified SLAM (ORB-SLAM2 light) for building 2D maps. Motion control is a multi-contour PID controller: the external contour corrects the deviation from

the trajectory according to the video (P+D), the internal one stabilizes the speed according to the encoder data (I-component). The software platform is ROS 2 Humble (Python 3.10). Key nodes: - vision_node – marker recognition (OpenCV + TensorFlow Lite); - navigation_node – route construction and correction (RRT); - control_node – engine control with adaptive PID adjustment depending on the weight of the cargo; - telemetry_node – data export to JSON/CSV and integration with ERP/MES via REST API. A sensor module is used to monitor the soil: multispectral cameras, humidity, temperature, pH, nutrient sensors, and a sampling device.

Results and conclusion. During the project, a modular self-propelled robotic platform was developed and physically prototyped, functioning as a universal ground component within the domestic Aeronet ecosystem. A unified mechanical and electrical platform with standardized connection interfaces (mechanical – quick-release dovetail mounts; electrical – GX16-4P industrial connectors; software – ROS 2-compatible topics), ensuring the modularity of the chassis, manipulators, sensor complexes, and actuators.

A visual navigation system has been developed and tested.

Based on OpenCV and fine-tuned YOLOv5, an algorithm for recognizing color lines, QR codes, and natural landmarks has been implemented. The platform has been integrated into the educational process at Melitopol State University in four areas of training.

The study confirmed the fundamental feasibility and high efficiency of the modular robotic platform as a tool for converging the Aeronet and Technet NTI roadmaps. The developed solution successfully combines the characteristics of technological sovereignty (domestic component base, open-source stack, rejection of dependent technologies), economic affordability, and functional flexibility.

The practical significance of the project is due to its dual purpose:

1) as an import-substituting industrial solution for the automation of intra-plant logistics at small and medium-sized enterprises;

2) as a multifunctional educational and research platform that forms a personnel reserve in the field of robotics, AI, and digital manufacturing.

Keywords: robotic platform; Aeronet ecosystem; RFID identification systems; computer vision; modular design

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Научная статья

МОДУЛЬНАЯ РОБОТИЗИРОВАННАЯ ПЛАТФОРМА ДЛЯ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ МОНИТОРИНГА ПОЧВ

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Аннотация

Обоснование. Модульная роботизированная платформа реализуется по принципу «робота-конструктора». Базовая платформа включает унифицированные интерфейсы для подключения различных модулей – специализированных шасси для разных типов покрытий, манипуляторов для грузопереработки, сенсорных систем для навигации и мониторинга окружающей среды. Такая архитектура позволяет быстро адаптировать роботизированную платформу под конкретные задачи заказчика без необходимости разработки полностью нового решения. Особую практическую значимость платформа демонстрирует в задачах агроэкологического мониторинга, где модульная архитектура позволяет оперативно адаптировать сенсорное оборудование для анализа ключевых параметров почв.

Цель. Представить архитектурное и функциональное решение модульной роботизированной платформы, реализующей принцип «робота-конструктора», и обосновать его эффективность как основы для создания адаптивных наземных систем в составе национальной аэронет-инфраструктуры.

Материалы и методы. Разработка модульной самоходной роботизированной платформы выполнена в рамках системного инжиниринга: концептуальное проектирование → синтез архитектуры → выбор компонентов → интеграция подсистем → верификация на физическом макете. Конструкция основана на лёгкой и жёсткой металлической раме, допускающей быструю замену модулей (шасси, манипуляторы, сенсоры). Для работы в агросекторе обеспечена возможность перехода с колёсной на гусеничную базу. Локализация и ориентация реализованы с помощью визуальной одометрии и упрощённого SLAM (ORB-SLAM2 light) для построения 2D-карт. Управление движением – многоконтурный PID-регулятор: внешний контур корректирует отклонение от траектории по видео (P+D), внутренний стабилизирует скорость по данным энкодеров (I-компонента). Программная платформа – ROS 2 Humble (Python 3.10). Ключевые узлы: - vision_node – распознавание маркеров (OpenCV + TensorFlow Lite); - navigation_node – построение и коррекция маршрута (RRT); - control_node – управление двигателями с адаптивной настройкой PID в зависимости от массы груза; - telemetry_node – экспорт данных в JSON/CSV и интеграция с ERP/MES через REST API. Для мониторинга почвы используется сенсорный модуль: мультиспектральные камеры, датчики влажности, температуры, pH, питательных веществ и устройство отбора проб.

Результаты и заключение. В ходе реализации проекта разработана и физически прототипирована модульная самоходная роботизированная платформа, функционирующая как универсальный наземный компонент в составе отечественной аэронет-экосистемы. Разработана унифицированная механико-электрическая платформа с интерфейсами стандартизированного подключения (механические – быстросъёмные крепления типа «ласточкин хвост»; электрические – промышленные коннекторы типа GX16-4P; программные – ROS 2-совместимые топики), обеспечивающая модульность шасси, манипуляторов, сенсорных комплексов и исполнительных устройств.

Разработана и протестирована система визуальной навигации.

На основе OpenCV и fine-tuned YOLOv5 реализован алгоритм распознавания цветовых линий, QR-кодов и естественных ориентиров. Платформа интегрирована в учебный процесс Мелитопольского государственного университета по 4 направлениям подготовки.

Проведенное исследование подтвердило принципиальную реализуемость и высокую эффективность модульной роботизированной платформы как инструмента конвергенции дорожных карт НТИ «Аэронет» и «Технет». Разработанное решение успешно сочетает признаки технологического суверенитета (отечественная компонентная база, open-source стек, отказ от зависимых технологий), экономической доступности и функциональной гибкости.

Практическая значимость проекта обусловлена его двойным назначением:

1) как импортозамещающего промышленного решения для автоматизации внутризаводской логистики у предприятий малого и среднего бизнеса;

2) как многофункциональной образовательно-исследовательской платформы, формирующей кадровый резерв в области робототехники, ИИ и цифровых производств.

Ключевые слова: роботизированная платформа; экосистема Аэронет; система RFID-идентификации; компьютерное зрение; модульный конструктор

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Introduction

In the context of global digital transformation and Russia's commitment to technological sovereignty, projects implementing the principles of the National Technology Initiative are particularly important. The Technet (advanced manufacturing technologies) and Aeronet (distributed unmanned aerial vehicle systems) roadmaps define the development trajectory for emerging markets, and their convergence opens new opportunities for creating integrated solutions. It is at the intersection of these strategic areas that the modular self-propelled robotic platform project is being developed at Melitopol State University. This technological product represents a universal ground platform for integration into the Aeronet ecosystem and addresses urgent import substitution needs. The platform's modular design, which embodies the robot-constructor concept, is particularly noteworthy. The basic platform includes standardized interfaces for connecting various modules – specialized chassis for different types of surfaces, manipulators for material handling, and sensor systems for navigation and environmental monitoring. This architecture enables rapid adaptation of the robotic platform to the customer's specific needs without requiring the development of an entirely new system.

Purpose. To present an architectural and functional solution for a modular robotic platform that implements the "robot-constructor" principle and to substantiate its effectiveness as a foundation for developing adaptive ground systems within the national aerospace infrastructure.

Materials and methods

The development of a modular self-propelled robotic platform was developed using a systems engineering approach with a sequential progression through the following stages: conceptual design → architecture synthesis → component selection → subsystem integration → verification on a physical mock-up.

The platform's design is based on a modular mechanical frame made of metal profiles, ensuring rigidity, low weight, and rapid replaceability functional modules (chassis, manipulators, sensor units). To improve cross-country performance on uneven and soft surfaces (in the agricultural sector), the wheelbase can be replaced with a tracked module.

Environmental data are collected using a multisensor system:

The platform's orientation and localization are based on a visual odometric approach. A pretrained model provides real-time marker-based positioning. The SLAM (Simultaneous Localization and Mapping) algorithm is implemented in a simplified form (ORB-SLAM2 light) for generating 2D maps of agricultural land.

A multi-loop PID controller is used to control motion along a specified trajectory:

- outer loop – image-based correction of line deviation (P- and D-components);
- inner loop – speed control and stabilization based on encoder data (I-component for drift compensation).
- The core software stack is implemented in Python 3.10 within the ROS 2 Humble environment, which provides modularity, distributed node execution, and compatibility with industry standards. Key nodes:
- vision_node – video processing and marker recognition (OpenCV + TensorFlow Lite);
- navigation_node – route generation based on map A and real-time correction (RRT);
- control_node – motor control through PWM with adaptive PID parameter tuning depending on the payload (estimated from motor current);
- telemetry_node – data acquisition and export in JSON/CSV formats for subsequent integration into a digital twin (including ERP/MES systems via a REST API).

For soil monitoring, the platform is equipped with a specialized sensor module, including:

- multispectral cameras for assessing vegetation indices
- soil moisture and temperature sensors
- electrochemical sensors for measuring pH and nutrient content
- sampling devices for laboratory analysis (lowercase s for consistency)

Results

The relevance of this development is driven by the increasing need to automate logistics processes in industrial facilities, the agro-industrial complex, and warehouse operations infrastructure. Modern production and logistics chains require reliable, precise, and safe cargo transport over short and medium distances. Market analysis shows that existing industrial solutions from leading international companies (such as MiR Robots, Boston Dynamics, and KUKA) present several constraints for Russian companies, including high cost, difficulty adapting to specific requirements, dependence on foreign technical support, and potential risks of sanctions. The proposed platform (Figure 1) effectively fills this market niche, offering a technologically advanced, affordable, and versatile solution tailored to the real needs of domestic industry.

Fig. 1. Model of a modular self-propelled robotic platform

The project's technology stack is a complex of interconnected solutions that ensure the platform's high functionality and adaptability. The navigation system elies on computer vision implemented via the OpenCV library, allowing the platform to navigate using visual markers (colored lines, QR codes, and natural features). This approach ensures complete independence from satellite positioning system signals (GPS/GLONASS), which is critical for stable operation indoors – in warehouses, workshops, and logistics centers – where traditional navigation methods are ineffective. To ensure smooth and stable motion, PID controllers are used, which compensate for external disturbances in real time such as uneven surfaces, changes in load weight and alignment, and fluctuations in supply voltage. PID control algorithms continuously adjust motor power, ensuring precise tracking of the intended path even under challenging operating conditions.

The platform can also be equipped with plant health monitoring sensors for agricultural applications, RFID cargo identification systems for warehouse applications, and manipulators for precise component delivery to assembly lines for production facilities.

The project's software is implemented in Python, enabling flexible development and extensive integration of artificial intelligence components. The current software architecture allows for the straightforward integration of machine learning modules to solve complex problems, such as object recognition and classification, semantic segmentation of the surrounding environment, and movement prediction in dynamic environments. The system is already capable of processing data from multiple sensors (lidars, ultrasonic sensors, inertial measurement units) and constructing a map of the surrounding environment for optimal route planning.

Within the framework of the Technet roadmap, the robotic platform being developed represents a practical tool for implementing the principles of Factories of the Future. Traditional automated intralogistics systems often require a complete redesign of infrastructure and significant investment, making them inaccessible to small and medium-sized enterprises. In contrast, a modular solution based on computer vision can be implemented in stages, with minimal modifications to the existing infrastructure – simply applying floor markings or installing visual markers. This is particularly important given the need for rapid reconfiguration production and logistics processes in response to changing market conditions.

The robotic platform produces substantial volumes of telemetry data – data on routes traveled, operation times, obstacles encountered, and energy consumption. These data can be integrated into enterprise management systems and used to build a digital twin of logistics flows. This digital twin enables route optimization, modeling of various operational scenarios, and forecasting of the load on logistics infrastructure – all of which is fully aligned with the key goals of Technet in terms of creating cyber-physical systems and digitalizing production.

For the Aeronet ecosystem, the ground-based robotic platform is becoming a critical element, completing the "last-meter" logistics segment. Modern unmanned aircraft systems effectively solve medium- and long-distance delivery problems, but encounter limitations when it comes to pinpoint delivery directly to a workstation or a designated area of an enterprise. The platform being developed addresses this issue by enabling seamless integration of air and ground logistics chains. In a practical use case, an unmanned aerial vehicle delivers cargo to an unloading area (a dedicated platform or building rooftop), where it is picked up by a ground robot for final delivery directly to the recipient. This type of operation is particularly in demand at large-scale industrial facilities with distributed infrastructure, in logistics hubs, and in agricultural complexes with large areas.

A promising area of project development is the creation of a unified software environment for controlling diverse robotic systems. The use of Python and ROS (Robot Operating System) creates the technical prerequisites for unifying navigation algorithms, route planning, and obstacle avoidance for air and ground robotic platforms. This aligns with the fundamental principles of AeroNet as an ecosystem of distributed intelligent systems capable of cooperating and collaboratively addressing complex problems. In agriculture, such integration enables the creation of an autonomous complex where UAVs monitor fields and carry out aerial treatments, while ground platforms perform targeted fertilizer application, soil sampling, and harvest transportation.

The project's significant potential lies in its educational and personnel development components. The integration of the platform into the educational process at Melitopol State University represents a strategic investment in training skilled specialists for high-tech industries. The platform serves as a multifunctional educational platform for students majoring in robotics, mechatronics, artificial intelligence, and information systems and technology. It provides practical skills in programming microcontrollers (Arduino, ESP32) and single-board computers (Raspberry Pi), implementing computer vision algorithms, configuring automatic control systems, and working with sensor systems. The study of modular design principles and system integration is particularly valuable – key competencies for digital transformation engineers.

The platform's educational potential is realized through several formats. In the basic course, students are introduced to the system architecture and basic operating principles. Advanced modules involve programming specific functions and algorithms. The most advanced students participate in research projects to improve individual platform subsystems. This multi-layered approach ensures the training of highly skilled engineers capable of working at the cutting edge of Technet and Aeronet technologies.

The robotic platform has well-defined market prospects and commercialization potential. The primary market segments for implementation are B2B (industrial enterprises, logistics operators, agricultural holdings), B2G (educational institutions, research centers, healthcare facilities), and, to a limited extent, B2C (DIY community, technology enthusiasts). Competitive advantages include adaptability to Russian operating conditions, competitive cost (two to three times lower than foreign equivalents), the ability to quickly customize to meet customer needs, complete technological independence, and compliance with import substitution requirements.

The development roadmap includes plans to create several platform modifications: a basic educational version, an industrial version for operation in challenging conditions, and a specialized version for integration with UAV systems. In parallel, methodological materials for educational institutions and technical documentation for industrial enterprises are being developed.

The robotic modular platform, being developed at Melitopol State University, represents a successful example of the deep convergence of NTI technological trends. For Technet, the project is an effective tool for flexible and accessible automation, a catalyst for the spread of smart manufacturing principles. For Aeronet, the development is becoming a key ground-based element that closes the logistics cycle and enhances the efficiency of the entire ecosystem of distributed unmanned systems.

Conclusion

A self-propelled robotic platform has been developed that functions as a universal ground component within the domestic AeroNet ecosystem. Key results:

A unified mechanical–electrical platform with standardized connection interfaces (mechanical – quick-release dovetail fasteners; electrical – industrial GX16-4P connectors; software – ROS 2-compatible topics) has been developed, enabling modularization of the chassis, manipulators, sensor systems, and actuators.

A visual navigation system has been developed and tested.

An algorithm for detecting color lines, QR codes, and natural features is implemented using OpenCV and fine-tuned YOLOv5. Indoor positioning accuracy is as follows:

- QR code: ±12 mm;
- Color line (30 mm width): ±25 mm at speeds up to 1.2 m/s;
- Marker-free mode (ORB-SLAM2 Light): ±65 mm at distances of up to 15 m.

The system demonstrates resilience to changing illumination (50–1000 lux) and partial occlusion of markers.

The platform has been integrated into the educational process at Melitopol State University across four academic programs.

An air-to-ground logistics scenario was implemented: a UAV (octocopter with a 5 kg payload) delivers cargo to the landing pad, the robotic platform automatically identifies the container via an RFID tag and delivers it to the designated point. The full cycle time is 4.2 minutes (including landing and cargo transfer), with final delivery accuracy of ±30 mm.

The study confirmed the technical feasibility and high efficiency of the modular robotic platform as a tool for converging the NTI AeroNet and TechNet roadmaps. The developed solution successfully combines the characteristics of technological sovereignty (domestic component base, open-source stack, elimination of dependency on external technologies), economic accessibility, and functional flexibility.

The practical significance of the project stems from its dual purpose:

1) as an import-substituting industrial solution for automating intraplant logistics for small and medium-sized businesses;

2) as a multifunctional educational and research platform that supports talent development in the fields of robotics, AI, and digital manufacturing.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

EFFECT OF TGF AND VEGF PROTEINS ON PRENATAL DISEASES OF CALVES: CORRELATION ANALYSIS UNDER COMPLICATED PREGNACY CONDITIONS IN COWS

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Abstract

Background. The study of the role of transforming growth factor (TGF) and vascular endothelial growth factor (VEGF) in the development of prenatal pathologies in calves, especially in the context of complicated pregnancy in cows, is relevant due to the high incidence of morbidity and mortality in newborn young animals, which significantly reduces the economic efficiency of the livestock industry. The study is based on analyzing placental tissue collected immediately after calving to identify relationships between the levels of these proteins and the incidence of pathologies in newborn calves. Changes in TGF and VEGF concentrations can serve as predictors of feto- and uteroplacental insufficiency, which in turn negatively affects the health of calves. Correlation analysis revealed statistically significant relationships between TGF and VEGF levels and clinical disease manifestations, highlighting their role in prenatal disorder pathogenesis. These studies underscore the importance of monitoring TGF and VEGF levels in veterinary practice, potentially enabling early risk identification and the development of effective disease prevention strategies in young animals.

Purpose. The objective of the present study is to develop new methods for predicting prenatal diseases in calves based on the correlation analysis of TGF and VEGF protein levels.

Materials and methods. At the SPC “Plemzavod Vtoraya Pyatiletka”, in the period from 2023 to 2024, a correlation analysis of the proteins TGF and VEGF in the context of complicated pregnancy was carried out.

For the experiment, 200 dry first-calf heifers aged 24 to 48 months were randomly selected. The animals were divided into two groups: Group A included 100

cows with a physiological pregnancy and uncomplicated births, and Group B consisted of 100 animals with complicated pregnancy, accompanied by feto- and uteroplacental insufficiency.

The distribution of livestock into groups was carried out on the basis of anamnesis data and clinical examination results.

Placental tissue collected immediately after calving in compliance with the temperature (cold) regime was used as research material.

The study analyzed the protein level of transforming growth factor (TGF), which regulates various cellular functions such as growth, development, immune responses, and tissue remodeling. The protein level of vascular endothelial growth factor (VEGF), which is involved in angiogenesis, was also assessed using enzyme immunoassay kits from the biotechnological company Cutimmune systems, located in the United States.

The licensed program "Primer of Biostatistics 4.03. For Windows" was used to process the data in the study.

The homogeneity of variances was assessed using the Fisher criterion, which allows determining the uniformity of variances in a group.

To test the statistical significance of differences between the compared groups, two criteria were used: the Student criterion and the nonparametric Mann-Whitney criterion. The Student criterion is a parametric method and is designed to compare the average values of two groups. The nonparametric Mann-Whitney criterion, in turn, is designed to compare two independent and unrelated small samples by a quantitative feature of two groups. Differences were considered reliable at $p<0.05$.

To conduct a correlation analysis, the Spearman method was used, which allows determining the strength and direction of the relationship between two features.

Results. During the study, it was found that prenatal disorders in calves born from cows with feto- and uteroplacental insufficiency have a direct correlation with the level of protein transforming growth factor (TGF) and protein vascular endothelial growth factor (VEGF).

Conclusion. The results of the studies revealed significant differences in the levels of VEGF and TGF proteins in cows with complicated pregnancy. Data analysis showed that the level of VEGF in animals from group B was 24% higher compared to the indicators of group A ($p<0.05$). At the same time, a significant decrease in the concentration of TGF in the placentas of cows with complicated pregnancy was observed - 2.4 times lower than in animals with a physiological course of pregnancy ($p<0.01$). These changes may indicate a compensatory mechanism in which an increase in VEGF production is aimed at leveling out the consequences of a sharp decrease in the level of TGF.

Also, special attention was paid to the ratio of VEGF and TGF in the placenta. In group A, this coefficient was 1.1%, which indicates a balance of the processes regulated by these growth factors. At the same time, a significant increase in the VEGF/TFR ratio was observed in Group B – approximately 3.2 times compared to Group A. This indicates a pronounced imbalance in the regulation of angiogenesis and metabolic processes in cows with complicated pregnancy.

The obtained VEGF/TFR ratio can become a valuable tool for predicting physiological disorders in calves during postembryonic ontogenesis. Its use will optimize veterinary strategies and, possibly, prevent the development of diseases in the long term. This is important not only for ensuring animal welfare, but also for increasing the economic efficiency of animal husbandry by reducing losses associated with morbidity and mortality of young animals.

Keywords: transforming growth factor; vascular endothelial growth factor; prenatal diseases; pregnancy; cows

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Научная статья

ВЛИЯНИЕ БЕЛКОВ TGF И VEGF НА ПРЕНАТАЛЬНЫЕ ЗАБОЛЕВАНИЯ ТЕЛЯТ: КОРРЕЛЯЦИОННЫЙ АНАЛИЗ В УСЛОВИЯХ ОСЛОЖНЕННОЙ БЕРЕМЕННОСТИ У КОРОВ

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Аннотация

Обоснование. Изучение роли трансформирующего фактора роста (TGF) и фактора роста эндотелия сосудов (VEGF) в развитии пренатальных патологий у телят, особенно в условиях осложненной беременности у коров, актуально в связи с высокой заболеваемостью и смертностью новорожденного молодняка, что значительно снижает экономическую эффективность животноводческой отрасли. Исследование основано на анализе плацентарной ткани, взятой сра-

зу после отела, с целью выявления взаимосвязи между уровнем этих белков и частотой патологий у новорожденных телят. Изменения концентрации TGF и VEGF могут служить предикторами фето- и маточно-плацентарной недостаточности, что, в свою очередь, негативно сказывается на здоровье телят. Корреляционный анализ выявил статистически значимые связи между уровнями TGF и VEGF и клиническими проявлениями заболеваний, что подчеркивает их роль в патогенезе пренатальных нарушений. Эти исследования подчеркивают важность мониторинга уровней TGF и VEGF в ветеринарной практике, что может способствовать раннему выявлению рисков и разработке эффективных стратегий профилактики заболеваний у молодых животных.

Цель. Целью исследования является разработка новых методов прогнозирования пренатальных заболеваний у телят на основе корреляционного анализа уровней белков TGF и VEGF.

Материалы и методы. В НПЦ «Племзавод “Вторая Пятилетка”» в период с 2023 по 2024 год был проведен корреляционный анализ белков TGF и VEGF в условиях осложненной беременности.

Для эксперимента были случайным образом отобраны 200 сухостойных первотелок в возрасте от 24 до 48 месяцев. Животные были разделены на две группы: В группу А вошли 100 коров с физиологической беременностью и неосложненными родами, а в группу Б – 100 животных с осложненной беременностью, сопровождающейся фето- и маточно-плацентарной недостаточностью.

Распределение поголовья по группам проводилось на основании данных анамнеза и результатов клинического обследования.

В качестве материала исследования использовали плацентарную ткань, собранную сразу после отела с соблюдением температурного (холодового) режима.

В ходе исследования был проанализирован уровень белка трансформирующего фактора роста (TGF), который регулирует различные клеточные функции, такие как рост, развитие, иммунные реакции и ремоделирование тканей. Уровень белка фактора роста эндотелия сосудов (VEGF), участвующего в ангиогенезе, также оценивали с помощью наборов для иммуноферментного анализа биотехнологической компании Cutimmune systems, расположенной в США.

Для обработки данных в исследовании использовалась лицензионная программа «Primer of Biostatistics 4.03. For Windows» использовалась для обработки данных в исследовании.

Однородность вариаций оценивали с помощью критерия Фишера, который позволяет определить однородность вариаций в группе.

Для проверки статистической значимости различий между сравниваемыми группами использовали два критерия: критерий Стьюдента и непараметрический критерий Манна-Уитни. Критерий Стьюдента является параметрическим методом и предназначен для сравнения средних значений двух групп. Непараметрический критерий Манна-Уитни, в свою очередь, предназначен для сравнения двух независимых и несвязанных малых выборок по количественному признаку двух групп. Различия считались достоверными при $p < 0,05$.

Для проведения корреляционного анализа использовали метод Спирмена, который позволяет определить силу и направление связи между двумя признаками.

Результаты. В ходе исследования было установлено, что пренатальные нарушения у телят, рожденных от коров с фето- и маточно-плацентарной недостаточностью, имеют прямую корреляцию с уровнем белка трансформирующего фактора роста (TGF) и белка сосудисто-эндотелиального фактора роста (VEGF).

Заключение. Результаты исследований выявили значительные различия в уровнях белков VEGF и TGF у коров с осложненной беременностью. Анализ данных показал, что уровень VEGF у животных из группы B был на 24 % выше по сравнению с показателями группы A ($p<0,05$). В то же время наблюдалось значительное снижение концентрации TGF в плацентах коров с осложненной беременностью - в 2,4 раза ниже, чем у животных с физиологическим течением беременности ($p<0,01$). Данные изменения могут свидетельствовать о компенсаторном механизме, при котором увеличение продукции VEGF направлено на нивелирование последствий резкого снижения уровня TGF.

Также особое внимание было уделено соотношению VEGF и TGF в плаценте. В группе A этот коэффициент составил 1,1%, что свидетельствует о сбалансированности процессов, регулируемых этими факторами роста. В то же время в группе B наблюдалось значительное увеличение соотношения VEGF/ТФР - примерно в 3,2 раза по сравнению с группой A. Это свидетельствует о выраженном дисбалансе в регуляции ангиогенеза и метаболических процессов у коров с осложненной беременностью.

Полученное соотношение VEGF/TFR может стать ценным инструментом для прогнозирования физиологических нарушений у телят в постэмбриональном онтогенезе. Его использование позволит оптимизировать ветеринарные стратегии и, возможно, предотвратить развитие заболеваний в долгосрочной перспективе. Это важно не только для обеспечения благополучия животных, но и для повышения экономической эффективности животноводства за счет снижения потерь, связанных с заболеваемостью и смертностью молодняка.

Ключевые слова: трансформирующий фактор роста; фактор роста эндотелия сосудов; пренатальные заболевания; беременность; коровы

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Introduction

The birth of calves with intrauterine pathologies is a major issue in veterinary medicine and animal husbandry, leading to significant economic losses and health deterioration in young animals [1; 2]. Prenatal disorders that occur in the context of complicated pregnancy require immediate intervention and correction to minimize their negative consequences.

One of the key elements that determine the health of the fetus is uteroplacental insufficiency, which is often accompanied by hemodynamic disorders and oxygen starvation of the fetus. Such conditions can cause severe damage to the tissues and organs of newborns, including disorders in the functioning of the nervous system [3; 5]. The main clinical manifestations of uteroplacental insufficiency are hypoxia and intrauterine growth retardation, which is confirmed by numerous studies [1; 2].

An important aspect in the development of these pathologies is the disruption of angiogenesis processes in the early stages of embryo formation. These processes directly depend on the production of growth factors – regulatory polypeptides that affect the development of the placenta, its growth and the formation of the vascular network. Among the many known growth factors, special attention is paid to transforming growth factor (TGF) and specific extrafollicular growth factor (VEGF). These proteins, synthesized by the placenta, play a key role in the regulation of metabolic processes and angiogenesis, which is critical for the normal course of pregnancy [8; 9].

An imbalance of these endogenous regulators can cause various pregnancy complications, including uteroplacental insufficiency. Normal fetal development and the course of gestation directly depend on the state of angiogenesis and the production of angiogenic factors that control the formation and regression of blood vessels.

Thus, there is a need to develop new methods for predicting prenatal diseases in calves based on a correlation analysis of TGF and VEGF protein levels. This will allow timely implementation of adequate pathogenetic therapy, which will help reduce the frequency and severity of manifestations of prenatal disorders, which will ultimately improve the health of newborn young animals and increase the efficiency of animal husbandry.

Purpose. The objective of the present study is to develop new methods for predicting prenatal diseases in calves based on the correlation analysis of TGF and VEGF protein levels.

Materials and methods

At the SPC "Plemzavod Vtoraya Pyatiletka", in the period from 2023 to 2024, a correlation analysis of the proteins TGF and VEGF in the context of complicated pregnancy was carried out.

For the experiment, 200 dry first-calf heifers aged 24 to 48 months were randomly selected. The animals were divided into two groups: Group A included 100 cows with a physiological pregnancy and uncomplicated births, and Group B consisted of 100 animals with complicated pregnancy, accompanied by feto- and uteroplacental insufficiency.

The distribution of livestock into groups was carried out on the basis of anamnesis data and clinical examination results.

Placental tissue collected immediately after calving in compliance with the temperature (cold) regime was used as research material.

The study analyzed the protein level of transforming growth factor (TGF), which regulates various cellular functions such as growth, development, immune responses, and tissue remodeling.

The protein level of vascular endothelial growth factor (VEGF), which is involved in angiogenesis, was also assessed using enzyme immunoassay kits from the biotechnological company Cutimmune systems, located in the United States.

The licensed program "Primer of Biostatistics 4.03. For Windows" was used to process the data in the study.

The homogeneity of variances was assessed using the Fisher criterion, which allows determining the uniformity of variances in a group.

To test the statistical significance of differences between the compared groups, two criteria were used: the Student criterion and the nonparametric Mann-Whitney criterion. The Student criterion is a parametric method and is designed to compare the average values of two groups. The nonparametric Mann-Whitney criterion, in turn, is designed to compare two independent and unrelated small samples by a quantitative feature of two groups. Differences were considered reliable at $p<0.05$.

To conduct a correlation analysis, the Spearman method was used, which allows determining the strength and direction of the relationship between two features.

Results of the research

The level of protein TGF and growth factor VEGF in complicated pregnancy.

During the study, it was found that prenatal disorders in calves born from cows with feto- and uteroplacental insufficiency have a direct correlation with the level of protein transforming growth factor (TGF) and protein vascular endothelial growth factor (VEGF) (Table 1).

Table 1.

Level of growth factors in the placenta of cows from groups A and B (M±m)

Study groups	Contents of the SEFR	Contents of TFR
A group – pregnancy without complications	0.34+0.1* (ng/mg tissue)	0.31+0.95 (ng/mg tissue)
Group B – complicated (pathological) pregnancy	0.41+0.2* (ng/mg tissue)	0.13+0.4* (ng/mg tissue)

* – deviations from the norm in pathological pregnancy are statistically confirmed.

The obtained data presented in Table 1 and their analysis clearly demonstrate that the level of vascular endothelial growth factor protein in cows from group B significantly exceeded the indicators of cows from group A by 24% ($p<0.05$). At the same time, the content of TGF significantly decreased in the placentas of the studied cows with complicated pregnancy from group B compared to group A by 2.4 times ($p<0.01$). This may indicate that an increase in the production of VEGF compensates for a sharp drop in the TGF level. The identified changes in the production of growth factors during complicated pregnancy in the studied cows are associated with the suppression of key functions of the placenta, which in turn leads to the progression of irreversible processes in this organ, thereby worsening the physiological development of the fetus.

The established disorganization in the production of growth factors such as VEGF and TGF can create favorable conditions for the development of feto- and uteroplacental insufficiency, and fetal growth retardation. It is important to note that the imbalance in the level of growth factors, accompanied by an increase in the production of VEGF and TGF, can be a consequence of hypoxic conditions inherent in complicated pregnancy. These changes can affect the regulation of blood flow, metabolism and immune responses in the body of the cow and the fetus, leading to intrauterine growth retardation.

Taking into account the important complex effect of growth factors on the processes they control and the relationship between their effects, it is proposed to calculate the ratio of the concentration of vascular endothelial growth factor

(VEGF) to transforming growth factor (TGF) and study changes in this coefficient at different stages of calf ontogenesis. This analysis involves monitoring calves for 60 days to identify the dynamics of changes.

Changes in the VEGF/TGF ratio may reflect the interaction between two key growth factors and their role in regulating physiological adaptation processes in calves during early postnatal ontogenesis. A high or low level of this ratio may indicate disturbances in the balance between the two factors, which may affect animal productivity.

Studying the dynamics of this ratio during the 60-day period after birth will help identify possible patterns between its change and physiological processes occurring during postembryonic development of calves. This approach helps identify factors influencing the productivity of young animals, as well as in developing strategies for maintaining an optimal balance of growth factors in animals during early postnatal ontogenesis.

The period of early neonatal ontogenesis in young cattle of all groups was recorded without complications. Despite the absence of physiological disorders in newborn calves of all groups, special attention was paid to the ratio of certain growth factors (VEGF/TGF) in the placenta. In group A, this coefficient was 1.1%, indicating a certain balance between vascular endothelial and transforming growth factor. However, in group B, a significant increase in this coefficient was observed, approximately 3.2 times that of group A (Table 2).

Table 2.

Growth factor coefficient of cows from groups A and B

Study groups	TFR/SEFR ratio
A group – pregnancy without complications	1.1
Group B – complicated (pathological) pregnancy	3.54

One of the characteristic features of physiological adaptation disorders in calves in postembryonic ontogenesis is often the absence of noticeable clinical signs during the initial examination, which appear only a few hours after birth. Clinical manifestations of these disorders in newborn calves differ from those in older calves. In this regard, newborn calves from Group B were under the supervision of a veterinarian during the first two months of life.

Upon reaching the age of one and a half months, clinical signs of cerebral disorders (n=32) were detected in calves of the studied Group B, namely: an uncertain standing posture, decreased appetite and changes in eating behavior, increased excitability or, on the contrary, passivity, deviations in physical development. Thus, monitoring the coefficient of growth factors and regulating their production can play a key role in improving pregnancy outcomes in cows, health and productivity of newborn offspring.

Discussion and conclusion

The results of the studies revealed significant differences in the levels of VEGF and TGF proteins in cows with complicated pregnancy. Data analysis showed that the level of VEGF in animals from group B was 24% higher compared to the indicators of group A ($p<0.05$). At the same time, a significant decrease in the concentration of TGF in the placentas of cows with complicated pregnancy was observed - 2.4 times lower than in animals with a physiological course of pregnancy ($p<0.01$). These changes may indicate a compensatory mechanism in which an increase in VEGF production is aimed at leveling out the consequences of a sharp decrease in the level of TGF.

Also, special attention was paid to the ratio of VEGF and TGF in the placenta. In group A, this coefficient was 1.1%, which indicates a balance of the processes regulated by these growth factors. At the same time, a significant increase in the VEGF/TFR ratio was observed in Group B — approximately 3.2 times compared to Group A. This indicates a pronounced imbalance in the regulation of angiogenesis and metabolic processes in cows with complicated pregnancy.

The obtained VEGF/TFR ratio can become a valuable tool for predicting physiological disorders in calves during postembryonic ontogenesis. Its use will optimize veterinary strategies and, possibly, prevent the development of diseases in the long term. This is important not only for ensuring animal welfare, but also for increasing the economic efficiency of animal husbandry by reducing losses associated with morbidity and mortality of young animals.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

THE INFLUENCE OF DEUTERIUM-DEPLETED WATER LARSEN D100 ON SEED GERMINATION PARAMETERS IN CEREAL, OILSEED, AND LEGUME CROPS

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Abstract

Background. The study aimed to investigate the species-specific effects of deuterium-depleted water (Larsen D100, <100 ppm D) on seed germination and early seedling growth parameters of key agricultural crops (barley, wheat, rapeseed, and lentil) under controlled in vitro conditions. Seeds were germinated in Petri dishes on a fabric material moistened with either distilled water (control) or Larsen D100. The experiment was set up in a completely randomized design (CRD) with several biological replications. After 10 days, the following key parameters were assessed: germination rate, seedling length, and fresh biomass. Data were statistically processed using Student's t-test or the Mann-Whitney U-test ($p<0.05$). Treatment with deuterium-depleted water had a pronounced and species-specific influence. A significant stimulatory effect was recorded in barley: germination increased by 20%, seedling length by 72%, and biomass by 17% compared to the control. Lentil showed a sharp increase in length (222%) and biomass (64%) of seedlings, although germination rate remained unchanged. In contrast, rapeseed exhibited inhibition of biomass accumulation (a 38% reduction), while wheat parameters did not change. Deuterium-depleted water acts as a powerful metabolic modulator, but its effects are strictly species-specific-ranging from significant stimulation to inhibition. The obtained data highlight the potential for its use in pre-sowing seed treatment for crops such as barley and lentil but strongly caution against universal application without mandatory prior species and cultivar testing. The observed effects are associated with isotope-mediated changes in the kinetics of key enzymatic and osmotic processes in the early stages of plant development.

Purpose. Of the study was to evaluate the effect of deuterium-depleted water (Larsen D100) on germination efficiency (germination rate) and initial growth vigor (length and fresh weight) of seedlings in four economically important species of agricultural crops representing cereals (barley, wheat), oilseeds (rapeseed), and legumes (lentil).

Materials and methods. Seeds of spring barley (Hordeum vulgare L.), soft wheat (*Triticum aestivum* L.), rapeseed (*Brassica napus* L.), and lentil (*Lens culinaris Medik*) were sterilized and germinated in Petri dishes on filter paper moistened with distilled water (control, pH=5.8, EC<5 μS/cm) or deuterium-depleted water (Larsen D100, <100 ppm D). The experiment was set up according to a completely randomized design (CRD) with several biological replications (Petri dishes). Germination was carried out for 10 days at a temperature of 23±1°C. Germination rate, seedling length, and fresh weight were recorded. Statistical analysis was performed using Statistica 10.0 software employing parametric (Student's t-test) or non-parametric (Mann-Whitney U-test) methods for independent samples at a significance level of $p<0.05$.

Results. The application of Larsen D100 water led to a complex, species-specific response. For barley, significant stimulation was found for all parameters. Germination rate increased by 20%, seedling length by 72%, and fresh weight by 17%. For lentil, no effect on germination rate (~97%) was characteristic, but a sharp increase in length (222%) and fresh weight (64%) of seedlings was observed. Data analysis for rapeseed showed no significant effect on germination and length, but a substantial reduction (38%) in seedling fresh weight. No statistically significant effect on any of the measured parameters of wheat was found.

Conclusion. Deuterium-depleted water Larsen D100 is not a universal biostimulant but represents a powerful species-specific modulator of germination and early growth processes. It significantly enhances the initial growth vigor in barley and lentil but inhibits biomass accumulation in rapeseed, while wheat demonstrates a neutral response. This specificity underscores the critical importance of mandatory preliminary testing on each target crop and cultivar before considering any agronomic application. The detected effects are likely rooted in isotope-induced modifications of the kinetics of metabolic reactions, energy metabolism, and osmotic processes.

Keywords: deuterium-depleted water; seed germination; plant growth; isotope effect

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Научная статья

ВЛИЯНИЕ ВОДЫ С ПОНИЖЕННЫМ СОДЕРЖАНИЕМ ДЕЙТРИЯ LARSEN D100 НА ПОКАЗАТЕЛИ ПРОРАСТАНИЯ СЕМЯН ЗЛАКОВЫХ, МАСЛИЧНЫХ И БОБОВЫХ КУЛЬТУР

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Аннотация

Обоснование. Исследование направлено на изучение видоспецифичных эффектов воды с пониженным содержанием дейтерия (Larsen D100, <100 ppm D) на показатели прорастания семян и раннего роста проростков ключевых сельскохозяйственных культур (ячменя, пшеницы, рапса и чечевицы) в контролируемых условиях in vitro. Семена проращивали в чашках Петри на тканном материале, увлажненной либо дистиллированной водой (контроль), либо водой Larsen D100. Опыт был заложен в полном рандомизированном дизайне (CRD) с несколькими биологическими повторностями. Через 10 дней оценивали следующие ключевые параметры: всхожесть, длину проростка и сырую биомассу. Данные были статистически обработаны с использованием t-критерия Стьюдента или U-критерия Манна-Уитни ($p<0,05$). Обработка дейтерий-дефицитной водой оказывала выраженное и видоспецифичное влияние. Достоверный стимулирующий эффект был зарегистрирован у ячменя: всхожесть увеличилась на 20%, длина проростков - на 72%, а биомасса - на 17% по сравнению с контролем. У чечевицы наблюдалось резкое увеличение длины (на 222%) и биомассы (на 64%) проростков, хотя всхожесть осталась неизменной. Напротив, у рапса было выявлено ингибирование накопления биомассы (снижение на 38%), в то время как параметры пшеницы не изменились. Вода с пониженным содержанием дейтерия выступает в роли мощного метаболического модулятора, но ее эффекты строго видоспецифичны - от значительной стимуляции до ингибирования. Полученные данные подчеркивают потенциальную возможность ее использования для предпосевной обработки семян таких культур, как ячмень и чечевица, но настоятельно предостерегают от универсального применения без обязательного предварительного видового и сортового тестирования. Наблюдаемые эффекты связаны с изотоп-опосредованными изменениями кинетики ключевых ферментативных и осмотических процессов на ранних стадиях развития растения.

Цель. Цель исследования заключалась в оценке влияния воды с пониженным содержанием дейтерия (Larsen D100) на эффективность прорастания (всхожесть) и энергию начального роста (длину и сырую массу) проростков у четырех экономически важных видов сельскохозяйственных культур, представляющих злаки (ячмень, пшеница), масличные (рапс) и бобовые (чечевица).

Материалы и методы. Семена ярового ячменя (*Hordeum vulgare* L.), мягкой пшеницы (*Triticum aestivum* L.), рапса (*Brassica napus* L.) и чечевицы (*Lens culinaris Medik*) проращены в чашках Петри на тканном материале, увлажненной дистиллированной водой (контроль, pH=5,8, ЭП<5 мкСм/см) или водой с пониженным содержанием дейтерия (Larsen D100, <100 ppm D). Опыт был заложен по принципу CRD с несколькими биологическими повторностями (чашки Петри). Проращивание проводили в течение 10 дней при температуре 23±1°C. Учитывали всхожесть, длину проростка и сырую массу. Статистический анализ проводили в программе Statistica 10.0 с использованием параметрического (t-критерий Стьюдента) или непараметрического (U-критерий Манна-Уитни) методов для независимых выборок при уровне значимости $p<0,05$.

Результаты. Применение воды Larsen D100 привело к сложному, видоспецифичному ответу. Для ячменя выявлена достоверная стимуляция по всем параметрам. Всхожесть увеличилась на 20%, длина проростков - на 72%, сырая масса - на 17%. Для чечевицы характерно отсутствие эффекта на всхожесть (~97%), но резкое увеличение длины (на 222%) и сырой массы (на 64%) проростков. Анализ данных по рапсу показал отсутствие достоверного эффекта на всхожесть и длину, но существенное снижение (на 38%) сырой массы проростков. Статистически значимого влияния на какие-либо из измеряемых параметров пшеницы не выявлено.

Заключение. Вода с пониженным содержанием дейтерия Larsen D100 не является универсальным биостимулятором, а представляет собой мощный видоспецифичный модулятор процессов прорастания и раннего роста. Она достоверно усиливает стартовую энергию роста у ячменя и чечевицы, но ингибирует накопление биомассы у рапса, в то время как пшеница демонстрирует нейтральный ответ. Эта специфичность подчеркивает критическую важность обязательного предварительного тестирования на каждой целевой культуре и сорте перед рассмотрением какой-либо агрономической аппликации. Обнаруженные эффекты, вероятно, коренятся в изотоп-индуцированных модификациях кинетики метаболических реакций, энергетического метаболизма и осмотических процессов.

Ключевые слова: вода обедненная дейтерием; прорастание семян; рост растений; изотопный эффект

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Introduction

Sustainable agricultural development in the face of climate change and growing population pressure requires innovative approaches to increasing the productivity of staple crops [1]. Research on crop growth and adaptation has become a fundamental factor in ensuring global food security. Since the Green Revolution, while the world's population has doubled, the area under grain crops has remained virtually unchanged, while crop yields have tripled. These indicators demonstrate the effectiveness of breeding programs, agronomic practices, and the introduction of innovative technologies [2]. In modern conditions, there is a need to ensure food security for a population close to 10 billion people [3] in the face of climate change, soil degradation, and limited water resources. These challenges require further intensification of scientific research and improvement of agricultural technologies. Seed germination is a critical stage in plant ontogenesis, determining further development and crop formation [4]. Germination energy, germination rate and initial growth vigor directly affect plant density, their competitiveness against weeds and resistance to abiotic stress [5; 6].

Water plays a fundamental role in the germination process, acting not only as a universal solvent and medium for biochemical reactions but also as an active participant in metabolic processes [7]. In recent decades, the biological effects of deuterium-depleted water (DDW) have been actively studied in medicine and microbiology. Existing evidence suggests that deuterium is a natural regulator of cell growth, capable of controlling the balance between mitochondrial oxidation and reduction [8]. Natural deuterium concentrations and a stable D/H ratio are vital conditions for maintaining normal cell growth rates and signaling, as well as for regulating the physiological functions of living systems [9]. In 1993, Somlyai et al. [9] noted the potential effect of DDW in suppressing tumor growth in xenograft-bearing mice. Since then, numerous publications have examined the antitumor effects of DDW both in vitro and in vivo, as well as its potential to prolong the survival of cancer patients and alleviate symptoms [10].

However, in contrast to medical and microbiological studies, the effects of deuterium-deficient water on higher plants, and particularly on the critical stage of seed germination, have been extremely poorly studied. An analysis of the existing literature reveals fragmentary and inconsistent data on the effects of DDW on plants [13]. Existing studies often focus on a single species or a limited set of parameters, preventing generalizable conclusions. A key shortcoming is the lack of comprehensive comparative studies within a single experimental protocol that would encompass representatives of different botanical families and economic groups.

Therefore, the aim of this study was to comprehensively assess the impact of deuterium-reduced water (Larsen D100, <100 ppm D) on germination and early growth parameters of four economically important agricultural crops: barley and wheat (cereals), rapeseed (oilseed rape), and lentils (legumes). Reducing the deuterium concentration in germination water will significantly impact physiological processes at a critical early stage of plant ontogenesis, and this effect will be highly species-specific, conditioned by the metabolic characteristics of each of the studied crops.

Purpose. The aim of the study was to evaluate the effect of deuterium-reduced water (Larsen D100) on germination efficiency and initial growth vigor (length and fresh weight) of seedlings in four economically important crop species representing cereals (barley, wheat), oilseeds (rapeseed) and legumes (lentils).

Materials and Methods

Seeds of spring barley (*Hordeum vulgare L.*), common wheat (*Triticum aestivum L.*), rapeseed (*Brassica napus L.*), and lentil (*Lens culinaris Medik*) were visually inspected before the experiment to ensure uniformity and absence of damage. The experiment was designed using the CRD principle. For the control variant, 4 Petri dishes were prepared (one for each of the indicated crops), each containing 25 seeds. For the experimental variant, 12 Petri dishes (biological replicates) were prepared, each containing 25 seeds. Distilled water was used as the control variant; pH = 5.8, electrical conductivity (EC) = <5 μS/cm. The experimental variant consisted of Larsen D100 deuterium-reduced drinking water (produced in Russia; the manufacturer's declared deuterium content is <100 ppm). Sterile Petri dishes (90 mm in diameter) were lined with three sterile cotton pads and moistened with 10 ml of the appropriate aqueous solution. The seeds were laid out with sterile tweezers, avoiding their contact with each other. The closed dishes were placed in a climatic chamber at a constant temperature of 23 ± 1 °C. During the 10-day germination period, the discs were additionally moistened daily with 2 ml aliquots of the respective solutions to maintain humidity. On the 10th day, the following parameters were recorded: seed germination, seedling length (measured from the root collar to the tip of the coleoptile or hypocotyl using a digital caliper), and fresh weight.

Statistical analysis was performed using Statistica 10.0 software (StatSoft, USA). Separate analyses were performed for each plant species. The normality of distribution of quantitative parameters (seedling length and weight) was tested using the Shapiro-Wilk test. Comparisons of quantitative parameters between the control and experimental groups were performed using the Student's t-test for independent samples (under the conditions of normal distribution and homogeneity of variances) or the Mann-Whitney U-test. Data are presented as the arithmetic mean and standard deviation (M ± SD). Differences were considered statistically significant at $p < 0.05$.

Results

In the course of the experiment, the effect of an aqueous solution with a reduced deuterium content (Larsen D100) on key parameters of seed germination of four agricultural crops was assessed (Figs. 1-4; Table 1). The results demonstrate a species-specific response to the applied treatment.

Table 1.

The effect of water with reduced deuterium content (Larsen D100) on seed germination parameters

Culture	Group	Germination rate, % (average)	Seedling length, cm (mean ± SD)	Seedling fresh weight, g (mean ± SD)	p-value (length)	p-value (mass)
Hordeum vulgare L.	Control	64	3.6 ± 2.0	0.133 ± 0.033	<0.001	0.004
	Test (D100)	84	6.2 ± 2.4	0.156 ± 0.030		
Lens culinaris Medik	Control	96	0.9 ± 0.5	0.058 ± 0.015	<0.001	<0.001
	Test (D100)	97	2.9 ± 1.5	0.095 ± 0.020		
Brassica napus L.	Control	92	1.3 ± 0.6	0.016 ± 0.009	0.25	0.004
	Test (D100)	84	1.4 ± 0.7	0.010 ± 0.001		
Triticum aestivum L.	Control	56	5.0 ± 1.7	0.107 ± 0.018	0.51	0.20
	Test (D100)	69	5.5 ± 3.3	0.098 ± 0.035		

Treatment with Larsen D100 water did not have a statistically significant effect on the germination of *Lens culinaris Medik* seeds, which remained at an exceptionally high level in both groups: 96% in the control and 97% in the experimental group ($p = 0.74$). However, a reliable stimulating effect on growth characteristics was observed. The average length of seedlings in the experimental group was more than three times higher than in the control group (2.9 cm versus 0.89 cm; $p < 0.001$). Similar positive dynamics were observed for seedling biomass: their fresh weight in the experimental group was significantly higher (0.095 g versus 0.058 g in the control; $p < 0.001$).

In *Brassica napus L.* seeds, the treatment showed an inhibitory effect on biomass accumulation. Despite a statistically insignificant difference in germination (92% in the control and 84% in the experiment; $p = 0.32$) and seedling length (1.27 cm and 1.44 cm, respectively; $p \approx 0.25$–0.31), the fresh weight of seedlings in the experimental group was significantly lower than in the control (0.010 g versus 0.016 g; $p < 0.01$).

In *Triticum aestivum L.* seedlings, no statistically significant effect of experimental water was found on any of the studied parameters. Germination rates (56% in the control and 69% in the test; $p = 0.22$), average length (5.0 cm and 5.5 cm), and fresh weight (0.107 g and 0.098 g) of seedlings did not differ significantly between groups ($p > 0.19$ for all comparisons).

The greatest stimulating effect of treatment with Larsen D100 water was recorded in *Hordeum vulgare L.* The treatment significantly increased seed germination by 20% compared to the control (84% versus 64%; $p = 0.003$). A significant increase in seedling length (6.2 cm in the experiment versus 3.6 cm in the control; $p < 0.01$) and their fresh weight (0.156 g versus 0.133 g; $p < 0.01$) was also observed.

Thus, water with a reduced deuterium content had a pronounced multidirectional effect on the germination and initial growth of the studied crops: from significant stimulation in *Hordeum vulgare L.* and *Lens culinaris Medik* to inhibition of biomass accumulation in *Brassica napus L.* The studied factor did not have a significant effect on *Triticum aestivum L.*

Conclusion

The study demonstrates complex and distinctly species-specific effects of deuterium-reduced water (Larsen D100) on the physiological processes of seed germination and initial seedling growth. The data obtained do not support a universal stimulating effect, but rather indicate the activation of multidirectional metabolic pathways in different species, requiring in-depth interdisciplinary analysis. Statistical analysis of the data confirmed a significant interaction between the factors “crop type” and “treatment type” ($p < 0.001$ for seedling length and weight), highlighting the complexity and non-linearity of the observed effects.

The most significant positive dynamics were observed in *Hordeum vulgare L.* (Fig. 1), which affect both germination energy (germination) and initial growth vigor (seedling length and weight), suggests that deuterium-deficient water acts as a metabolic modulator. The primary hypothesis explaining this effect is the influence of the isotopic composition of water on the kinetics of biochemical reactions. Reducing the concentration of deuterium, which has twice the mass of protium, increases the rate and efficiency of enzymatic processes, particularly those associated with the hydrolysis of endosperm storage substances in cereals.

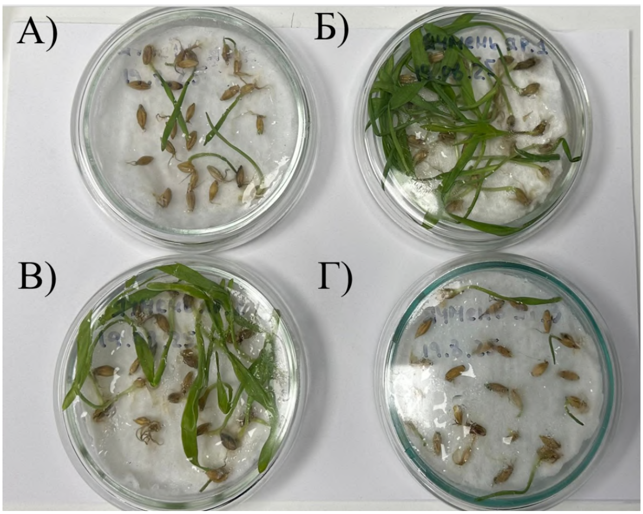

Fig. 1. Appearance of Hordeum vulgare L. seedlings 10 days after germination in distilled water (A) and in Larsen D100 water (B, C, D)

In *Lens culinaris Medik*, stimulation was observed exclusively in morphometric parameters, not in germination. This may indicate that the biochemical pathways responsible for overcoming seed dormancy and initiating cell division (which determine germination) are less sensitive to isotopic composition than the processes of subsequent cell elongation and differentiation (which determine growth). The effect is related to the influence on aquaporin function and the osmotic gradient, facilitating cell hydration and subsequent elongation.

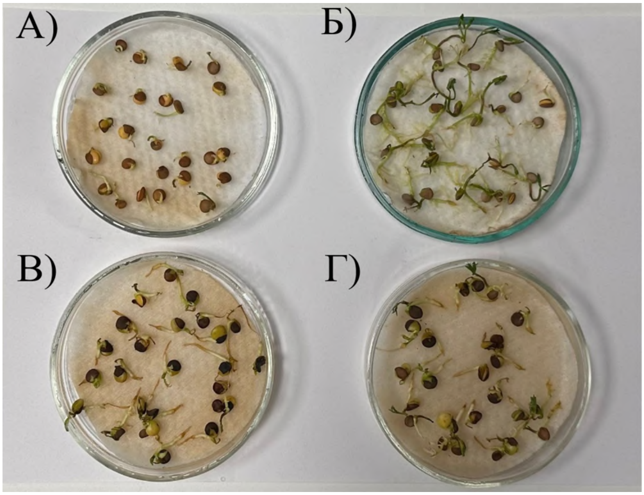

Fig. 2. Appearance of Lens culinaris Medik sprouts 10 days after germination in distilled water (A) and in Larsen D100 water (B, C, D)

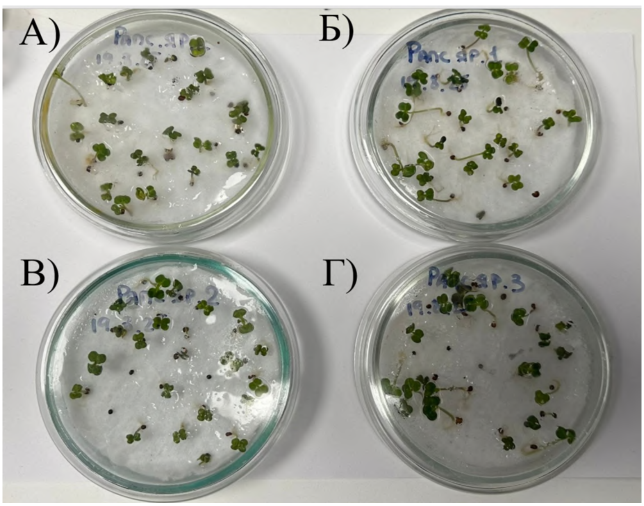

Fig. 3. Appearance of Brassica napus L. sprouts 10 days after germination in distilled water (A) and in Larsen D100 water (B, C, D)

The inhibitory effect on biomass accumulation in Brassica napus L. is of particular interest. For this crop, the reduction in deuterium levels disrupted the delicate balance of isotope effects in key metabolic cycles, such as lipid biosynthesis, which is crucial for oilseed crops. An alternative explanation is the induction of mild oxidative stress, forcing the plant to expend energy resources to compensate, ultimately reducing growth productivity in the early stages.

The neutral response of *Triticum aestivum L.* highlights the role of the genetic background and selection history of the species, which led to the fixation of alleles that ensure high metabolic stability regardless of slight variations in the isotopic composition of the water.

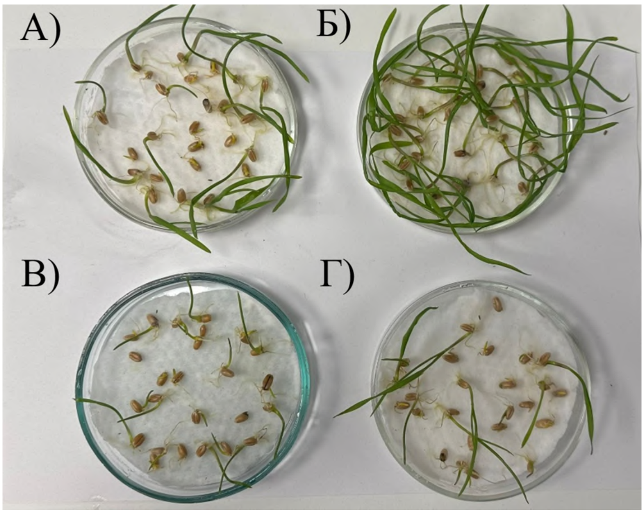

Fig. 4. Appearance of Triticum aestivum L. seedlings 10 days after germination in distilled water (A) and in Larsen D100 water (B, C, D)

Sensitivity to deuterium correlates with the species' initial metabolic activity, genome size, cell division rate, and seed biochemical composition (protein, carbohydrate, and lipid ratios). Cereals (*Hordeum vulgare L.*, *Triticum aestivum L.*) and legumes (*Lens culinaris Medik*) exhibit different responses, which may be due to differences in the mechanisms for mobilizing reserve nutrients. Evolutionary adaptation of species to specific ecological niches with different isotopic compositions of natural waters could also contribute to the observed specificity.

The results of the multivariate analysis confirmed that the effect of Larsen D100 water treatment significantly depends on the crop species ($p < 0.001$ for all main parameters). This underscores the need for a species-specific approach when assessing such effects. However, it should be noted that statistical analysis based on individual seeds (rather than average values across replicates) can lead to potentially false-positive results due to intra-group correlation. Future studies plan to increase the number of biological replicates (Petri dishes) for each condition and conduct analyses based on average values, which will enhance the reliability of the conclusions.

The obtained results open up prospects for developing new pre-sowing seed treatment techniques for crops such as *Hordeum vulgare L.* and *Lens culinaris Medik*, aimed at improving field germination and initial development. However, the pronounced negative effect on *Brassica napus L.* is a serious warning against the general use of this technology without preliminary species-specific and varietal testing.

The main limitation of this study is the lack of direct instrumental measurements of the final deuterium concentration in the working solutions, which prevents a definitive attribution of the observed effects to this factor. Furthermore, the experiment was conducted under controlled in vitro laboratory conditions, which can mitigate the complex soil-microbial interactions occurring in natural agrocenoses.

To gain a deeper understanding of the mechanisms underlying the observed effects, it is necessary to monitor deuterium content (using isotope mass spectrometry) not only in water but also in seedling biomass to assess its biochemical composition. Gene expression associated with the metabolism of reserve nutrients, stress response, and cell division must be assessed. Validation of the obtained results in the field will assess not only initial growth but also final plant productivity. Screening of different varieties within each species will be necessary to identify the most responsive genotypes.

Thus, deuterium-reduced water represents a powerful tool for controlling the germination process, but its use requires a highly differentiated approach and a deep understanding of the underlying physiological mechanisms.

Conflict of interest information. The authors declare that they have no conflict of interest.

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All authors made an equal contribution to the preparation of this article for publication.

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Scientific Reviews

INFLUENCE OF STRESS FACTORS ON CRUSTACEAN GENE EXPRESSION

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Abstract

Background. This review systematizes current scientific data on the influence of abiotic (pH, temperature, hypoxia, ammonia, nitrite) and biotic (viral and bacterial infections) stress factors on gene expression in crustaceans of the order *Decapoda*. Molecular responses affecting key functional groups of genes associated with immunity, osmoregulation, antioxidant defense, chitin metabolism, and cellular homeostasis are analyzed. Stress-induced changes in gene expression are complex, tissue-specific, and time-dependent, representing key adaptive mechanisms. The results of this analysis have important practical implications for aquaculture, opening up prospects for identifying molecular markers of stress resistance and developing strategies for optimizing the maintenance conditions of commercially important species.

Purpose. This review aims to systematize and analyze current scientific data on the influence of abiotic (such as pH, temperature, hypoxia, ammonia, nitrites) and biotic (viral and bacterial infections) stress factors on expression of genes associated with immunity, osmoregulation, antioxidant defense, chitin metabolism and cellular homeostasis in crustaceans of the order *Decapoda*.

Materials and methods. The research was conducted in the scientific research laboratory "Center of Agrobiotechnology" of the Don State Technical University in 2024-2025.

Results. Complex changes in the expression of key genes regulating immunity, osmoregulation, antioxidant protection, chitin metabolism, and cellular homeostasis have been identified. It has been shown that these tissue-specific and time-dependent changes in expression are the central mechanism of the adaptive response to stress.

Conclusion. An analysis of current scientific data has allowed us to systematize information on the influence of abiotic and biotic stress factors on gene expression in crustaceans, particularly in members of the order *Decapoda*. It has been established that changes in key environmental parameters (such as temperature, pH, ammonia and nitrite concentrations) and exposure to pathogens (viruses, bacteria) trigger complex molecular responses affecting genes associated with immunity, osmoregulation, antioxidant defense, chitin metabolism, and cellular homeostasis.

Keywords: crustaceans; stress factors; gene expression; immunity; aquaculture; transcriptome analysis; antioxidant system; chitin metabolism; osmoregulation; *Decapoda*

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Научные обзоры

ВЛИЯНИЕ СТРЕСС-ФАКТОРОВ НА ЭКСПРЕССИЮ ГЕНОВ РАКООБРАЗНЫХ

Д.Ю. Ковальчук, Д.С. Саркисян,
Э.Э. Чолутаева, В.Н. Шевченко

Аннотация

Обоснование. В данном обзоре систематизированы современные научные данные о влиянии абиотических (pH, температура, гипоксия, аммиак, нитриты) и биотических (вирусные и бактериальные инфекции) стресс-факторов на экспрессию генов у ракообразного отряда Decapoda. Проанализированы молекулярные ответы, затрагивающие ключевые функциональные группы генов, связанные с иммунитетом, осморегуляцией, антиоксидантной защитой, метаболизмом хитина и клеточным гомеостазом. Показано, что стресс-индуцированные изменения экспрессии носят комплексный, тканеспецифичный и времязависимый характер, выступая ключевым механизмом адаптации. Результаты анализа имеют важное прикладное значение для аквакультуры, открывая перспективы для идентификации молекулярных маркеров стрессоустойчивости и разработки стратегий оптимизации условий содержания коммерчески важных видов.

Цель. Целью обзора является систематизация и анализ современных научных данных о влиянии абиотических (таких как pH, температура, гипоксия, аммиак, нитриты) и биотических (вирусные и бактериальные инфекции) стресс-факторов на экспрессию генов, ассоциированных с иммунитетом, осморегуляцией, антиоксидантной защитой, метаболизмом хитина и клеточным гомеостазом, у ракообразного отряда *Decapoda*.

Материалы и методы. Исследования проводились в научно-исследовательской лаборатории «Центр агробиотехнологии» Донского государственного технического университета 2024-2025 гг.

Результаты. Выявлены комплексные изменения в экспрессии ключевых генов, регулирующих иммунитет, осморегуляцию, антиоксидантную защиту, метаболизм хитина и клеточный гомеостаз. Показано, что эти тканеспецифичные и времязависимые изменения экспрессии являются центральным механизмом адаптационного ответа на стресс.

Заключение. Проведенный анализ современных научных данных позволил систематизировать информацию о влиянии абиотических и биотических стресс-факторов на экспрессию генов у ракообразных, в частности у представителей отряда *Decapoda*. Установлено, что изменения ключевых параметров окружающей среды (таких как температура, pH, концентрация аммиака и нитритов) и воздействие патогенов (вирусов, бактерий) вызывают сложные молекулярные ответы, затрагивающие гены, связанные с иммунитетом, осморегуляцией, антиоксидантной защитой, метаболизмом хитина и клеточным гомеостазом.

Ключевые слова: ракообразные; стресс-факторы; экспрессия генов; иммунитет; аквакультура; транскриптомный анализ; антиоксидантная система; хитиновый метаболизм; осморегуляция; Decapoda

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Introduction

Aquatic crustaceans, particularly commercially and ecologically important species from the order *Decapoda* (shrimp, crayfish, crabs, lobsters, and spiny lobsters), represent valuable economic resources. Their global cultivation is continually challenged by disease outbreaks caused by pathogen infection and exposure to unfavorable environmental factors [5]. These problems lead to immune suppression, mass mortality, and, consequently, significant economic losses [5]. When grown in aquaculture, these organisms are exposed to the complex effects of a number of abiotic and biotic stress factors, the parameters of which (temperature, pH, salinity, dissolved oxygen concentration, ammonium, etc.) often fluctuate outside optimal ranges [13]. Such fluctuations negatively impact the physiological state, immune status, and overall health of the organism [5; 13]. Changes in key environmental parameters, as well as exposure to pathogens, trigger complex stress and immune responses at the molecular and cellular levels [5]. However, the underlying mechanisms by which these stressors mediate changes in immune parameters are not fully understood [13]. In recent years, advances in molecular biology techniques such as RNA sequencing (RNA-seq) and real-time PCR have made it possible to thoroughly investigate the transcriptomic responses of crustaceans to various stressors [5; 13].

Thus, the aim of this review is to systematize and analyze current scientific data on the influence of abiotic and biotic stress factors on the expression of immunity-associated genes in crustaceans of the order *Decapoda*.

Purpose. The aim of the review is to systematize and analyze current scientific data on the influence of abiotic (such as pH, temperature, hypoxia, ammonia, nitrites) and biotic (viral and bacterial infections) stress factors on expression of genes associated with immunity, osmoregulation, antioxidant defense, chitin metabolism and cellular homeostasis in crustaceans of the order *Decapoda*.

The influence of abiotic factors on gene expression

Abiotic factors are non-living environmental conditions that directly or indirectly affect living organisms. These factors are essential for the existence of agroecosystems, but at the same time, these conditions can become extreme (for example, changes in water temperature or pH from optimal to suboptimal). These changes can have a significant impact on the productivity of aquaculture species. Therefore, a better understanding of the genes that control responses to stress factors will allow us to optimize the production of commercially farmed crustaceans under varying water parameters [5; 17].

he hydrogen ion concentration (pH) characterizes the acid-base balance of water. For most crustacean species, the optimal range lies in the neutral or slightly alkaline zone, approximately 7.5 - 8.5. Deviations from this range trigger a cascade of stress reactions. Under low pH conditions, that is, in an acidic environment, the most dangerous thing for crustaceans occurs – demineralization of their exoskeleton. Calcium carbonate, the main structural component of the shell, begins to dissolve, weakening the existing shell, making the process of molting and forming a new one extremely difficult and often fatal. The new shell becomes soft, unable to protect the animal from mechanical damage, pathogens, and cannibalism. At the same time, the acidic environment damages the gill filaments, disrupting gas exchange and osmoregulation, and reduces the effectiveness of hemocyanin, the respiratory pigment that carries oxygen [5].

On the other hand, the high pH characteristic of an alkaline environment has a direct toxic effect on gill tissue and disrupts the excretion process. In crustaceans, ammonia is the end product of nitrogen metabolism, and it is normally excreted through the gills by diffusion. However, in alkaline water, the chemical equilibrium shifts toward the formation of highly toxic free ammonia (NH_3), which, instead of being excreted, begins to passively diffuse back into the body's tissues, causing severe internal poisoning [17].

Thus, at the School of Earth, Environmental and Biological Sciences (Queensland University of Technology, Brisbane, Queensland, Australia), expression of genes controlling osmoregulation in the Australian red-claw crayfish *Cherax quadricarinatus* (von Martens, 1868) was studied [2]. The animals were distributed into three separate glass containers with water temperature of 25.5 °C and conductivity of 521 μS/cm [2]. A total of nine crayfish (average length 131.9 mm and body weight 56.3 g) were used in the experiment. The crayfish were placed in three different pH levels: 6, 7 and 8 conventional units [2]. RNA was isolated from gill tissues. Isolation was performed using the guanidine thiocyanate-phenol-chloroform extraction method (TRIZOL/Chloroform method) [2]. The yield and quality of RNA were checked using agarose gel electrophoresis, spectrophotometry and a bioanalyzer using the RNA 2100 nanochip chip [2]. The obtained RNA was then used to construct a cDNA library and subsequent sequencing on the Illumina platform. The obtained sequences were assembled into longer chains using bioinformatics tools [2].

Real-time PCR (qPCR) analysis was performed to test the expression of the identified genes [2]. Specific primers developed based on sequencing data were used, with 18S rRNA serving as the reference gene for normalization. The statistical significance of differences in gene expression between the three pH groups was determined using one-way analysis of variance [2].

As a result, five transcripts belonging to the carbonic anhydrase (CA) gene family were identified [2]. Among them, three full-length isoforms were described: cytoplasmic CA (ChqCAc), membrane-bound (GPI-anchored) CA (ChqCAg), and beta-class CA (ChqCA-beta), which represents the first complete sequence of the β-CA gene in cancer [2]. Two partial sequences (ChqCA-p1 and ChqCA-p2) were also found that showed high similarity to the GPI-linked isoform, suggesting a duplication of this gene. In addition to the CA genes, numerous other key osmoregulatory genes were found in the transcriptome, such as various subunits of Na+/K+-ATPase and V-type H+-ATPase [2].

A key finding was that when gene expression was examined in response to changes in the pH of the surrounding water, significant differences were found only for cytoplasmic carbonic anhydrase (ChqCAc) [2]. Its expression was highest at pH 6, where the mRNA level was approximately 2-fold higher than at pH 7, and 6-fold higher than at pH 8 [2]. Expression of the GPI-linked and beta isoforms of CA, as well as other tested osmoregulatory genes (with the exception of an increase in V-type H+-ATPase), did not show statistically significant changes depending on the pH level. These results suggest that cytoplasmic carbonic anhydrase (ChqCAc) plays an important role in the systemic acid-base balance in crayfish [2].

The influence of pH on gene expression was also studied at the Key Laboratory of Experimental Marine Biology of the Chinese Academy of Sciences, where a bioinformatics analysis of chitin metabolism gene expression was conducted. Specifically, the glutamine and fructose-6-phosphate aminotransferase (GFAT) gene was analyzed in *Litopenaeus vannamei*. GFAT is the first and key rate-limiting enzyme of the hexosamine biosynthetic pathway, which directs metabolic flux toward the synthesis of chitin precursors [18]. The study indicated that LvGFAT gene expression was significantly upregulated in shrimp hepatopancreas when exposed to two abiotic stress factors: alkaline pH and the toxic heavy metal cadmium [18]. The hepatopancreas, as a central organ of digestion, metabolism, and detoxification, plays a key role in stress response [18]. The increased LvGFAT expression under these conditions suggests that this gene and the entire hexosamine pathway may be involved in cellular defense mechanisms. One possible molecular mechanism is that activation of this pathway provides a substrate for O-GlcNAcylation, an important post-translational modification of proteins that regulates the cellular response to various stressors, including toxins and changes in redox status [18]. Thus, chitin metabolism appears to be not limited to the construction of structural components but can also be integrated into complex biochemical networks that respond to adverse environmental conditions. The work was based on a comprehensive analysis of genomic and transcriptomic data [18]. Published genomic sequences of more than twenty crustacean species were used as materials, including economically important species such as *Litopenaeus vannamei*, *Penaeus monodon* and *Portunus trituberculatus*, as well as model and ecologically significant species such as *Daphnia magna* and copepods. In addition, multiple transcriptome (RNA-Seq) datasets obtained from publicly available databases such as NCBI were analyzed, covering various tissues, developmental stages, physiological states (e.g., molting cycle), and exposure conditions [18].

The study methodology relied on bioinformatics tools. Homology searches against known sequences using protein alignment and domain architecture analysis tools were used to identify genes associated with chitin metabolism [18]. Protein structural characteristics such as molecular weight and isoelectric point were predicted using computational tools such as ExPASy Compute pI/Mw [18]. Phylogenetic analysis was performed to classify genes and establish evolutionary relationships between them [18]. Gene expression pattern analysis was performed using RNA-Seq data to determine tissues and molt stages where genes are active [18]. Regarding stress data, the results were apparently taken from cited experimental studies that likely used quantitative PCR (qPCR) methods to accurately measure gene expression levels in shrimp subjected to controlled stress conditions [18].

A genomic analysis revealed systemic features of chitin metabolism in crustaceans. A key discovery was the fundamental difference between synthesis and degradation genes: biosynthesis genes, such as chitin synthase (CHS), are highly conserved and typically present in one or two copies, while degradation genes, particularly the chitinase family (CHT), are significantly expanded and form multi-copy families, highlighting their functional diversity [18]. The general pathways of chitin metabolism were found to be similar to those in insects, but possess specific features, including groups of chitinases unique to crustaceans [18]. Expression analysis revealed that these genes have distinct tissue-specific and temporal regulation, closely linked to the molting cycle [18]. In addition, their role in the response to stress, both abiotic (increased GFAT gene expression under the influence of alkaline pH and cadmium) and biotic (changes in chitinase expression during immune response to pathogens) was confirmed [18]. Thus, chitin metabolism is not only a growth mechanism, but also a multifunctional system integrated into the processes of adaptation and defense of the organism [18].

Environmental temperature is the dominant factor determining the rate of metabolic processes in poikilothermic animals, which include crustaceans. Each species has a specific temperature optimum. Temperatures exceeding the species optimum induce the development of a stress response [5,6].

When temperatures reach critical values, an exponential acceleration of metabolic activity is observed. Despite the potential increase in growth rate, this process leads to a number of physiological dysfunctions. The increasing metabolic demand for oxygen conflicts with the decreasing solubility of gases in water. An imbalance arises between the body’s energy expenditure and the availability of resources (oxygen and nutrients), which can lead to heat shock. At the cellular level, heat shock is characterized by disruption of the catalytic function of key enzymes, denaturation of protein structures, and subsequent systemic homeostasis failure, which is a common cause of mortality [5; 6].

Suboptimal temperatures, in turn, act as a limiting factor, inhibiting physiological functions. A decrease in environmental temperature causes a slowdown in metabolism, which is manifested by a significant reduction in feeding activity and motility. This leads to the cessation of feeding and, consequently, to growth arrest. Digestive processes are disrupted due to a decrease in the catalytic efficiency of enzymes at low temperatures [5; 6].

The Center for the Study of Food and Development (CIAD) conducted a study on the effects of high temperatures and hypoxia on the expression of selenium-dependent CqGPx3 isoforms. The study was also conducted on C. quadricarinatus. Two isoforms of glutathione peroxidase 3 (CqGPx3a and CqGPx3b) were examined. This enzyme protects against oxidative damage by catalyzing the reduction of hydrogen peroxide to water, thereby neutralizing this potentially dangerous oxidant [12].

Methods included exposure to stress factors, RNA isolation from various tissues, gene cloning, quantitative PCR, and bioinformatics analysis [12].

Two distinct isoforms were discovered: CqGPx3a was expressed predominantly in the nervous system, while CqGPx3b was expressed in pereiopods (walking legs). Under stress, CqGPx3a expression was significantly increased by hypoxia and high temperature, while CqGPx3b expression remained unchanged. Bioinformatics analysis revealed that CqGPx3b contains a proline-rich C-terminal domain with potential antimicrobial activity [12].

Thus, the isoforms exhibit tissue-specific expression and distinct responses to stress: CqGPx3a plays a role in antioxidant defense in the nervous system, while CqGPx3b likely performs dual functions in peripheral tissues [12].

Research on the effects of low temperatures was conducted at the Jiangsu Provincial Institute of Freshwater Fisheries. This study examined the effects of long-term (8 weeks) acclimation to low temperatures (10, 15, 20, 25, and 30 °C) on *C. quadricarinatus*. A number of physiological, biochemical, and molecular methods were used to comprehensively assess the organism's response. Growth parameters (weight and length gain, molting frequency) were measured, and the activity of key antioxidant enzymes (glutathione-S-transferase, GST; glutathione reductase, GR) and antioxidant content (total, reduced, and oxidized glutathione) were determined in the hepatopancreas. Gene expression of heat shock proteins (HSP20, HSP21, HSP60, HSP70, HSP90) and cold shock protein (CSP) was analyzed using quantitative PCR. To identify global molecular changes, transcriptome analysis (RNA-Seq) of the hepatopancreas of crayfish from the 10°C and 25°C groups was performed, followed by bioinformatics analysis to identify expressed genes and affected biological pathways [20].

Results showed that low temperatures (15 and 10°C) inhibited crayfish growth, reducing the rate of weight and length gain, and disrupted normal molting dynamics. Biochemically, the activity of the antioxidant enzyme GST decreased, but the content of reduced glutathione (GSH) and the GSH/GSSG ratio increased, indicating activation of non-enzymatic antioxidant defenses. Gene expression analysis revealed a specific response of different HSPs: the expression of *HSP60* and *HSP70* was significantly increased at low temperatures, while HSP20 was suppressed. Expression of the cold shock protein (*CSP*) gene was also significantly increased. Transcriptome analysis identified 589 differentially expressed genes. Long-term cold exposure was shown to disrupt the endocrine system (steroid and thyroid hormone biosynthesis), glucose metabolism, and suppress immune function (reduced expression of genes associated with the antibacterial response and inflammation). At the same time, defense mechanisms were activated, including glutathione metabolism and expression of genes associated with longevity. Thus, adaptation of *C. quadricarinatus* to cold is achieved by slowing growth and basal metabolism while simultaneously activating specific molecular defense mechanisms, which ensures survival [20].

Ammonia nitrogen and nitrite, which are formed through bacterial nitrification of ammonia or denitrification of nitrate, are common toxicants in aquaculture. These elements are a serious problem in aquatic ecosystems, as they accumulate from a number of anthropogenic sources, such as wastewater from metal, dye, and celluloid industries, municipal wastewater, and aquaculture. Being a stress factor similar to temperature and pH fluctuations, they can affect gene expression [3, 9].

The Key Laboratory of Mariculture at Ocean University in China conducted a study to investigate the effects of ammonia nitrogen (ammonia-N) on the molecular immune mechanisms of *Litopenaeus vannamei* [3].

Healthy shrimp were acclimatized for two weeks and then divided into four groups: control (0 mg/L) and three experimental groups (2, 10 and 20 mg/L ammonia-N) for 48 hours [3].

Hemolymph was collected at different time points (0, 3, 6, 12, 24 and 48 h). Quantitative real-time PCR (qRT-PCR) was used to determine the expression level of a wide range of genes in hemocytes, including genes encoding complement components, a cascade system of proteolytic enzymes designed to protect the body from foreign agents (*C1q, MBL, Ficolin, A2M, Integrin*), C-type lectins, which are involved in intercellular interactions, immune response and apoptosis (*C-lectin 1, 2*), intracellular signaling factors (*PLC, NF-κB, PKA, CREB*), phagocytosis (*ROCK, Myosin, Cubilin, Peroxinectin, Dynamin*) and exocytosis (*SNAP, Syntaxin, VAMP*) [15, 16]. Expression of genes of the propenol oxidase system (*PPAE, PPO3*), immune factors (*Pen3, Crustin, Stylicins, ALFs, LYC*) and inflammatory factors *(*HSP90, TNFa, IL-16**) was also analyzed. Functional immune parameters were also assessed in parallel: phagocytic activity of hemocytes, total hemocyte count (*THC*), and in plasma – serine proteinase activity, phenol oxidase (*PO*), antibacterial and bacteriolytic activity. Statistical analysis of the data was performed using one-way analysis of variance (*ANOVA*) followed by Duncan's test [3].

The results demonstrated a marked suppression of immune function under the influence of ammonia-N [3]. The expression of key complement components (*C1q, MBL, Ficolin, A2M*) and their receptor Integrin was significantly reduced, especially at 6-24 hours of exposure [3]. The C-type lectin genes demonstrated opposite dynamics: C-lectin 1 was suppressed, while C-lectin 2 was transiently activated at 3 and 6 hours with a subsequent decrease. In signaling pathways, a decrease in NF-κB and transient activation of *PLC*, *PKA* and *CREB* were observed. This correlated with a significant decrease in expression of genes associated with phagocytosis (*ROCK, Myosin, Cubilin, Dynamin*), and a drop in phagocytic activity itself and the total number of hemocytes. Humoral immunity was also impaired: the expression of exocytosis genes (*SNAP, Syntaxin, VAMP*) and the proPO system (*PPAE, PPO3*) was suppressed, which was accompanied by a decrease in PO and serine proteinase activity in plasma. Plasma antibacterial and bacteriolytic activities also significantly decreased. The expression of many antimicrobial peptides (*Pen3, Crustin, Stylicins*) was suppressed, while ALFs and LYC showed a transient increase. Inflammatory factors (*HSP90, TNFa, IL-16*) demonstrated complex changes, indicating the development of an immune imbalance [3].

This study demonstrates that nitrogen stress leads to profound suppression of both cellular (phagocytosis) and humoral (exocytosis, proPO system, antimicrobial peptides) immunity in shrimp. The authors suggest that this suppression is mediated by coordinated changes in the expression of complement components and C-type lectins, which, in turn, affect intracellular signaling pathways (NF-κB, PKA/CREB) regulating key immune behaviors of hemocytes [3].

The study on the effects of nitrite was conducted at the Key Laboratory of Aquatic Live Feed Production and the Key Laboratory of Biodiversity and Biotechnology, Jiangsu Provincial College of Life Sciences. The effect of acute nitrite exposure on gene expression was studied using Australian red-claw crayfish [9]. Juveniles with an average weight of 20 ± 2 g were used in the study [9]. After acclimation for four weeks, the crayfish were exposed to four nitrite concentrations (NO_2-N: 0.5, 1, 1.5, and 2 mg/L) and a control for 48 h, while maintaining a constant chloride level (10 mg/L) [9]. The temperature was 26 ± 1 °C, pH 7.1 ± 0.5, and dissolved oxygen concentration was approximately 5.0 mg/L. Gill tissue samples were collected after 12, 24, and 48 h. Relative mRNA expression of ten genes was measured using real-time reverse transcription-PCR (RT-PCR): antioxidant enzymes (mitochondrial and cytosolic Mn-SOD, extracellular Cu/ZnSOD, catalase CAT, glutathione-S-transferase GST) and metabolic enzymes (arginine kinase AK, glutamate dehydrogenase GDH, mitochondrial malate dehydrogenase mMDH, α-subunit of Na^+/K^+-ATPase and phosphoenolpyruvate carboxykinase PEPCK) [9]. Statistical significance was determined using two-way analysis of variance and Post Hoc tests [9].

As a result, it was found that the expression of antioxidant enzyme genes increased significantly after 12 and 24 hours of exposure in all experimental groups, indicating the activation of oxidative stress defense system [9]. However, after 48 hours at high nitrite concentrations (1.5 and 2 mg/L), their expression was suppressed, indicating a breakdown of compensatory mechanisms [9]. The genes of metabolic enzymes (AK, GDH, mMDH, Na^+/K^+-ATPase) demonstrated similar dynamics: an increase in expression at early stages, probably to meet increased energy needs, and a subsequent decrease after 48 hours [9]. In contrast, the expression of the PEPCK gene was significantly suppressed throughout the experiment at high nitrite concentrations. The obtained data indicate that acute exposure to nitrite causes dose- and time-dependent oxidative and metabolic stress in crayfish [9].

The effect of nitrite on gene expression in *Litopenaeus vannamei* (Boone, 1931) was also studied at the Key Laboratory of Ecology and Environmental Science of Guangdong Province Higher Education Institutions. Shrimp with an average weight of 4.41 ± 1.80 g, which were acclimated for two weeks under laboratory conditions, were used as experimental animals [19]. Exposure to nitrite nitrogen at a concentration of 20 mg/L, which is considered suitable for aquaculture conditions, was carried out for different periods of time: 0, 4, 8, 12, 24, 48, and 72 hours [19]. The control group was kept in water without the addition of nitrite. Hemolymph was collected from the shrimp at specified time points for analysis [19]. Flow cytometry with Annexin V-FITC and propidium iodide (PI) staining was used to assess hemocyte apoptosis, allowing the use of viable, early and late apoptotic, and necrotic cells [19]. Concurrently, total RNA was isolated from the hemolymph cell pellet for gene expression analysis [19]. mRNA levels for seven key genes were determined using quantitative real-time PCR: two apoptosis-related genes (caspase-3 and cathepsin B (CTSB)), one stress protein (HSP70), and four antioxidant enzymes (manganese superoxide dismutase (MnSOD), catalase (CAT), glutathione peroxidase (GPx), and thioredoxin (TRx)) [19]. Statistical significance of differences between the control and experimental groups was determined using one-way analysis of variance (ANOVA) [19].

The study found that nitrite exposure caused a significant increase in the proportion of apoptotic hemocytes, but this effect was only evident at late stages of exposure – 48 and 72 hours. Gene expression analysis revealed complex, temporal dynamics of the molecular response. Genes responsible for antioxidant defense and the immediate stress response were activated first. Thus, the expression of MnSOD, GPx, and the heat shock protein HSP70 was significantly increased as early as 8 hours after exposure. GPx expression then decreased, while MnSOD demonstrated a second peak of activation at 48 hours. A later response was demonstrated by catalase (CAT), whose mRNA level increased at 24 and 48 hours, and thioredoxin (TRx), whose expression increased sharply at 48 hours. Regarding apoptotic genes, caspase-3 expression increased significantly at 24 and 48 hours, preceding the visible increase in the number of apoptotic cells. Cathepsin B (CTSB) expression was also significantly increased at later stages – 48 and 72 hours – correlating with the peak of apoptosis [19].

Thus, the obtained results indicate that the toxic effect of nitrite on shrimp hemocytes is mediated by oxidative stress. The cells trigger a cascade of protective molecular reactions: first, fast-acting antioxidant enzymes (GPx) and the chaperone HSP70 are activated, followed by the involvement of other components of the antioxidant system (MnSOD, CAT, TRx). Long-term exposure to stress leads to the activation of apoptotic pathways, in which caspase-3 and, possibly, cathepsin B play a key role, which ultimately leads to cell death and can weaken the shrimp immune system [19].

The influence of biotic factors on gene expression

Innate immunity is characteristic of both invertebrates and mammals. In crustaceans, innate immunity is considered the primary defense factor, playing a critical role in identifying viral infections and initiating antiviral responses [5; 8]. Defense mechanisms against pathogens are directly mediated through changes in gene expression. Diseases, such as viral infections, have a direct and powerful effect on the transcriptome, inducing increased expression of genes encoding antimicrobial peptides and immune system components. Thus, studying which genes are turned on or off during disease allows us to uncover molecular mechanisms of immune response and pathogenesis, providing key insights into crustacean resistance to infections [7; 10].

A study on the molecular response to white spot syndrome virus (WSSV) infection was conducted at the State Key Laboratory of Marine Ecology, College of Oceanography and Environmental Sciences, Xiamen University [10]. Hematopoietic tissue (Hpt) cell culture isolated from *C. quadricarinatus* was used in the experiment [10]. The cells were infected with WSSV, and suppressive subtractive hybridization (SSH) was used to identify genes with altered expression, creating two libraries: L1 (1 hour after infection) and L12 (12 hours after infection) [10]. Differential expression was further confirmed using semi-quantitative real-time PCR (RT-PCR) [10].

As a result, 366 genes were identified whose expression levels were statistically significantly increased in response to infection [10]. Among them, the genes were divided into functional groups: immune response (e.g., anti-lipopolysaccharide factor ALF, apoptosis gene ALG-2), cytoskeletal system (actin, tubulin), signal transduction (various kinases, transcription factors), stress (heat shock proteins), metabolism and homeostasis, and protein synthesis and processing. An important result was that 176 of these genes were described in the context of WSSV infection for the first time [10]. Confirmed overexpression of eight randomly selected genes (such as DNA helicase, coatomer, and TRIM32) by RT-PCR revealed that WSSV infection activates a complex cellular response involving not only classical immune pathways but also cytoskeletal remodeling, the ubiquitination system, and intracellular transport [10].

Another study on the impact of diseases was conducted at the Key Laboratory of Freshwater Aquaculture Genetics and Breeding of Zhejiang Province, Zhejiang Institute of Fisheries [7]. The study examined changes in gene expression in Australian red-claw crayfish infected with the iridescent virus (Decapod iridescent virus 1, DIV1).

In this study, clinically healthy crayfish were artificially infected with DIV1 by intramuscular injection, and naturally infected individuals were also collected from farms to investigate the response of *C. quadricarinatus* to virus infection [7]. Nested PCR and histopathological examination of tissues (gills and hepatopancreas) with hematoxylin and eosin staining were used to confirm infection [7]. The expression profile of 90 immune genes in hemocytes was analyzed using a qRT-PCR array [7]. The composition of the intestinal microbiota was studied by high-throughput sequencing of the 16S rRNA gene (V3–V4 regions) followed by bioinformatics processing in QIIME2 [7]. Statistical analysis included alpha diversity assessment, Student/Welch tests, and Spearman correlation analysis to identify relationships between gene expression and microbiota composition [7].

As a result, it was found that DIV1 infection causes characteristic histopathological changes in tissues (eosinophilic inclusions and karyopyknosis) [7]. Gene expression analysis revealed significant activation of 27 immune genes associated with antimicrobial peptides (e.g., *Crustin2, lyz*), Toll-like and JAK-STAT signaling pathways, as well as with stress response (*Hsp70*) [7]. Analysis of the microbiome revealed a decrease in alpha diversity (Chao1 and Faith's PD indices) and significant changes in its composition: an increase in the proportion of Enterobacter and Acinetobacter bacteria and a decrease in the proportion of Fusobacterium and Bosea at the genus level [7]. Correlation analysis revealed a close relationship between changes in the abundance of certain bacterial genera (e.g., *Enterobacter, Hyphomicrobium*) and the expression level of immune genes (such as *Toll and Foxn*), indicating a complex impact of infection on immune system and the host's symbiotic microbiota [7].

The influence of abiotic factors on chitin metabolism gene expression has been described previously; however, these are not the only factors affecting its regulation.

In addition to their central role in molting and growth, chitin metabolism genes exhibit a pronounced response to biotic stress factors, serving as an important component of the crustacean immune system. Numerous studies confirm the activation of these genes in response to pathogens. In particular, upregulation of shrimp chitinase genes is observed during viral infection with white spot syndrome virus (WSSV) [18]. It has been shown that individual enzymes, such as endo-beta-N-acetylglucosaminidase (NAG) in *Penaeus monodon*, can directly interact with viral proteins (e.g., VP41B of WSSV), which in some cases may facilitate infection, while in others, it may be part of a defense response [18].

Similarly, bacterial infections with pathogens such as *Vibrio parahaemolyticus* and *Aeromonas hydrophila* induce expression of genes encoding chitin-degrading enzymes, as demonstrated for the NAG gene in *Exopalaemon carinicauda*. Key immune tissues such as hemocytes and hepatopancreas are the main sites of expression of these immune-associated genes [18]. Knockdown experiments with chitinases (e.g., LvCHT5 in *Litopenaeus vannamei*) result in significant changes in the expression profile of a wide range of immune genes, including antimicrobial peptide genes, suggesting a regulatory role for chitin metabolism in immune networks [18]. Thus, chitin metabolism system is integrated into overall defense mechanisms of crustaceans, maintaining cuticle integrity as a physical barrier and participating in both direct and indirect responses to viral, bacterial, and potentially fungal pathogens [18].

Conclusion

An analysis of current scientific data has allowed us to systematize information on the influence of abiotic and biotic stress factors on gene expression in crustaceans, particularly in members of the order *Decapoda*. It has been established that changes in key environmental parameters (such as temperature, pH, ammonia and nitrite concentrations) and exposure to pathogens (viruses, bacteria) trigger complex molecular responses affecting genes associated with immunity, osmoregulation, antioxidant defense, chitin metabolism, and cellular homeostasis [2; 3; 7; 9; 10; 12; 18].

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Original article

INCREASE THE YIELD OF INDUSTRIAL CROPS DUE TO BIONUTRIENTS

Yu.A. Shirokov, M.V. Abramov, D.N. Denisov

Abstract

Background. The article is devoted to the search for effective ways of a reasonable approach to the chemicalization of agriculture, which will increase crop yields without increasing the doses of applied mineral fertilizers and pesticides. The materials of the analysis and generalization of the results of long-term studies of bionutrients safe for humans and animals synthesized using the triethanolammonium salt of orthocresoxyacetic acid and 1-chloromethylsilatran are presented. The conducted studies have shown that it is possible to achieve high yields of industrial crops that do not depend on the constantly increasing values of mineral fertilizers and pesticides introduced into the soil. An increase in sugar beet yield of up to 20% is recorded when processing seeds and fruiting plants with bionutrients. This is due to an increase in germination energy, and, as a result, seed germination improves. At the same time, the sugar content in plants increases by 0.7 ...1% without the use of additional doses of mineral fertilizers. A similar effect was obtained on sunflower: the yield increase was 18...20%. the weight of seeds from one basket and the weight of 1000 seeds and their oil content increased. Bionutrients restrained the spread of fungal diseases, which makes it possible to reduce or eliminate the use of pesticides. Thus, silatrans and other organosilicon compounds can become important components of agricultural technologies that do not harm the ecosystem, but can improve metabolic processes in plant organisms, increase the efficiency of using nutrients from mineral fertilizers and reducedependence on pesticides used in agriculture.

Purpose. Purpose of the present study is to increase the yield of industrial crops using bionutrients.

Materials and methods. Let's consider the effectiveness of the use of 1-chloromethylsilatran and triethanolammonium salt of orthocresoxyacetic acid with auxin activity as independent bionutrients and in combination with each other. The research methodology is based on the analysis and generalization of materials from field experiments conducted in different regions of the Russian Federation on industrial crops (sugar beet and sunflower). Bionutrients were used in the form of solutions for the treatment of seeds and vegetative plants, both individually and in combination.

Further, to simplify, we denote the bionutrient 1-chloromethylsilatran with the letter C, the triethanolammonium salt of orthocresoxyacetic acid with the letter T, and their combinations.

Results. An economic assessment using the example of wheat has shown that the use of bionutrients to increase yields instead of increasing the applied doses of mineral fertilizers can reduce the cost of production and increase business profitability. And this is already an effective incentive for the revision of traditional crop production technologies and the transition to the reasonable use of agrochemistry, reducing the cost of fertilizers that are not involved in the formation of an economically useful part of the crop.

Conclusion. The results of the assessment of the possibility of a reasonable approach to the chemicalization of agriculture while increasing crop yields due to bionutrients safe for humans and animals based on organosilicon compounds 1-chloromethylsilatran and a substance with auxin activity – triethanolammonium salt of orthocresoxyacetic acid, showed a real prospect of minimizing doses of mineral fertilizers and pesticides. In particular, it was found that beet yields increased by 14...18%, and sugar content – by 0.7... 1% without the use of additional doses of mineral fertilizers.

A similar effect was obtained on sunflower: the yield increase was 18...20%. the weight of seeds from one basket and the weight of 1000 seeds and their oil content increased. Bionutrients restrained the spread of fungal diseases.

Thus, silatrans and other organosilicon compounds can become important components of agricultural technologies that do not harm the ecosystem, but can improve metabolic processes in plant organisms, increase the efficiency of using nutrients from mineral fertilizers and reduce dependence on pesticides used in agriculture.

Keywords: bionutrients; chloromethylsilatran; mineral fertilizers; minimization; sugar beet; sunflower

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Научная статья

ПОВЫШЕНИЕ УРОЖАЙНОСТИ ТЕХНИЧЕСКИХ КУЛЬТУР ЗА СЧЕТ БИОНУТРИЕНТОВ

Ю.А. Широков, М.В. Абрамов, Д.Н. Денисов

Аннотация

Обоснование. Статья посвящена поиску эффективных путей разумного подхода к химизации сельского хозяйства, позволяющих повысить урожайность сельскохозяйственных культур без увеличения доз вносимых минеральных удобрений и пестицидов. Представлены материалы анализа и обобщения результатов многолетних исследований безопасных для человека и животных бионутриентов, синтезированных с использованием триэтаноламмониевой соли ортокрезоксиуксусной кислоты и 1-хлорметилсилатрана. Проведенные исследования показали возможность получения высоких урожаев технических культур, не зависящих от постоянно возрастающих значений вносимых в почву минеральных удобрений и пестицидов. При обработке семян и плодовых растений бионутриентами отмечается увеличение урожайности сахарной свеклы до 20 %. Это связано с увеличением энергии прорастания и, как следствие, улучшением всхожести семян. При этом содержание сахара в растениях увеличивается на 0,7...1 % без применения дополнительных доз минеральных удобрений. Аналогичный эффект получен на подсолнечнике: прибавка урожая составила 18...20 %, увеличились масса семян из одной корзинки и масса 1000 семян, содержание масла в них. Бионутриенты сдерживают распространение грибковых заболеваний, что дает возможность сократить или вовсе отказаться от применения пестицидов. Таким образом, силатраны и другие кремнийорганические соединения могут стать важными компонентами сельскохозяйственных технологий, которые не наносят вреда экосистеме, но способны улучшить обменные процессы в растительных организмах, повысить эффективность использования питательных веществ из минеральных удобрений и снизить зависимость от пестицидов, применяемых в сельском хозяйстве.

Цель. Цель исследования – повысить урожайность технических культур с помощью бионутриентов.

Материалы и методы. Рассмотрим эффективность применения 1-хлорметилсилатрана и триэтаноламмониевой соли ортокрезоксиуксусной кислоты с ауксиновой активностью в качестве самостоятельных биоудобрений и в сочетании друг с другом. Методология исследований основана на анализе и обобщении материалов полевых опытов, проведенных в различных регионах Российской Федерации на технических культурах (сахарной свекле и подсолнечнике). Биоудобрения применялись в виде растворов для обработки семян и вегетирующих растений, как по отдельности, так и в сочетании друг с другом.

Далее для упрощения обозначим биоэлемент 1-хлорметилсилатран буквой С, триэтаноламмониевую соль ортокрезоксиуксусной кислоты – буквой Т, а их сочетания – буквами.

Результаты. Экономическая оценка на примере пшеницы показала, что использование бионутриентов для повышения урожайности вместо увеличения вносимых доз минеральных удобрений позволяет снизить себестоимость продукции и повысить рентабельность бизнеса. А это уже эффективный стимул для пересмотра традиционных технологий растениеводства и перехода к разумному использованию агрохимии, снижению затрат на удобрения, которые не участвуют в формировании экономически полезной части урожая.

Заключение. Результаты оценки возможности разумного подхода к химизации сельского хозяйства при повышении урожайности за счет безопасных для человека и животных бионутриентов на основе кремнийорганических соединений 1-хлорметилсилатрана и вещества с ауксиновой активностью – триэтаноламмониевой соли ортокрезоксиуксусной кислоты, показали реальную перспективу минимизации доз минеральных удобрений и пестицидов. В частности, было установлено, что урожайность свеклы увеличилась на 14...18 %, а сахаристость – на 0,7... 1% без применения дополнительных доз минеральных удобрений.

Аналогичный эффект получен на подсолнечнике: прибавка урожая составила 18...20 %, увеличились масса семян с одной корзинки и масса 1000 семян, содержание масла в них. Бионаполнители сдерживали распространение грибковых заболеваний.

Таким образом, силатраны и другие кремнийорганические соединения могут стать важными компонентами агротехнологий, которые не наносят вреда экосистеме, но способны улучшить обменные процессы в растительных организмах, повысить эффективность использования питательных веществ из минеральных удобрений и снизить зависимость от пестицидов, применяемых в сельском хозяйстве.

Ключевые слова: биоудобрения; хлорметилсилатран; минеральные удобрения; минимизация; сахарная свекла; подсолнечник

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Introduction

In recent years, we have seen significant progress in the development of agriculture, which not only successfully solves the problem of food security in our country, but also makes a significant contribution to providing food to many countries around the world. At the same time, the potential of Russian agriculture is far from being exhausted [1].

The genetic potential of the varieties, photosynthetically active radiation and soil moisture supply are mainly used by 30-60%. For example, grain yields in the last record year amounted to just over 3.0 t/ha, and the genetic potential of varieties significantly exceeds 12.0 t/ha. The same applies to other cultures. However, it is known that with the traditional approach to increasing yields, an increasing dose of mineral fertilizers and pesticides is required for each subsequent hundredweight achieved [2-5].

Using well-known yield forecasting formulas, it is not difficult to calculate how much NPK needs to be applied to increase wheat yields from 10 to 60 c/ha. For example, to increase wheat yield from 30 to 10 c/ha, you need: 25...35 kg of nitrogen, 11... 13 kg of phosphorus, 20... 27 kg of potassium. And this can produce a total of more than 45 million tons of grain, increasing the export potential by more than 100%. A similar situation is observed with other cultures (Fig.1).

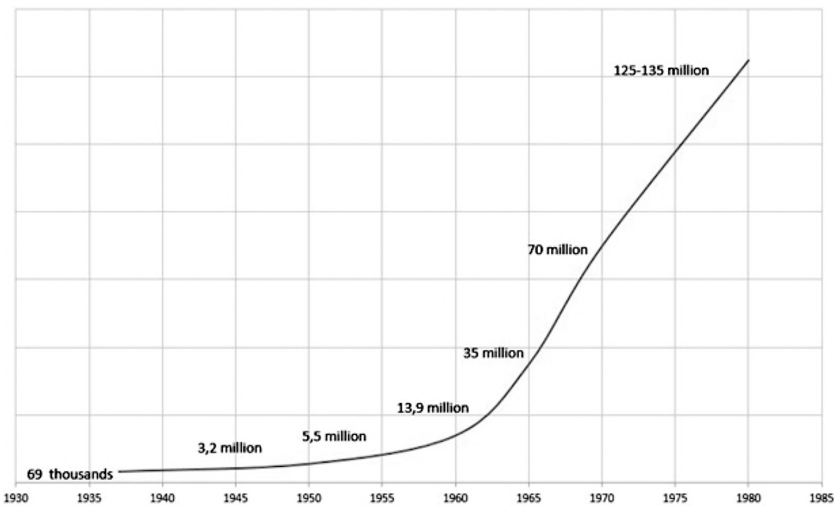

Fig. 1. The growth of the use of mineral fertilizers
(formulated by the authors on the basis of statistical data)

The increase in the use of mineral fertilizers (formulated by the authors on the basis of statistical data) As a result, Russia can become the absolute breadwinner of the world (if we also take care of logistics and storage of such an increase in grain reserves in advance). However, traditional chemicalization of crop production leads to chemicalization of food products, disruption of the ecological balance and, as a result, to a serious deterioration in public health, which will not contribute to the preservation of national nature or the solution of demographic problems [6-11].

At the same time, intensive chemicalization of agriculture does not have the expected effect. With an increase in the volume of fertilizers applied in the USSR from 1960 to 1980 by almost 10 times (from 13.9 million tons to 135 million tons) (Fig. 1), grain yields increased by no more than 2 times (from 1.3 t/ha to 1.8 t/ha). The increase in the use of mineral fertilizers (formulated by the authors on the basis of statistical data) is no secret that the chemicalization of crop production leads to the chemicalization of food products, disruption of the ecological balance and, as a result, to a serious deterioration in public health, destruction of ecological imbalance, decreased reproductive functions and the birth of children with various developmental disorders [12-14]. (Fig. 2).

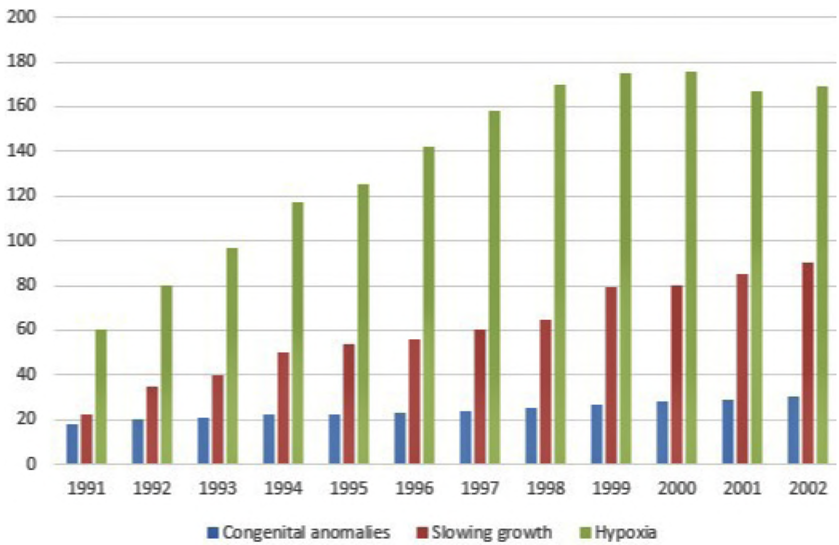

Fig. 2. The dynamics of the increase in the birth of children with abnormalities

Agrotechnologies should be considered not only from the point of view of increasing yields and profitability, but also ensuring the safety of agriculture for the population of our country with a full understanding of food security in the interpretation of the FAO. The search for effective ways of a reasonable approach to the chemicalization of agriculture has been going on for many decades [15-19].

The greatest attention is paid to the issues of accurate transfer of nutrients in various forms to the root system of plants of the desired species during a given growing season and increasing the efficiency of their assimilation [13; 17-19]. Much attention is paid to the introduction of drugs into plant cultivation technology that promote the better use of nutrients from mineral fertilizers, which allows either reducing fertilizer doses without compromising yields, or increasing yields without increasing fertilizer doses [1; 13; 20]. For example, these can be well-known chemical compounds such as Ce-Ce, Epin, etc. Of great interest are natural products such as humates of various origins or silatrans and other variants of organoelement compounds or bionutrients - products that do not create a burden on the ecosystem, but can improve metabolic processes in plant organisms, increase the efficiency of the use of nutrients from mineral fertilizers and reduce the need for pesticides [1].

To confirm the possibility of intensifying crop production with the reasonable use of agrochemicals, we will additionally consider the effectiveness of the introduction of silatrans into agricultural technology. It was found that the biological activity of silatrans is due to their unique molecular structure, the presence of a silicon atom and a specific electronic configuration. A wide range of their biological effects as a new type of biostimulants of metabolic processes allows them to be successfully used in the cultivation of industrial crops [1]. It is important to understand the practical applicability of silatrans to improve metabolic processes and increase the yield of industrial crops without increasing the doses of mineral fertilizers.

The purpose of the study is to summarize and analyze experiments conducted to assess the possibility of increasing the yield of industrial crops without increasing the doses of mineral fertilizers due to bionutrients based on organosilicon compounds that are safe for humans and animals.

Purpose

The main objective of the present study is to increase the yield of industrial crops using bionutrients.

Materials and methods

Let's consider the effectiveness of the use of 1-chloromethylsilatran and triethanolammonium salt of orthocresoxyacetic acid with auxin activity as independent bionutrients and in combination with each other. The research methodology is based on the analysis and generalization of materials from field experiments conducted in different regions of the Russian Federation on industrial crops (sugar beet and sunflower). Bionutrients were used in the form of solutions for the treatment of seeds and vegetative plants, both individually and in combination.

Further, to simplify, we denote the bionutrient 1-chloromethylsilatran with the letter C, the triethanolammonium salt of orthocresoxyacetic acid with the letter T, and their combinations with.

Results

Vegetative and field studies of the bionutrient CT and its components – C and T were carried out at the Russian State Agricultural Academy named after K.A. Timiryazev, NPO Sugar Beet, agro-industrial Complex Kuban for many years. The results of studies with soaking sugar beet seeds before sowing are shown in Table 1.

In all cases, it was noted that in addition to increasing the yield of sugar beet, an increase in the sugar content by 0.3...0.7% is observed during seed treatment with the bionutrient CT, which is most important for this crop.

Vegetative experiments with sugar beet of the Yaltushkovskaya single-seeded variety were carried out on dark gray forest sandy-loamy soil with the following agrochemical indicators: humus content of 1.3%, pH value – 5.1 NG – 4.2 mg-eq./ 100 g of soil.

Table 1.

The effect of processing sugar beet seeds with bionutrients on the productivity and quality of root crops

Option (soaking the seeds for 40... 60 min.)	Dose, mg/l	Yield of root crops, kg/ha	Sugar collection, t/ha		Sugar content, %
			common	the increase	
Control, water	-	67700	9,07	-	13,4
T, 0,02…0,05%	5,0	69000	9,82	0,75	13,7
C, 0,02…0,05%	50,0	71000	9,88	0,81	13,5
CT, 0,02…0,05%	50,0	72500	10,15	1,08	14,1

The seeds were soaked in 0.02 ...0.05% solution of CT and C. The effect of growth regulators was studied on two backgrounds – a control one (pure, without herbicides) and an experimental one (with the addition of the herbicide Eptam). Data on seed germination are given in Table 2.

Table 2.

Effect of sugar beet seed treatment on germination

Option	Germination, %	
	Control, without herbicide	Eptam, 12 mg/vessel
Control, water	80,4 ± 3,5	67,8 ±1,3
C, 0,02%	39,0 ± 1,7	37,6 ± 3,1
C, 0,05%	72,0 ± 5,9	71,4 ± 2,2
CT, 0,02%	82,0 ± 2,6	80,8 ± 2,1
CT, 0,05%	79,6 ± 3,6	80,6 ± 2,3

In continuation of the research on the same soil and with the same variety, field experiments were conducted on the basis of an experimental farm of the IGF. Agrotechnics in field experiments are generally accepted for this soil and climatic zone. The research objectives included studying the effect of pre-sowing treatment of sugar beet seeds with silicon-containing bionutrients on seed germination, yield and accumulation of sugars in sugar beet root crops (Table 3).

Table 3.

The effect of bionutrients CT and C on the yield of sugar beet Yaltushkovskaya (seed soaking)

Option	Control, without herbicide		Eptam,3 kg/ha		Eptam,5 kg/ha	
	t/ha	sugar, %	t/ha	sugar, %	t/ha	sugar, %
Control, water	47,9	16,8	47,5	16,5	41,0	16,7
C, 0,02%	43,0	16,5	46,0	16,5	39,8	16,6
C 0,05%	47,8	16,9	49,0	16,7	48,5	16,8
CT, 0,02%	48,9	16,9	50,5	16,7	49,0	16,5
CT, 0,05%	50,0	16,9	51,0	16,9	49,2	16,8

The results of the experiment show that CT and C neutralize the phytotoxic effect of the herbicide eptam, which is often used in the cultivation of sugar beet using standard technologies. CT neutralizes the phytotoxic effect of the herbicide on sugar beet. The increase in yield, depending on the dose of eptam, ranges from 7 to 20% compared with the control.

In production tests of modern technologies (2003-2021, Orel region) with the variety of sugar beet Barres (joint French-Russian breeding), the research results were confirmed.

Field tests of the CT preparation on sugar beet of the North Caucasian 42 variety (SKO-42) were carried out on slightly leached Western pre-Caucasian chernozem, pH - 7...8, the content in 100 g of soil P2O5 is average, K2O is high. The predecessor is winter wheat. The results of the research are shown in Table 4.

Table 4.

The effect of bionutrients on the productivity of sugar beet of the SKO-42 variety

Option	Yield, t/ha	Sugar content, %	Sugar is obtained	
			Average yield, t/ha	+/- to control, t/ha
Processing in the phase of 3-4 pairs of real leaves				
Control	677,0	13,4	9,07	-
T, 40 mg / l	725,0	14,3	10,15	1,08
(15 g / ha)	736,0	13,4	9,86	0,79
C, 40 mg/l	756,0	14,5	10,46	1,39
Processing in the closing phase of the leaves				
Control	685,0	13,5	92,5	-
T, 40 mg / l	740,0	13,4	104,3	1,18
(15 g / ha)	756,0	14,0	105,8	1,33
C, 40 mg/l	764,0	14,2	107,4	1,49

The treatment of plants with solutions of bionutrients was carried out during the initial growth period in the phase 3...4 pairs of real leaves and during the mass formation of the root crop before the row spacing closed. The working solution was prepared at the rate of 40 mg of the drug per 1 liter, the consumption of the tank mixture was 400 l / ha, the consumption rate of the drug was 20 g / ha.

The treatment of plants with bionutrients contributed to an increase in yield by 12%, which, with such a high yield level at the control (677...685 c/ha), in absolute terms amounts to 79 c/ha. It is important to note that an increase in the sugar content in root crops to 1% was found, which made it possible to increase the sugar harvest from 1 ha by 13.9 ... 14.9 c/ha in the variant with bionutrient CT treatment, at a consumption of 10... 15 g/ha.

Production tests in the southern beet-growing regions (Belgorod and Voronezh regions) confirm the results of field experiments.

The most uniform shoots and the formation of a powerful root system are noted during the germination of seeds treated with CT. The control group for these indicators has the lowest values. Control measurements in the first decade of August, i.e. the season of the most intensive growth showed an increase in the weight of root crops from 200 to 1000 g (in the control group it did not exceed 200 g), the formation of elastic leaves with thickened petioles in plants in the amount of 18 to 24 pieces (in control samples – no more than 19 pieces), and the defeat of shoots as a result of the disease was noted up to 1 point (control group – up to 3 points).

The sugar content in the root crops under control was 13.2%, in the experiment with CT – 15.2%. The use of CT increased yields by an average of 30...40 c/ha with an average yield of 200 c/ha, which is 15...20%.

Research on sunflower. Field studies were conducted to study the effect of the bio nutrient CT on the yield and quality of sunflower oil seeds, the srednerанniy – Saratovsky 87 variety (super elite seeds). The soil of the experimental site is light chestnut, slightly loamy, slightly saline. The thickness of the humus horizon is 27 cm. The water regime is not of the flushing type, the maximum soaking is 100...130 cm.

The scheme of the experience:

- control, without processing;
- seed treatment with a Ta solution – consumption of 15 ...20 g/t per 10 liters of water;
- seed treatment with Agate solution-25 To 10 ml/t;
- seed treatment with CT solution – consumption of 20 g / t per 10 liters of water.

The experiment was conducted in the conditions of crop rotation, the predecessor of sunflower is oats. Pre-sowing treatment of CT seeds improved germination and germination energy, the number of seedlings 63.5...66.5 thousand units/ha is significantly higher than in the control (60.4...63.2 thousand plants per 1 ha). The results of the experiment are shown in Tables 5 and 6.

Table 5.

Analysis of the pathogen infestation of sunflower plants

Option	The spread of a harmful object, %		
	gray rot	dry rot	verticillosis
Control	5,5	1,5	1,7
T	1,5	1,0	1,0
Agat 25K	1,5	1,0	1,0
CT	0,5	0,0	0,0

The determination of the infestation of plants with a complex of diseases was carried out before harvesting. Pre-sowing treatment of seeds with CT significantly reduced the incidence to the complete exclusion of fungal diseases.

Growth regulators helped to increase plant productivity and increased the fat content in seeds.

Table 6.

Sunflower yield and fat content in oilseeds

Option	Diameter of the sunflower basket, cm	Weight 1000 seeds, g	Seed weight from 1 root, g	Yield, t/ha	Fat content, %, (on a completely dry substance)
Control	10,6	42,1	17,2	1,04	42,5
T	11,1	43,7	19,7	1,20	43,5
Agat 25 K	10,8	42,7	19,0	1,12	43,5
CT	11,7	43,3	20,1	1,23	43,3

Tests of the CT preparation on sunflower culture, which showed a noticeable increase in the main indicators of sunflower yield. There is an increase in seed germination, vegetative plants have a thick, durable stem. The forming sunflower leaves are larger and more intensely colored with green pigment, their number is also increasing. The size of the baskets exceeds the control figures, and the seed content increases. Secondary roots appear 8 days earlier, which leads to the formation of a more powerful root system. Flowering accelerates, and as a result, maturation, on average for 10-15 days. There is an increase in the drought tolerance of a group of treated plants. The effect of CT stimulated an increase in sunflower yield by 20%, to 24.1 c/ha, in the control group – 20 (Table 7).

Table 7.

Assessment of the effect of bionutrients on sunflower yield

Option	Weight of seeds from 1 basket, g	Basket diameter, cm	Yield,t/ha	The increase	
				t/ha	%
Control	31,4	17,6	2,00	-	-
C	32,7	17,9	2,18	0,18	9,0
CT	35,7	19,1	2,41	0,41	20,5

The complex bionutrient (preparation CT), when used in the processing of sunflower seeds, gives an increase in yield to 19 c /ha, which in its effect is comparable to the efficiency of processing C and T. At the same time, the control group of plants shows a yield at the border of 10.4 c / ha, i.e. there is an increase in sunflower yield by 18.2%. The tendency to increase is clearly expressed the fat content in oilseeds when using CT. The fat content in the seeds increases by 0.8...1.0% (from 43.7 to 44.6% for absolutely dry matter).

An economic assessment using the example of wheat has shown that the use of bionutrients to increase yields instead of increasing the applied doses of mineral fertilizers can reduce the cost of production and increase business profitability. And this is already an effective incentive for the revision of traditional crop production technologies and the transition to the reasonable use of agrochemistry, reducing the cost of fertilizers that are not involved in the formation of an economically useful part of the crop [4; 11].

Conclusion

The results of the assessment of the possibility of a reasonable approach to the chemicalization of agriculture while increasing crop yields due to bionutrients safe for humans and animals based on organosilicon compounds 1-chloromethylsilatran and a substance with auxin activity – triethanolammonium salt of orthocresoxyacetic acid, showed a real prospect of minimizing doses of mineral fertilizers and pesticides. In particular, it was found that beet yields increased by 14...18%, and sugar content - by 0.7... 1% without the use of additional doses of mineral fertilizers.

A similar effect was obtained on sunflower: the yield increase was 18...20%. the weight of seeds from one basket and the weight of 1000 seeds and their oil content increased. Bionutrients restrained the spread of fungal diseases.

Thus, silatrans and other organosilicon compounds can become important components of agricultural technologies that do not harm the ecosystem, but can improve metabolic processes in plant organisms, increase the efficiency of using nutrients from mineral fertilizers and reduce dependence on pesticides used in agriculture.

Conflict of interest information. The authors declare that they have no conflict of interest.

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The authors contributed equally to this article.

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Original article

ACCELERATED DEVELOPMENT OF RICE POPULATIONS USING ANTHER CULTURE *IN VITRO* METHOD

E.G. Savenko, V.A. Glazyrina, L.A. Shundrina, Zn.M. Mukhina, L.V. Esaulova

Abstract

Background. Inclusion of doubled haploids in the breeding process allows increasing the speed and reliability of selection of desired forms with smaller population volumes. To stabilize the genotype, anthers of hybrid combinations of F_2, F_3, F_4 and F_5 generations, developed in crossings of white-grained samples with traits of high nutritional value of grain, and anthers of combinations of F_4 generation from crossings of varieties contrasting in pericarp color and amylose content, were introduced into the culture. The responsiveness to gamete technologies was studied in 21 hybrid combinations. New genetically stable material (DH - doubled haploids) was developed. Phenotyping was carried out in conditions of a vegetation experiment for economic and biological traits and elements of plant productivity in four populations, which included 45 DH lines. Variability was noted in a number of traits within the DH line populations. Based on the results of the biometric analysis of the regenerated populations, 6 sources with a “1000 grain mass” of more than 30 grams were identified.

The study was carried out with the financial support of the Kuban Science Foundation and the Russian Science Foundation within the framework of the scientific project No. 25-16-20103 “Application of the genomic approach in rice breeding for high technological grain quality”

Purpose. To study the response of hybrids obtained from crossing contrasting rice samples to in vitro pollen culture, to accelerate the creation of DH line populations based on the studied genotypes, and to phenotype them.

Materials and methods. The research was conducted at the Laboratory of Biotechnology and Molecular Biology at the Federal Research Center for Rice, using the culture of isolated anthers in vitro according to the generally accepted method of R.G. Butenko (1990).

Results. The genetic determinism of the “regeneration” trait in the donor plants used in the crossbreeding was noted. The genotypes of the crossbreeding involving the varieties Favorit and Azovsky proved to be the most productive in terms of the output of highly morphogenic calluses and androgenic lines. Phenotypic analysis revealed significant diversity among the plants in the individual DH populations in terms of the shape of the panicle, the angle of the flag leaf deviation, the length of the growing season, the weight of 1,000 grains, the height of the plants, and the length of the growing season.

Conclusion. Phenotypic analysis of the DH lines’ traits showed that their genesis originates from microspores, thus these lines are a valuable genetic resource. The inclusion of doubled haploids in the breeding process will help to facilitate the assessment of recombinant genotypes arising from the cross, will allow to detect rare recessive alleles, will increase the speed and reliability of the selection of desired forms with smaller population volumes.

Keywords: Oryza sativa L. rice; in vitro pollen culture; doubled haploid (DH) lines; economic and biological traits; productivity elements

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Научная статья

УСКОРЕННОЕ РАЗВИТИЕ ПОПУЛЯЦИЙ РИСА С ИСПОЛЬЗОВАНИЕМ КУЛЬТУРЫ ПЫЛЬНИКОВ

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Аннотация

Обоснование. Включение удвоенных гаплоидов в селекционный процесс способствует повышению скорости и надежности отбора желаемых форм при меньших объемах популяции. Для стабилизации генотипа в культуру введены пыльники гибридных комбинаций F_2, F_3, F_4 и F_5 поколений, созданных в скрещиваниях белозерных образцов с признаками высокой пищевой ценности зерна и пыльники комбинаций F_4 поколения от скрещиваний сортов контрастных по окраске перикарпа и содержанию амилозы. Изучена отзывчивость на гаметные технологии у 21 гибридной комбинации. Выделены отзывчивые на культуру пыльников *in vitro* генотипы. Создан новый генетически стабильный материал. В условиях вегетационного опыта изучены морфологические признаки растений 45 удвоенных гаплоидных линий риса четырех популяций. Отмечена вариабельность по ряду признаков внутри популяций DH линий. По результатам биометрического анализа регенерантных популяций выделено 6 источников с «Массой 1000 зерен» более 30 грамм.

Цель. Изучение отзывчивости гибридов, полученных от скрещивания контрастных образцов риса, на культуру пыльников *in vitro,* ускоренное создание популяций DH линий на основе изучаемых генотипов и их фенотипирование.

Материалы и методы. Исследования проводились в лаборатории биотехнологии и молекулярной биологии ФГБНУ «ФНЦ риса» с использованием культуры изолированных пыльников *in vitro* по общепринятой методике Бутенко Р.Г. (1990).

Результаты. Отмечена генетическая детерминированность по признаку «регенерация» вводимых в скрещивания растений – доноров. Наиболее продуктивными по выходу высоко морфогенных каллусов и андрогенных линий оказались генотипы скрещивания с участием сортов Фаворит и Азовский. Фенотипический анализ выявил существенное разнообразие растений в линиях индивидуальных популяций DH по форме метелки, углу отклонения флагового листа, длине вегетационного периода, массе 1000 зерен, высоте растений и длине вегетационного периода.

Заключение. Фенотипический анализ признаков линий DH показал, что их генезис происходит от микроспор, таким образом, эти линии являются ценным генетическим ресурсом. Включение удвоенных гаплоидов в селекционный процесс поможет облегчить оценку рекомбинантных генотипов, возникающих в результате скрещивания, позволит обнаружить редкие рецессивные аллели, повысит скорость и надежность отбора желаемых форм при меньших объемах популяции.

Ключевые слова: рис *Oryza sativa* L.; культура пыльников in vitro; удвоенные гаплоидные (DH) линии; хозяйственно биологические признаки; элементы продуктивности

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Introduction

To select varieties with economically valuable traits, it is necessary to replenish the genetic base using not only hybridization, but also new biotechnological methods. These methods make it possible to create lines with a high level of homozygosity in one year, instead of 8-10 years. Currently, there is an urgent need to create varieties with accelerated breeding traits. [1].

The efficiency of breeding can be increased by stabilizing the genetic material using gamete technologies *in vitro.*

Doubled haploid lines play an important role in breeding due to their phenotypic homogeneity, wide range of variations, and the manifestation of both dominant and recessive traits. [2-5].

The offspring of regenerants is studied to identify new phenotypic traits and gametoclonal variations [6; 7]. Gametoclonal variability is observed in many economically valuable traits, including biochemical ones. Most often, genetic variability manifests itself in changes in the level of ploidy, chromosome and gene mutations. This phenomenon is successfully used by breeders in programs aimed at developing varieties with improved characteristics. The use of doubled haploids in breeding has a positive effect [8]. Useful variations in individual traits and 100% homozygosity have been found in androgenic lines of wheat, potatoes, teff, and rice. Based on gametoclonal variants, the Dam variety, which is resistant to pyricularia and has good culinary qualities, has been developed. The Federal Research Center for Rice has studied a variety of factors to develop an effective protocol for the regeneration of rice anthers in vitro in the japonika and indika subspecies. The effectiveness of the rice anther culture in vitro scheme has been confirmed by practical results: thousands of doubled haploids of rice have been created, which have been studied by the breeding departments of the research center in the field to test their morphological uniformity and evaluate their economically important characteristics. Based on the selected homozygous DH lines, the following rice varieties have been registered in the State Register of Breeding Achievements of the Russian Federation, zoned, and approved for use in the North Caucasus region: Sonet, Sonata, Privolny 4, Ivushka, and Vodopad. When cultivated in the Krasnodar rice-growing zone, these varieties consistently demonstrate high yields, resistance to lodging, shedding, and pyricularia, as well as excellent grain quality. The culture of gametes in vitro includes two stages. The first stage is the induction of organo/embryogenic calluses, and the second stage is the regeneration of green plants [9]. This strategy helps to reduce the selection process, increases the efficiency of selection, and increases genetic diversity [10]. DH populations do not split and are used in various molecular genetic studies for mapping fixed homozygotes [11; 12]. They are also an ideal material for genetic mapping of morphological and complex traits [13].

Thus, plants derived from gametes have characteristics that differ from those of their donors, making them attractive for use in breeding programs and genetic engineering [14; 15].

The goal of the research was to study the responsiveness of hybrids obtained from crossing contrasting rice samples to *in vitro* anther culture and to accelerate the development of DH line populations based on the studied genotypes.

Purpose. To study the response of hybrids obtained from crossing contrasting rice samples to in vitro pollen culture, to accelerate the creation of DH line populations based on the studied genotypes, and to phenotype them.

Materials and methods

The research was conducted at the Federal State Budgetary Scientific Institution "Federal Scientific Rice Centre" using standard methods according to Butenko R.G. (1990) [16]. To stabilize the genotype, the culture includes the anthers of hybrid combinations of F2, F3, F4, and F5 generations, created by crossing white-grained samples with high grain nutritional value, and the anthers of F4 combinations from crossing varieties with contrasting pericarp color and amylose content. The anthers were inoculated under aseptic conditions in a laminar flow hood using the Blades basic agar medium with phytohormones (17). Calluses were cultured on Murashige and Skoog medium until green shoots appeared, which were transferred to a hormone-free MS medium for rooting (18).

Results

To stabilize the genotype, anthers of hybrid combinations of F_2, F_3, F_4 and F_5 generations, developed in crossings of white-grained samples with traits of high nutritional value of grain, and anthers of combinations of F_4 generation from crossings of varieties contrasting in pericarp color and amylose content, were introduced into the culture. Anthers were inoculated onto Blaydes induction medium (0-passage) with an increased content of 2,4-D (4.0 mg/l) until calli appeared, then calli were transferred to Blaydes subcultivation medium with a reduced concentration of 2,4-D (2.0 mg/l), enriched with proline 500.0 mg/l and glutamine 500.0 mg/l. Cultivated for 20-30 days (1st passage). For further incubation and stimulation of regeneration processes, the calli were transferred to MS medium + 1.0 mg/l α-NUA + 5.0 mg/l kinetin + 500.0 mg/l proline + 500.0 mg/l glutamine + 30.0 g/l sucrose.

When cultivating anthers of rice hybrids of F_2, F_3, F_4 and F_5 generations, developed by crossing white-grained samples with traits of high nutritional value of grain, high responsiveness of all studied genotypes for the trait of callusogenesis induction was noted. The maximum result (13.72%) was shown by the F_5 hybrid Yakhont / Azovsky. The minimum indicator was demonstrated by the F_4 hybrid Atlant / Sprint - 2.35% ($LSD_{0.05}$ = 0.48) (see Fig. 1).

The formed callus lines had a high regenerative capacity. Genetic determination by the "regeneration" trait of the donor plants introduced into the crossing was noted. The most productive in terms of the yield of androgenic lines were the genotypes of the crossing involving the varieties Favorit and Azovsky: F_3 Favorit / Azovsky (60 lines), F_3 Favorit / Sonet (31 lines), F_3 Apollon / Favorit (49 lines), F_4 Atlant / Azovsky (14 lines), F_2 Neve / Azovsky (79 lines), F_5 Yakhont / Azovsky (8 lines).

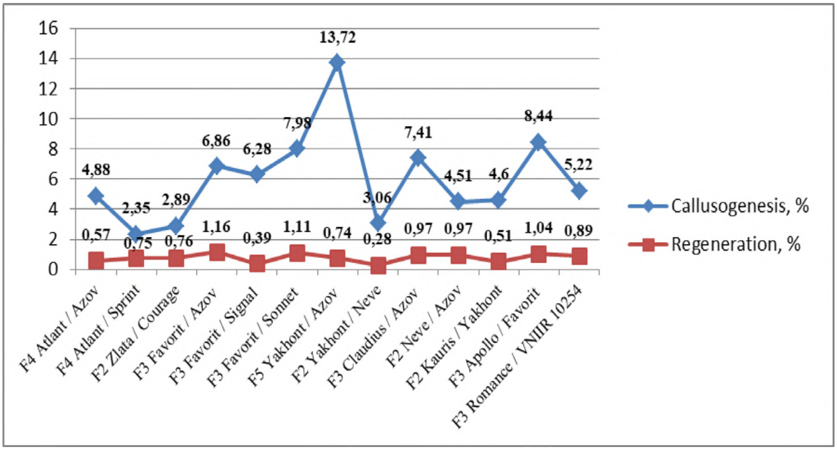

Fig. 1. Callusogenesis and regeneration in anther culture *in vitro* of hybrid rice combinations of F_2, F_3, F_4 and F_5 generations developed in crossing white-grained samples with traits of high nutritional value of grain

When cultivating anthers of rice hybrids of the F_4 generation from crossing samples contrasting in pericarp color and amylose content, all samples also showed high responsiveness to callus induction from 5.42% to 20.39% (see Fig. 2).

The maximum result of callusogenesis was noted in genotypes involving the variety Violetta in the crossing: F_4 Violetta / Zlata and F_4 Violetta / CRLB-1 –17.10% and 20.39%, respectively. The indicators for these genotypes were at the same level (LSD_{05} = 3.24).

2950 morphogenic callus lines were obtained. During the cultivation, 52.8% of the callus lines were realized by gemmogenesis and gemmorhizogenesis into 1557 full-fledged plants (see Fig. 3).

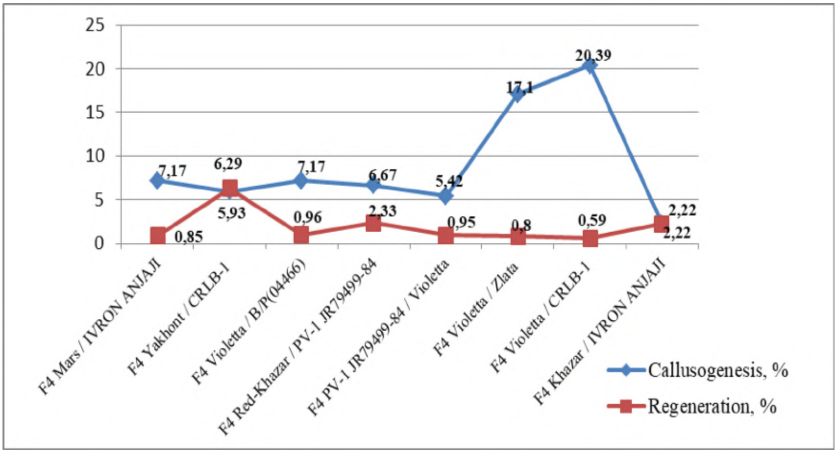

Fig. 2. Callusogenesis and regeneration in anther culture *in vitro* of hybrid combinations of rice F_4 generation from crossings rice samples contrasting in pericarp color and amylose content

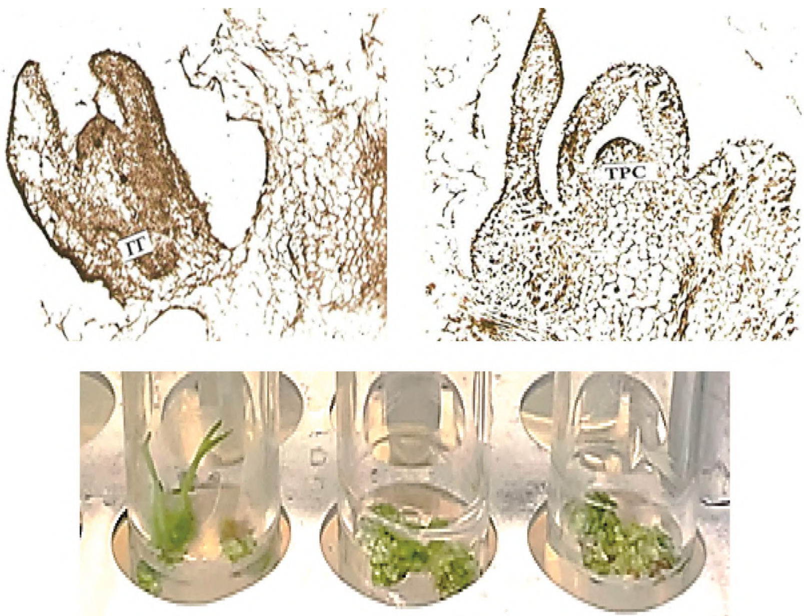

Fig. 3. Gemmogenesis processes in rice callus F_5 hybrid Yakhont / Azov (macro photo)

Regenerants were planted in specialized plant growth chambers under conditions of high humidity and controlled temperatures to adapt to *ex vitro* conditions. After spontaneous chromosome doubling in some callus lines, the cells proliferated into doubled haploids, which produced seed progeny.

Under the conditions of a pot experiment, phenotyping of plants from four populations, which included 45 DH lines, was carried out for a number of vegetative, morphological and biological traits.

Phenotypic analysis in DH line populations revealed significant diversity in panicle shape. In the F_1 Violetta/Zlata population and in the F_1 Violetta/CRLB-1 population, all plants had an upright compact panicle. In the F_1 Mars/IVRON ANJAJI population, plants with an upright compact panicle, with a weakly spreading panicle, and lines with a weakly spreading inclined panicle were identified. In the F_1 Violetta/B/P (04466) population, various forms of a weakly spreading panicle were noted in the lines: drooping, inclined, vertical (see Fig. 4).

F_1 Violetta / B/R (04466) F_1 Mars / IVRON ANJAJI F_1 Violetta/ CRLB-1

Fig. 4. Variability in the shape of panicles in populations of doubled haploid lines

Within the populations, the lines varied in the length of the growing season; early ripening lines– 110 days, mid-ripening lines – 112 days, and late ripening lines – 130 days were identified. No lines with a growing season of less than 100 days were identified.

Plants of lines within populations differed in the angle of deviation of the flag leaf; there were individuals with a semi-vertical angle of 30-45^0, an intermediate angle of 50-70^0, and a horizontal angle of 80-90^0. DH lines with a vertical angle of deviation of the flag leaf from the stem of up to 30^0 were identified, and line No. 5 DH F1 Violetta / B/P (04466) had an angle of 20^0.

Dwarfy lines (60-70 cm) were identified. Tall plants (125-135 cm) were noted in all lines of the F_1 Mars/IVRON ANJAJI population. Most of the plants in the populations were medium-sized, from 80 to 102 cm, with a low mass of 1000 grains (20-25 g). The F_1 Violetta/CRLB-1 population lines had a high mass of 1000 grains - over 30 g (min – 32.1 g, max – 35.4 g (LSD 1.2)); these lines also had a strong stem resistant to lodging (1 point).

Discussion

The main limiting factor in obtaining a large number of androgenic plants is the genotype. To overcome this problem, it is necessary to develop a reliable and efficient system for pollen culture regeneration, which will allow the production of genetically stable rice lines with targeted traits from hybrids. Although cultured cells are usually able to synthesize all the necessary amino acids, the addition of proline and glutamine to the medium can increase the growth rate of cells. It has been reported that the use of proline and glutamine amino acids in the medium has a positive effect on the frequency of callus formation and regeneration of rice (Chowdhry et al., 1993; Ge et al., 2006; Shahsavari, 2011). The addition of proline and glutamine to the induction medium reduced the time from anther inoculation to callus formation and improved the quality of the callus. This is because amino acids are an easily accessible source of nitrogen for growing tissue cells and can maintain a high rate of callus cell growth for an extended period. On callus obtained on medium supplemented with proline and glutamine, the intensity of green plant regeneration was higher. This is in line with the studies of Chowdhry et al. (1993) and Shahsavari (2011), who also reported that these amino acids increase the percentage of plant regeneration. In our experiment, all rice genotypes were responsive to anther culture. However, the frequency of callus formation and plant regeneration varied greatly among the genotypes. Ge et al. (2006) also reported different potential of rice genotypes in inducing callus and regeneration.

The maximum callus formation rates were noted in the F_5 Yakhont/Azov hybrid (13.7%) and genotypes involving the variety Violetta variety in the crossing: F_4 Violetta/Zlata and F_4 Violetta/CRLB-1 - 17.10% and 20.39%, respectively, which was associated with the high combining ability of the crossing samples for the “callus formation” trait.

The ability to regenerate depended on the quality and degree of development of the callus tissues, as well as the presence of auxin-type hormones in the nutrient medium, as at a certain stage, their cells no longer needed certain auxins, as they began to produce them on their own.

During long-term cultivation of calluses on inducing media without subculturing and subsequent transfer to regeneration media, the cells of androgenic structures (gemm) stopped proliferating and underwent dedifferentiation, i.e., the differentiation of the morphogenic complex stopped, and the cells transformed from meristematic to parenchymatous. The studies have shown that it is particularly successful to cultivate the anthers until calluses appear, followed by subculturing the newly formed calluses on a nutrient medium with a reduced concentration of 2,4-D for 20-30 days, and then culturing them for 30-45 days on regeneration media, which ensures maximum yield of regenerated plants.

The analysis of economically valuable traits and productivity elements of androgenic lines revealed their variability among populations. The similarities and differences in the morphological traits of DH lines in populations were expressed in the uniformity of plants within a single line and the diversity in economic and biological characteristics and biometric traits between lines within a single population.

The biometric trait “mass of 1000 grains” is an important element of productivity, negatively correlating with the number of spikelets on a panicle and positively - with the yield of the variety. In the studied samples, the value of the trait “mass of 1000 grains” varied from 17.4 to 35.4 grams. All domestic rice varieties have an average grain size (26-30 grams). Based on the results of the biometric analysis of regenerated populations, 6 sources of large grains with a “mass of 1000 grains” over 30 grams, with an average panicle length from 13.5 to 14.9 cm were identified, all of them are lines of the F_1 Violetta / CRLB-1 population.

According to breeders, a highly productive rice morphotype should have an erectoid (up to 15^0) or vertical arrangement of leaves (20-30^0). Thus, the development of samples with such an angle of deviation of the flag leaf from the stem is an important trait, since varieties with vertical leaves allow thickening crops and increasing productivity. During phenotyping, variation of this trait in populations from 80-90^0 (horizontal) to 20-30^0 (vertical) was noted. Forms with an erectoid arrangement of leaves were not identified.

Most DH lines developed on the basis of anther culture had a compact vertical panicle, which domestic breeders prefer in the original forms, which is associated with the weather and climatic conditions of rice cultivation in Russia.

Conclusion

The obtained data of biometric analysis and economic-biological characteristics indicate gametoclonal variability in populations of doubled haploids, which is based on the isolated anthers culture *in vitro*, which contributes to the development of genetic diversity of the source material. Phenotypic analysis of the DH lines showed that their genesis comes from microspores. Thus, these lines are a valuable genetic resource. Inclusion of doubled haploids in the breeding process will help to facilitate the evaluation of recombinant genotypes arising from crossing, will allow detection of rare recessive alleles, will increase the speed and reliability of selection of desired forms with smaller population volumes. In self-pollinating cereals, one homozygous genotype often carries successful single traits or combinations of traits and can be used to improve the variety or potentially become a new variety.

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Original article

REPRODUCTIVE QUALITIES OF BOARS IN THE ASSESSMENT OF ADAPTIVE CAPABILITIES WHEN USING INTRODUCTORY CROSSBREEDING OF DIFFERENT VARIANTS

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Abstract

Background. The article deals with the study of the reproductive performance of breeding boars of Poltava meat breed when using different variants of introductory crossbreeding. At the same time, the objectives of using introductory crossbreeding determine the dynamics of changes.

By introductory crossing in the breed new genotypes were created with Finnish Landrace pigs (in order to improve productive qualities) and fast-ripening meat pigs (in order to increase the adaptive capacity of animals to natural and climatic conditions of the farm). To conduct research we formed four groups according to the principle of pair-analogs: Group I – boars descendants of introductory crossbreeding, with a share of blood of the fast-ripening meat breed 25%, Group II – boars descendants of introductory crossbreeding, with a share of blood of the Finnish Landrace breed 25%, Group III – boars descendants of introductory crossbreeding, with a share of blood of the fast-ripening meat breed 50%, Group IV – boars descendants of introductory crossbreeding, with a share of blood of the Finnish Landrace breed 50%. We evaluated boar development indicators (live weight, body length, age at 100 kg live weight, thickness of the bailiffs follower) and indicators characterizing reproductive capacity (number of inseminated and farrowed breeding sows, fertilizing capacity of the boar, multiple fertility of farrowed breeding sows, weight of one piglet at weaning at 45 days).

Infusion of Finnish Landrace blood in order to improve meat qualities leads in boars of Poltava meat breed to a violation of adaptive capabilities, manifested in an increase in the age of achieving a live weight of 100 kg and a decrease in reproductive performance, not actively involved in the selection process. Increasing the level of bloodlines of breeding boars up to 50% for Finnish Landrace breed is not reasonable in these natural and climatic conditions and will require additional costs to improve efficiency.

The infusion of blood of the soon-to-be ripe meat breed to boars of Poltava meat breed with the purpose of improvement of adaptive qualities leads to strengthening of adaptive properties of the organism, by means of increase of protective capabilities and increase of reproductive indicators.

Purpose. The aim of the study is to investigate reproductive qualities of boars in the evaluation of adaptive capabilities when using introductory crossbreeding of different variants

Materials and methods. The data of 40 breeding boars-producers of Poltava meat breed, belonging to genetic groups with the infusion of blood of Finnish Landrace and soon-breeding meat breed, were used in the work. All animals belonged to the elite and first classes. The age of the animals was 24 months.

We evaluated boar development indicators (live weight, body length, age at 100 kg live weight, thickness of the rump) and indicators characterizing reproductive capacity (number of inseminated and farrowed sows, fertilizing capacity of the boar, multiple fertility of farrowed sows, weight of one piglet at weaning at 45 days, weight of one piglet at weaning at 45 days).

Results. As a result of the study it was found that in boars of Poltava meat breed of all examined groups the obtained average values of live weight and body length did not differ significantly from each other.

The study revealed that the use of introductory crossbreeding using 25% bloodlines for the two improving breeds did not cause significant changes in the average number of sows inseminated and interviewed. Increasing the proportion of bloodlines up to 50% resulted in multidirectional significant differences depending on the breeds used. Thus, the use of Finnish Landrace breed decreased the value of both studied indicators by 20.96 head (64.6%) ($p \leq 0.05$) and 15.77 head (66.4%) ($p \leq 0.05$), respectively.

When the proportion of bloodlines of the fast-ripening meat breed increased from 25% to 50%, boars showed a significant increase in the number of farrowing sows by 9.85 head or 41.5% ($p \leq 0.05$). This group also showed the highest value of fertilizing ability of boars. The difference amounted to 13.49% ($p \leq 0.05$) compared to the group with lower bloodlines. No significant differences were found in groups with Finnish Landrace blood for this indicator.

Conclusion. The infusion of the blood of the fast-ripening meat breed in order to increase the adaptive qualities of the Poltava meat breed and increasing the share of its bloodline up to 50% led to a reliable increase in reproductive indicators (the number of inseminated sows, the number of farrowing sows, the fertilizing ability of the boar), not related to the primary in the breeding process, but determining, among other things, the efficiency of the pig breeding industry.

In the indicators of development, the use of blood of the early maturing meat breed was reflected in the indicator of the thickness of the speck. We found a significant increase in fat thickness with increasing bloodlines of the fast-ripening beef breed. Earlier studies have clearly shown that increased fat thickness can have a favorable effect on reproductive performance. Our study also demonstrated a significant effect of rump thickness on the fertilizing ability of boars. Taking into account that an increase in the thickness of the rump can be considered as an increase in the protective properties of the skin, it gives us the opportunity to talk about the increase in the protective and adaptive (adaptive) capabilities of the organism in this case.

Keywords: genotype; breeding boars; reproductive performance; Poltava meat breed

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Научная статья

РЕПРОДУКТИВНЫЕ КАЧЕСТВА ХРЯКОВ В ОЦЕНКЕ АДАПТАЦИОННЫХ ВОЗМОЖНОСТЕЙ ПРИ ИСПОЛЬЗОВАНИИ ВВОДНОГО СКРЕЩИВАНИЯ РАЗЛИЧНЫХ ВАРИАНТОВ

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Аннотация

Обоснование. В статье рассмотрены вопросы изучения репродуктивных показателей у племенных хряков полтавской мясной породы при использовании различных вариантов вводного скрещивания. При этом, цели использования вводного скрещивания, определяют динамику изменений.

Путём вводного скрещивания в породе были созданы новые генотипы со свиньями породы финский ландрас (с целью улучшения продуктивных ка-

честв) и скороспелая мясная (с целью повышения адаптационных возможностей животных к природно-климатическим условиям хозяйства). Для проведения исследований нами по принципу пар-аналогов были сформированы четыре группы: I группа – хряки-потомки вводного скрещивания, с долей крови скороспелой мясной породы 25%, II группа – хряки-потомки вводного скрещивания, с долей крови породы финский ландрас 25%, III группа – хряки-потомки вводного скрещивания, с долей крови скороспелой мясной породы 50%, IV группа – хряки-потомки вводного скрещивания, с долей крови породы финский ландрас 50%. Мы оценивали показатели развития хряков (живая масса, длина туловища, возраст достижения живой массы 100 кг, толщина шпика) и показатели, характеризующие репродуктивные возможности (количество осеменённых и опоросившихся свиноматок, оплодотворяющую возможность хряка, многоплодие опоросившихся свиноматок, масса одного поросёнка при отъёме в 45 дней, масса одного поросёнка при отъёме в 45 дней).

Прилитие крови финского ландраса с целью улучшения мясных качеств приводит у хряков полтавской мясной породы к нарушению адаптивных возможностей, проявляющихся в увеличении возраста достижения живой массы 100 кг и снижению репродуктивных показателей, активно не вовлечённых в селекционный процесс. Увеличение уровня кровности племенных хряков до 50% по породе финский ландрас не целесообразно в данных природно-климатических условиях и будет требовать дополнительных затрат для повышения эффективности.

Прилитие крови скороспелой мясной породы хрякам полтавской мясной породы с целью улучшения адаптивных качеств приводит к усилению адаптационных свойств организма, путём повышения защитных возможностей и повышению репродуктивных показателей.

Цель. Цель исследования – изучить репродуктивные качества хряков в оценке адаптационных возможностей при использовании вводного скрещивания различных вариантов

Материалы и методы. В работе использованы данные 40 племенных хряков-производителей полтавской мясной породы, принадлежащих к генетическим группам с прилитием крови финского ландраса и скороспелой мясной породы. Все животные относились к классам элита и первый. Возраст животных составил 24 месяца.

Мы оценивали показатели развития хряков (живая масса, длина туловища, возраст достижения живой массы 100 кг, толщина шпика) и показатели, характеризующие репродуктивные возможности (количество осеменённых и опоросившихся свиноматок, оплодотворяющую возможность хряка, многоплодие опоросившихся свиноматок, масса одного поросёнка при отъёме в 45 дней, масса одного поросёнка при отъёме в 45 дней).

Результаты. В результате проведённого исследования было установлено, что у хряков полтавской мясной породы всех обследованных групп полученные средние значения показателей живой массы и длины туловища достоверно друг от друга не отличались.

Исследование выявило, что применение вводного скрещивания при использовании 25% кровности по двум улучшающим породам не вызывало достоверных изменений по среднему установленному количеству осеменённых и опросившихся свиноматок. Увеличение доли кровности до 50% приводило к разнонаправленным достоверным отличиям в зависимости от использованных пород. Так, использование породы финский ландрас снижало значение обоих изученных показателей на 20,96 голов (64,6%) ($p \leq 0{,}05$) и 15,77 голов (66,4%) ($p \leq 0{,}05$) соответственно.

При увеличении доли кровности по скороспелой мясной породе с 25% до 50% у хряков наблюдался достоверный рост количества опоросившихся свиноматок на 9,85 голов или 41,5% ($p \leq 0{,}05$). В этой группе также было отмечено наивысшее значение оплодотворяющей способности хряков. Разница составила 13,49% ($p \leq 0{,}05$) в сравнении с группой с меньшей долей кровности. Достоверных отличий в группах с кровью финского ландраса по данному показателю выявлено не было.

Заключение. Прилитие крови скороспелой мясной породы с целью повышения адаптивных качеств полтавской мясной породы и увеличение доли её кровности до 50% привело к достоверному увеличению репродуктивных показателей (количество осеменённых свиноматок, количество опоросившихся свиноматок, оплодотворяющая способность хряка), не относящихся к первичным в селекционном процессе, но определяющих в том числе эффективность отрасли свиноводства.

В показателях развития использование крови скороспелой мясной породы нашло отражение в показателе толщины шпика. Нами было установлено достоверное повышение толщины шпика при увеличении кровности по скороспелой мясной породе. Более ранние исследования ясно показали, что увеличение толщины шпика может благоприятно отразиться на репродуктивных качествах. Наше исследование также продемонстрировало достоверное влияние толщины шпика оплодотворяющую способность хряка. Учитывая, что увеличение толщины шпика можно рассматривать как повышение защитных свойств кожи, это даёт нам возможность говорить о повышении в данном случае защитных и приспособительных (адаптивных) возможностей организма.

Ключевые слова: генотип; племенные хряки; репродуктивные показатели; полтавская мясная порода

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Introduction

In pig breeding, industry viability and profit depend on the flow of animals in the production chain, which starts with the reproductive efficiency of the breeding herd [1]. Paternal factors are known to be able to modulate many critical characteristics of the reproductive process [2]. Boars, as well as their semen, are an important component of the pig herd, strongly influencing production efficiency and profitability [3; 4]. Boars make an integral contribution to the genetic potential of pig farms and pig production, and their role in this is undoubtedly key. Therefore, understanding and improving the reproductive performance of boars is essential to maintain high quality pork production and to adapt to ever-changing market demands [5].

A number of researchers have emphasized the importance of the environmental conditions encountered by the father during spermatogenesis as critical determinants of offspring outcome [6; 7]. In the literature, this phenomenon is known as paternal programming, a phenomenon in which the father's environment during spermatogenesis can have effects that not only affect sperm but also influence offspring outcome [8].

Although the genetic selection currently used in pig production is aimed at making pigs as homogeneous as possible, each living organism reacts differently to different environmental conditions and changes [9]. This implies the development of an appropriate strategy to manage the genotype x environment interaction [10].

Genotype-environment interactions imply that different genotypes may respond differently to environmental changes, affecting performance in different environments. Consequently, the breeding value of an animal depending on environmental conditions reflects the heterogeneous effects of genetic background in different environments [11]. In pigs, genotype x environment interaction exists [12; 13]. It has also been found that some animal traits, such as reproductive traits, may be more sensitive to various environmental factors than other traits [14].

At present, due to the distribution in different regions of the world with diverse ecological and climatic conditions of a limited number of highly productive breeds created in Europe and North America, considerable attention is paid to the study of mechanisms of adaptation of farm animals to unfavorable environmental conditions [15].

According to Abdu Niyas et al. (2015) [16], the term “adaptation” refers to morphological, anatomical, physiological and biochemical characteristics of an animal that combine to promote the animal’s well-being and facilitate its survival in a particular environment.

Based on the opinion of F. Phocas et al. (2016) [17], crossbreeding can provide some immediate benefits in terms of improving certain traits that allow animals to adapt well to local environmental conditions. Crossbreeding, as a method of animal breeding, is fundamental to modern pig production [18].

Thus, given the importance of using different crossbreeding variants in pig production and the role of boar producers in this process, it is probably necessary to determine the reproductive potential of individual breeds and breed groups of pigs in specific natural and technological breeding conditions to assess the potential for the realization of reproductive success or loss mechanisms.

The *aim* of this work is to study the effect of different variants of introductory crossbreeding of breeding boars of Poltava meat breed on reproductive performance.

Materials and methods

The data of 40 breeding boars-producers of Poltava meat breed, belonging to genetic groups with the infusion of blood of Finnish Landrace and soon-breeding meat breed, were used in the work. All animals belonged to the elite and first classes. The age of the animals was 24 months.

The Poltava meat breed of pigs belongs to the group of breeds of meat direction of productivity. By introductory crossing in the breed were created new genotypes with pigs of Finnish Landrace breed (in order to improve productive qualities) and fast-ripening meat breed (in order to increase the adaptive capacity of animals to natural and climatic conditions of the farm). To conduct research we formed four groups according to the principle of pair-analogs: Group I – boars descendants of introductory crossbreeding, with a share of blood of the fast-ripening meat breed 25%, Group II – boars descendants of introductory crossbreeding, with a share of blood of the Finnish Landrace breed 25%, Group III – boars descendants of introductory crossbreeding, with a share of blood of the fast-ripening meat breed 50%, Group IV – boars descendants of introductory crossbreeding, with a share of blood of the Finnish Landrace breed 50%. Data on genotype were taken from breeding and zootechnical records. All animals were bred under traditional conditions and kept on the same farm with the same staff.

Boars of all genetic groups received the same diet composition under the same conditions. The rations of animals used in the experiment were formulated in such a way as to meet the required norms taking into account age and live weight. Feeding type was concentrate with the use of self-produced fodder. The animals were kept free-range.

We evaluated boar development indicators (live weight, body length, age at 100 kg live weight, thickness of the rump) and indicators characterizing reproductive capacity (number of inseminated and farrowed sows, fertilizing capacity of the boar, multiple fertility of farrowed sows, weight of one piglet at weaning at 45 days, weight of one piglet at weaning at 45 days).

The obtained results of the study were processed biometrically using the package of applied computer programs “Statistika-10”.

Results

In order to determine the possibility of predicting the indicators that determine the reproductive traits of breeding boars, we initially studied the effect of different variants of introductory crossbreeding on animal development indicators in this study. The obtained results of boars of Poltava meat breed of different genotypes are shown in Table 1.

As a result of the study it was found that in boars of Poltava meat breed of all examined groups the obtained average values of live weight and body length did not differ significantly from each other.

The infusion of Finnish Landrace blood in breeding boars caused an increase in the age of reaching a live weight of 100 kg. Thus, the increase in the animals’ blood share from 25% to 50% led to a reliable increase in the index by 3.55 days or 1.8% ($p \leq 0.05$). In comparison with the group-analog of 50% blood on the breed, the meat index of boars with Finnish Ladras blood was also significantly higher by 6.67 days or 3.3% ($p \leq 0.05$).

With the increase in the proportion of blood from 25% to 50%, the thickness of the rump increased significantly by 0.45 mm or 1.9% ($p \leq 0.05$). No significant change in this indicator was observed in boars with Finnish Landrace blood. At the same time, groups with different breed variants, but the same proportion of blood, also did not differ significantly from each other in terms of the thickness of the rump.

Table 1.

Development indicators of boars of Poltava meat breed of different genotypes, (M±m)

Indicator	Boars with the blood of the early maturing meat breed of 25% bloodlines (I group) (n=12)	Boars with Finnish Landrace blood of 25% bloodlines (II group) (n=10)	Boars with 50% blood of fast-growing beef breed (III group) (n=13)	Boars with Finnish Landrace blood of 50% bloodlines (IV group) (n=5)
Live mass, kg	297.5±0.7	296.1±1.44	290.89±3.33	296.5±2.22
Lim (R)	294-300 (6)	293-306 (13)	291-325 (34)	293-303 (10)
Cv,%	0.98	1.54	4.03	1.49
Body length, sm	183.75±0,46	183.1±0,41	183.84±0.71	183.25±0.95
Lim (R)	182-186 (4)	182-186 (4)	181-189 (8)	182-186 (4)
Cv,%	0.88	0.7	1.4	1.03
Age when reaching 100 kg of live mass, days	199.75±0,77	202.2±0.99	199.08±1.32	205.75±0.25•*
Lim (R)	194-204 (10)	199-206 (7)	189-205 (16)	205-206 (1)
Cv,%	1.49	1.54	2.4	0.2
Speck thickness, mm	23,17±0,11	23.4±0.16	23.62±0.14 *	23.75±0.25
Lim (R)	23-24 (1)	23-24 (1)	23-24 (1)	23-24 (1)
Cv,%	1.68	2.21	2.14	2.1

Here and further: * – probability of difference between groups with bloodlines of 25% and 50 % $p \leq 0.05$;

• – probability of difference between groups with the same bloodlines $p \leq 0.05$.

Very low values characterizing the variability of developmental indices are noteworthy. Low variability values may indicate a strong selection pressure when breeding for these traits. Within the groups, the variability of traits was the highest in boars with blood of the fast-ripening meat breed with a blood share of 50%, as evidenced by the established range of variability of traits and the coefficient of variation.

The data obtained when analyzing reproductive performance of breeding boars of Poltava meat breed of different variants of introductory crossbreeding are shown in Table 2.

Table 2.

Indicators of reproductive qualities of boars of Poltava meat breed of different genotypes, (M±m)

Indicator	Boars with the blood of the early maturing meat breed of 25% blood-lines (I group) (n=12)	Boars with Finnish Landrace blood of 25% bloodlines (II group) (n=10)	Boars with 50% blood of fast-growing beef breed (III group) (n=13)	Boars with Finnish Landrace blood of 50% bloodlines (IV group) (n=5)
Inseminated sows, animals	22.75±2.65	22.3±3.61	32.46±4.45	11.5±3.88•
Lim (R)	3-36 (33)	6-38 (32)	11-60 (49)	6-23 (17)
Cv,%	40.43	51.17	49.41	67.57
Sows farrowed, animals	13.92±1.69	14.3±2.28	23.77±3.05*	8.0±2.97•
Lim (R)	5-23 (18)	3-24 (21)	10-42 (32)	3-16 (13)
Cv,%	42.17	50.42	46.23	74.25
Fertility of the boar, %	62.78±4.66	65.07±5.05	76.27±2.69*	68.44±12.77
Lim (R)	34.48-90.9 (56.42)	37.5-100 (62.5)	64.29-90.9 (26.61)	37.5-100 (62.5)
Cv,%	25.72	24.56	12.7	37.34
Multiple fertility of farrowing sows, animals	11.14±0.12	11.09±0.13	10.91±0.01	11.08±0.23
Lim (R)	10.4-11.7 (1.3)	10.7-11.9 (1.2)	10.3-11.4 (1.1)	10.7-11.7 (1,0)
Cv,%	3.83	3.69	3.14	4.06
Nest weight at weaning at 45 days of age, kg	119.83±1.37	125.2±3.9	120.46±2.7	130.85±8.5
Lim (R)	112-126 (14)	105-142 (37)	105-133 (28)	105-142 (37)
Cv,%	3.96	9.84	8.09	13.07
Weight of one piglet at weaning at 45 days of age, kg	12.03±0.09	12.66±0.54	12.14±0.32	13.68±1.15
Lim (R)	11.6-12.6 (1)	10.3-15.5 (2.2)	10.5-14.1 (36)	10.3-15.5 (5.2)
Cv,%	2.66	13.59	9.55	16.89

The study revealed that the use of introductory crossbreeding using 25% bloodlines for the two improving breeds did not cause significant changes in the average number of sows inseminated and interviewed. Increasing the proportion of bloodlines up to 50% resulted in multidirectional significant differences depending on the breeds used. Thus, the use of Finnish Landrace breed decreased the value of both studied indicators by 20.96 head (64.6%) ($p \leq 0.05$) and 15.77 head (66.4%) ($p \leq 0.05$), respectively.

When the proportion of bloodlines of the fast-ripening meat breed increased from 25% to 50%, boars showed a significant increase in the number of farrowing sows by 9.85 head or 41.5% ($p \leq 0.05$). This group also showed the highest value of fertilizing ability of boars. The difference amounted to 13.49% ($p \leq 0.05$) compared to the group with lower bloodlines. No significant differences were found in groups with Finnish Landrace blood for this indicator.

We did not observe a significant effect of boar genotype on the mean values of multiple births of farrowing sows, nest weight at weaning at 45 days of age, and weight of one piglet at weaning at 45 days of age, as no significant difference was observed in these values among groups with different variants of introductory crossbreeding.

It was found that the average number of sows inseminated and polled was not homogeneous and showed the highest genetic diversity (based on Cv and Lim values) among all reproductive parameters considered. The multiple fertility of farrowing sows was characterized by the lowest level of variation.

It should also be noted that boars with Finnish Landrace blood have the highest values of trait variability in reproductive parameters.

During the correlation analysis we noted reliable interrelations between the development and reproduction indicators in boars of Poltava meat breed of different variants of introductory crossbreeding. Thus, the thickness of the boars' fat had a significant effect on their fertilizing ability ($r=0.37$ at $p \leq 0.05$), the age of reaching a live weight of 100 kg was significantly correlated with the number of inseminated sows ($r=-0.62$ at $p \leq 0.001$) and the number of farrowed sows ($r=-0.59$ at $p \leq 0.001$).

Discussion

Boars have a critical influence on the progress of adoption in pig genetics and reproduction. Numerous studies indicate that both boar-dependent and boar-independent factors influence performance. However, the reproductive traits of the animals depend strictly on the effects of their interactions. [19]. At the same time, there is no doubt that the genotype of breeding boars is a factor determining their reproductive performance and longevity [20].

The presented results indicate that different variants of introductory crossbreeding used in the farm have an impact on reproductive performance, which in turn is interrelated with developmental performance. We have previously obtained similar results in a study of sows [21].

Conducting studies of the influence of the used breed in variants of introductory crossbreeding, we found that the infusion of blood of Finnish Landrace breed did not lead to improvement of boars' development indicators, but, on the contrary, significantly increased in these natural-climatic and economic conditions the indicator of the age of reaching the live weight of 100 kg, which can be considered as a strain of adaptation and adaptive mechanisms of the animal organism. At the same time, the established low values of variability of the trait indicate that among these individuals it is practically impossible to select animals with the optimal period of reaching the live weight of 100 kg, especially with an increased value of blood. The established negative correlation of this indicator of development with reproductive indicators gives grounds to confirm the deterioration of reproductive indicators as a violation of adaptive capabilities when carrying out breeding measures to improve productivity.

The data of our study indicate that the increase in meat qualities of Poltava beef boars using different variants of Finnish Landrace bloodlines leads to deterioration of some reproductive parameters and to an increase in their variability (especially with a blood share of 50%). "Instability" of adaptation mechanisms in animals of this group was also manifested by high variability of reproductive indicators, which can be considered as an increased response of the organism to the 'load of the environment'.

The infusion of the blood of the fast-ripening meat breed in order to increase the adaptive qualities of the Poltava meat breed and increasing the share of its bloodline up to 50% led to a reliable increase in reproductive indicators (the number of inseminated sows, the number of farrowing sows, the fertilizing ability of the boar), not related to the primary in the breeding process, but determining, among other things, the efficiency of the pig breeding industry.

In the indicators of development, the use of blood of the early maturing meat breed was reflected in the indicator of the thickness of the speck. We found a significant increase in fat thickness with increasing bloodlines of the fast-ripening beef breed. Earlier studies have clearly shown that increased fat thickness can have a favorable effect on reproductive performance [22]. Our study also demonstrated a significant effect of rump thickness on the fertilizing ability of boars. Taking into account that an increase in the thickness of the rump can be considered as an increase in the protective properties of the skin, it gives us the opportunity to talk about the increase in the protective and adaptive (adaptive) capabilities of the organism in this case.

In addition, the observed lower values of variability of parameters in boars with blood of the fast-maturing meat breed may indicate their greater stability in these breeding conditions.

Conclusion

The analysis of the use of breeding boars in combination with different genotypes, studied in this study, can be of great importance for the optimal direction of breeding work not only with the Poltava meat breed, but also with the fast-ripening meat breed and Finnish Landrace breed. We have established that the use of different variants of introductory crossbreeding in breeding boars of Poltava meat breed with the use of blood of soon-to-be-matured meat breed and Finnish Landrace breed leads to changes in reproductive indicators, interrelated with developmental indicators and may reflect the processes of adaptation of animals. The purposes of using introductory crossbreeding, in this case, determine the dynamics of changes.

Infusion of Finnish Landrace blood in order to improve meat qualities leads in boars of Poltava meat breed to a violation of adaptive capabilities, manifested in an increase in the age of achieving a live weight of 100 kg and a decrease in reproductive performance, not actively involved in the selection process. Increasing the level of bloodlines of breeding boars up to 50% for Finnish Landrace breed is not reasonable in these natural and climatic conditions and will require additional costs to improve efficiency.

The infusion of blood of the soon-ripening meat breed to boars of the Poltava meat breed with the purpose of improvement of adaptive qualities leads to strengthening of adaptive properties of an organism, by means of increase of protective possibilities and increase of reproductive indicators

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

RHEOLOGY OF HETEROGENEOUS FOOD SYSTEMS ON THE BASIS OF BIOPOLYMERS

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Abstract

Background. Problem of transformation of complex food systems is incompletely solved. In the framework of this problem, the incompletely solved problem of three-dimensional structure of proteids, including collagen, takes place. In this regard, the authors propose solutions of this problem basing on the study of structural rheological properties of polydisperse heterogeneous systems on the basis of natural intentionally modified biopolymers, incl. their microstructures. The rotational viscometry and analysis of images obtained with the scanning electron microscopy have been used as test methods. As a result, dependencies of the dynamic viscosity from the speed rate of the shear deformation have been obtained. They have shown relatively regular changes of the viscosity indicators. Data from the electronic microscopy let us to diagnose the structure of raw material and specially prepared semi-finished product, dominated by biopolymers, for further processing in industries.

Purpose. Taking into account the problem urgency, introduced in the first part of the article, we have stated the characteristic dependence between the dynamic viscosity of the typical polymer solution – alginate (semi-finished product for artificial caviar production) and shear deformation speed rate.

Materials and methods. The directions of solving the issue of microstructure and properties of biopolymers from different groups are actualized. In particular, biopolymers of alginate type and proteins from the collagen group have been investigated.

The peculiarities of the denaturation of native proteins cause the necessity of their further study (analysis of the initial architectonics of molecules, their changes under chemical and/or thermal influences) in the preparation of raw materials for the product manufacturing, feeds, etc. The general orientation of process organization is to avoid denaturation transformations.

However, treatment in media with the adjustable pH level is expected. The example is the treatment with electrolyte solutions (OH^-), which weakens the complex of cross-links, which causes some disturbance of the original histological structure of tissues, but does not lead to denaturation, preserving in general the molecular structure of the main structural molecular units (chains) of proteids.

Results. The first section of the rheogram, the "difficulty" of the system shear and then, a relatively uniform course of the graph, which may indicate that this solution is "stabilized" by structural agents based on natural biopolymers. The approximation reliability coefficient R2 = 0.98 demonstrates a high approximation of the trend line to the exponential model of the equation.

It is worth to mention the study by E.Yu. Agarkova et.al. which made it possible to reveal the exponential dependence between dynamic viscosity of polydisperse milk-based food systems depending on the mass fraction of psyllium in them. The obtained rheograms revealed nonlinear and non-additive dependences between viscosity and psyllium content in them.

Enhancing our own results, we have pointed out that the composition of the studied Collagen brand supplements also includes color-forming and flavor-forming additives. Comparative analysis of rheological data is hampered by the lack of publications in domestic sources. There is some information on mechanical parameters (e.g., the Young modulus, etc.) for protein hydrogels in foreign sources, F. Linglan. However, the elasticity modulus is used to characterize hydrogels.

It seems that these results are consistent with the studies of biopolymers by Hu Shiao et.al. [16], who revealed the special rheology of biopolymers with carbohydrate compartment. Thus, their thixotropic behavior was revealed.

Conclusion. The non-Newtonian flow character of biopolymer solutions can be characterized as visco-plastic, the properties of thixotropic medium were observed.

Based on the obtained results, the database on rational directions of processing of various biopolymers, which play, first of all, the role of structure formers, is being replenished. It is possible to combine these or those biopolymers in vitro with the purpose of further involvement in the production of food products and biologically active food additives.

The use of the combinatorics principles, more effective and functional food systems, will establish the compliance of the developed products with the principles of healthy nutrition. Especially it expands the possibilities of tissue repair from the group of supporting tissues, optimizes the functions of the gastrointestinal tract of humans and/or animals.

Thus, prospects for the food system development, creation of new feeds, materials for medical purposes, etc. are opened.

Keywords: food medium; viscosity; heterogeneous systems; proteins; biopolymers; feed purposes

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Научная статья

РЕОЛОГИЯ ГЕТЕРОГЕННЫХ ПИЩЕВЫХ СИСТЕМ НА ОСНОВЕ БИОПОЛИМЕРОВ

А.Ю. Соколов, Д.И. Шишкина, О.Г. Шепоткина

Аннотация

Обоснование. Проблема трансформации сложных пищевых систем является неполноценно решенной. В рамках этой проблемы имеет место не до конца решенная проблема трехмерной структуры белков, в том числе коллагена. В связи с этим авторы предлагают решение данной проблемы на основе изучения структурно-реологических свойств полидисперсных гетерогенных систем на основе природных намеренно модифицированных биополимеров, в том числе их микроструктур. В качестве методов исследования использованы ротационная вискозиметрия и анализ изображений, полученных с помощью сканирующей электронной микроскопии. В результате были получены зависимости динамической вязкости от скорости сдвиговой деформации. Они показали относительно регулярное изменение показателей вязкости. Данные электронной микроскопии позволяют диагностировать структуру сырья и специально подготовленного полуфабриката с преобладанием биополимеров для дальнейшей переработки в промышленности.

Цель. Учитывая актуальность проблемы, представленной в первой части статьи, нами была установлена характерная зависимость между динамической вязкостью раствора типичного полимера – альгината (полуфабриката для производства искусственной икры) и скоростью сдвиговой деформации.

Материалы и методы. Актуализированы направления решения вопроса о микроструктуре и свойствах биополимеров различных групп. В частности, исследованы биополимеры альгинатного типа и белки из группы коллагена.

Особенности денатурации нативных белков обуславливают необходимость их дальнейшего изучения (анализ исходной архитектоники молекул, их изменений при химических и/или термических воздействиях) при подготовке

сырья для производства продуктов, кормов и т.д. Общая направленность организации процесса заключается в том, чтобы избежать денатурационных превращений.

Однако предполагается обработка в средах с регулируемым уровнем pH. Примером может служить обработка растворами электролитов (OH^-), которые ослабляют комплекс поперечных связей, что вызывает некоторое нарушение исходной гистологической структуры тканей, но не приводит к денатурации, сохраняя в целом молекулярную структуру основных структурных молекулярных единиц (цепей) протеидов.

Результаты. Первый участок реограммы, «трудность» сдвига системы, а затем, относительно равномерный ход графика, что может свидетельствовать о том, что данный раствор «стабилизирован» структурообразователями на основе природных биополимеров. Коэффициент достоверности аппроксимации R2 = 0,98 свидетельствует о высокой степени приближения линии тренда к экспоненциальной модели уравнения.

Следует отметить исследование Е.Ю. Агарковой с соавторами, которое позволило выявить экспоненциальную зависимость динамической вязкости полидисперсных пищевых систем на основе молока от массовой доли псиллиума в них. Полученные реограммы выявили нелинейные и неаддитивные зависимости между вязкостью и содержанием в них псиллиума.

Усиливая собственные результаты, мы указали, что в состав исследуемых добавок марки «Коллаген» также входят цветообразующие и вкусообразующие добавки. Сравнительный анализ реологических данных затруднен отсутствием публикаций в отечественных источниках. Некоторая информация о механических параметрах (например, модуль Юнга и др.) для белковых гидрогелей есть в зарубежных источниках, Ф. Линглан. Однако для характеристики гидрогелей используется модуль упругости.

Эти результаты согласуются с исследованиями биополимеров, проведенными Ху Шиао и соавт., которые выявили особую реологию биополимеров с углеводным компартментом. Так, было выявлено их тиксотропное поведение.

Заключение. Неньютоновский характер течения растворов биополимеров можно охарактеризовать как вязко-пластический, наблюдались свойства тиксотропной среды.

На основании полученных результатов пополняется база данных по рациональным направлениям переработки различных биополимеров, играющих, прежде всего, роль структурообразователей. Возможна комбинация тех или иных биополимеров in vitro с целью дальнейшего вовлечения в производство пищевых продуктов и биологически активных добавок к пище.

Использование принципов комбинаторики, более эффективных и функциональных пищевых систем, позволит установить соответствие разрабатываемых продуктов принципам здорового питания. Особенно это расширяет возможности восстановления тканей из группы опорных тканей, оптимизирует функции желудочно-кишечного тракта человека и/или животных.

Таким образом, открываются перспективы для развития системы питания, создания новых кормов, материалов медицинского назначения и т.д.

Ключевые слова: пищевая среда; вязкость; гетерогенные системы; белки; биополимеры; кормовые цели

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Introduction

Problem of transformation of complex food systems is incompletely solved. In the framework of this problem, the incompletely solved problem of three-dimensional structure of proteids, including collagen, takes place. In this regard, the authors propose solutions of this problem basing on the study of structural rheological properties of polydisperse heterogeneous systems on the basis of natural intentionally modified biopolymers, incl. their microstructures. The rotational viscometry and analysis of images obtained with the scanning electron microscopy have been used as test methods. As a result, dependencies of the dynamic viscosity from the speed rate of the shear deformation have been obtained. They have shown relatively regular changes of the viscosity indicators. Data from the electronic microscopy let us to diagnose the structure of raw material and specially prepared semi-finished product, dominated by biopolymers, for further processing in industries.

Purpose. The protein issue is not completely solved both in Russian and foreign science. There are questions about heterogeneous in structure and properties food systems. In some sources they are called polydisperse, for instance, in works by E.Yu. Agarkov and others [2]. In particular, the work by Yu.F. Shutilin [8] is devoted to the issue of biopolymer study. The key contribution into the formation of properties and physical-structural features of biopolymers is made mostly by protein substances, glycosaminoglycans, etc.

In particular, authors A. Ed-Daoui et. al. [9] studied features of the process of agarose dissolution – biopolymer extracted from algae. Gel with variable stiffness emerges from this polymer. It serves as a basis for food industry

products, pharmaceutical preparations. Rheological properties of this gel have shown the elastic microscopic behavior. Moreover, in order to understand the value of hydrogen bonds in the gel formation, we have measured the entropy of different modified agarose variants.

Materials and methods

The protein issue is not completely solved both in Russian and foreign science. There are questions about heterogeneous in structure and properties food systems. In some sources they are called polydisperse, for instance, in works by E.Yu. Agarkov and others [2]. In particular, the work by Yu.F. Shutilin [8] is devoted to the issue of biopolymer study. The key contribution into the formation of properties and physical-structural features of biopolymers is made mostly by protein substances, glycosaminoglycans, etc.

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The work by A.L. Ishevskiy is devoted the investigation of the alginate properties and their application in the food industry [7].

Such systems as protein, soybean have been sufficiently studied. They are able to form "dynamic" bases of disperse systems by K. N. Garrity [14].

Processes like lyophilization have facilitated formation of gelatin bases of disperse media according to V. Peres-Puyana [15].

The methods for studying complex systems from protein mixes, including mucoids or cellulose derivatives, have been formed by Akkermans C. [18], Juan-Carlos Arboleya [19]. Features of adsorption of protein with methyl cellulose and other polysaccharides have been found out in some works by J.-C. Arboleya [19].

The protein mix, activating the gel-forming process, has been analyzed by N. Yuno-Ohta [17].

The active investigation of biopolymers, their composition, has become the theoretic base for own developments in the sphere of the smart use of biopolymers.

While developing our own model food systems on the basis of biopolymers, in particular proteins, it is preferred to take into account pieces of information about other biopolymers similar in their structural-mechanical and microstructural properties, including derivatives of agarose, proteins (hydrolysed), etc.

As biopolymers serve as the base for creating products of "molecular gastronomy" or as thickeners-structure formers.

Conjecturally, the systems, incl. food ones responsible for the unified concept of manufacturing products of the given quality and safety level, can be developed from raw materials or waste heterogeneous in their structure and properties.

The present work uses methods of rheological tests, in particular, the rotational viscometry and microstructural image analysis; the images have been obtained through the method of the scanning electron microscopy (SEM) [1; 3].

Results

Taking into account problem urgency, introduced in the first part of the article, we have stated the characteristic dependence between the dynamic viscosity of the typical polymer solution – alginate (semi-finished product for artificial caviar production) and shear deformation speed rate (Fig. 1).

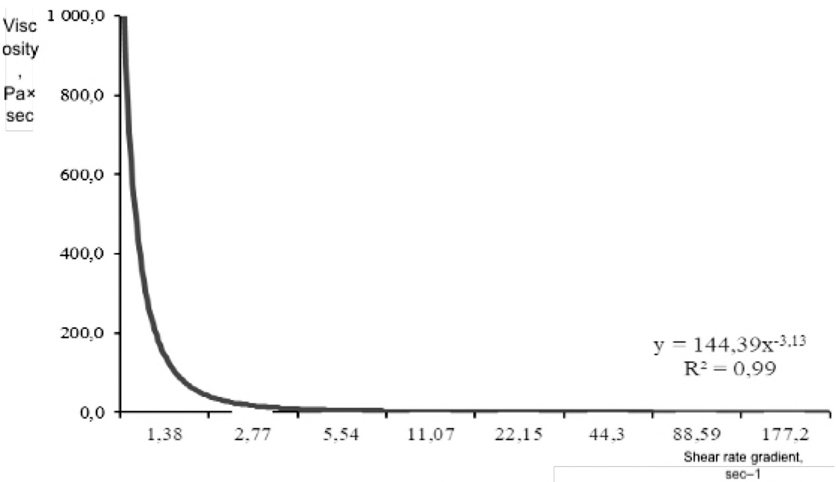


Fig. 1. Rheogram of the colloidal solution on the basis of alginate (Ca) with 20% mass fraction

On the basis of the analysis of Fig.1, it is obvious that the graphical dependency is of the power character which can attest to the specificity of the rheological behavior of the biopolymer solution that refer to the group of non-Newtonian fluids (seemingly, thixotropic) with the sharp viscosity decline under increase in the shear velocity in the rotational viscometry from 914.0 to 2.0 Pa×sec, when there is the increase in the shear velocity from 1.38 to 2.77 sec^{-1}. For food media it important to study viscosity properties during the heat treatment process. However, this issue is beyond the scope of the present article.

It seems that the texture of products may be non-uniform, formed according to the principal of the biopolymer layering. It has been revealed during the analysis of the histologic images. In this regard, probably, the directional modification of biopolymer properties of the alginate group by means of the addition of other related biopolymers [4; 5].

In order to use different polymers in combination, we will consider further collagen-containing raw materials representing a reach source of protein of collagen, elastin, keratin and other groups. These proteins account for at least one-third of the total mass of the raw sample of raw materials. In the raw condition, protein preparations contain protein on the concentration 80.0-90.0% which distinguishes them from other raw materials.

The directions in which they are used vary. In particular, food direction is in priority. In this case, collagens are considered to be a necessary part in healthy diet as a biologically active supplement, A.P. Korzh, Yu.G. Bazarnova [5].

When utilize raw material of the food industry rationally, including side-products, forming along with the main ones, the optimized methods of their preparation and processing into different products are necessary. So, raw materials, being a thick connective tissue, includes elementary fibers which are stronger than steel wire of equal cross-section. They represent a coarse substance with high mechanical strength, hence, the high textural properties of products, incl. gelled, structured products.

In order to transform it into an acceptable one in terms of structural, mechanical and chemical properties, it is necessary to apply a pre-treatment consisting mainly in chemical or, less frequently, biochemical action on the initial substrate, which is reflected in Fig. 2.

For economic and technological reasons, it is easier and cheaper to apply treatment in solutions with the adjustable pH value, which provide practical use of swelling maxima, reducing the energy of the complex of chemical bonds, for example, hydrogen bonds, which are considered a type of electrostatic, having donor-acceptor nature (N.D. Sokolov. Hydrogen bonding. – M. Publishing House: Nauka). This type of bonds is divided into weak and strong bonds. Without going into details of chemical interactions, we would like to note that in general the non-compliance of side-product raw materials, formed during slaughtering, primary processing of connective tissue, hides, etc., with the requirements for food systems.

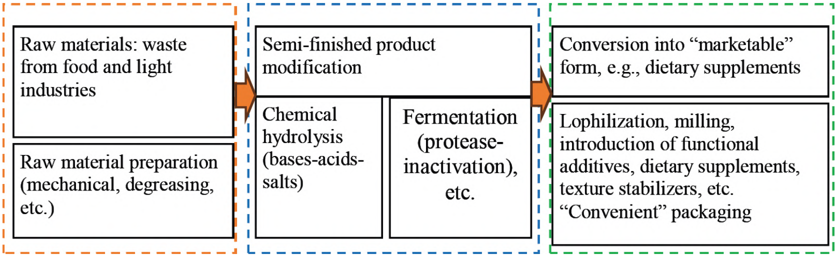
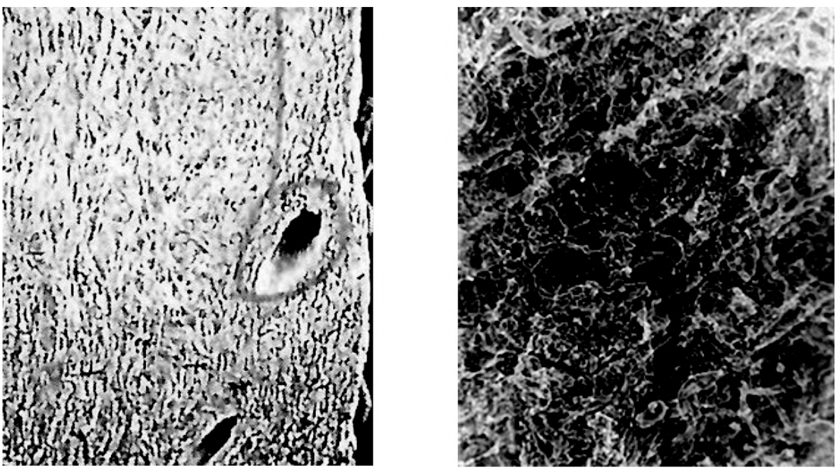


Fig. 2. Block-modular scheme for conversion of raw materials or side-products into protein-based dietary supplements

Specifically, basing on the image analysis introduced in the Fig. 3, the texture features of the raw material and produced from it modified products, referring to the class of protein stabilizing systems, become clear. The modification is performed using the chemical method (Fig. 2).



a b

Fig. 3. Histological structure *a*) pork skin (K. Yoshimura et.al.); *b*) protein modified stabilizing system obtained from the collagen-containing pork raw material, author’s photo (the SEM method, amplification ≈ 600×)

The initial structure has a quite thick microstructure arrangement due to the tightly interwoven collagen compartments. It is hard to trace the course of individual fibers but analysis of a number of histological images reveals transverse weaves, loop structures, and parallel bundles. The nature of fiber interlacing is related to the topography of the raw material. However, its investigation is beyond the scope of this paper.

The structural characteristic of hair follicles, causing the heterogeneity of raw material structures, can be mentioned. On the other hand, the presence of pores can positively affect the hydrophilic properties of raw materials, enhancing their moisture-binding capacity and other technological properties. The obtained data are in general agreement with the results of the work by E. V. Litvinova et. al [11].

Modification in media with the adjustable pH level allows, at pH 12-14, to break strong, including intermolecular, bonds quite effectively and to give a higher level of technological properties to the prepared raw material. As it is known from the experience of Russian and foreign science, proteid fibers are aggregated due to chemical cross-links forming essentially the 3D mesh. Further, the solubility of protein structures depends on the degree of crystallinity of key sub-fibrillar units of the molecular structure of proteins. Sub-fibrils (size <50 nm) can be detected by electron microscopy.

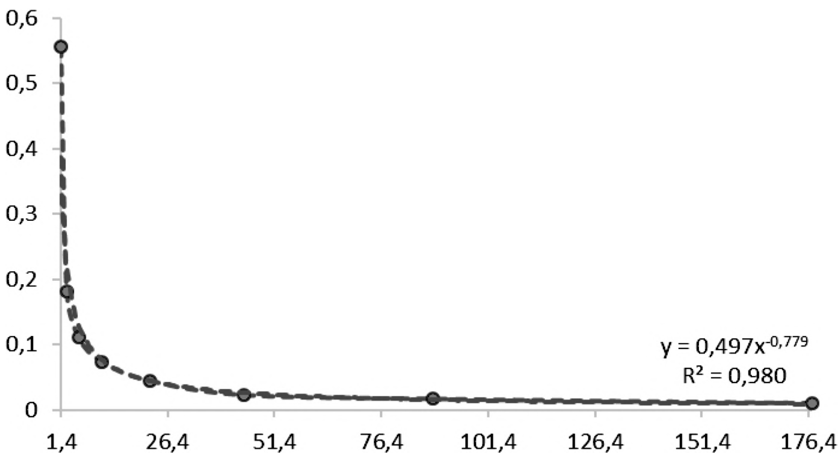


Fig. 4. Rheogram of beef collagen hydrolysate solution (Collagen supplement), dry matter concentration about 20%

The main principle of obtaining commercial products from collagen-containing raw materials is directed hydrolysis at the optimized pH. It allows to obtain dissolution products forming a solution close to the idealized one. In particular, hydrolysate of beef connective tissue protein forms the solution, which is convenient for taking as a biologically active food supplement. Its rheogram is presented in Fig. 4.

The first section of the rheogram, the “difficulty” of the system shear and then, a relatively uniform course of the graph, which may indicate that this solution is “stabilized” by structural agents based on natural biopolymers. The approximation reliability coefficient $R^2 = 0.98$ demonstrates a high approximation of the trend line to the exponential model of the equation.

Discussion

It is worth to mention the study by E.Yu. Agarkova et.al. [2] which made it possible to reveal the exponential dependence between dynamic viscosity of polydisperse milk-based food systems depending on the mass fraction of psyllium in them. The obtained rheograms revealed nonlinear and non-additive dependences between viscosity and psyllium content in them.

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It seems that these results are consistent with the studies of biopolymers by Hu Shiao et.al. [16], who revealed the special rheology of biopolymers with carbohydrate compartment. Thus, their thixotropic behavior was revealed. For pullulan, Newtonian viscosity was observed even at its content of 20%, which provides a basis for application in industries, particularly in food.

In the monograph by S.A. Muslov et.al. [4] presented visco-elastic properties of leather by various mechanical methods, and the results (ultimate strength, the Young modulus, etc.) have been processed using polynomial mathematical models.

Skin properties are determined by the indices of collagen, elastin fibers and intercellular substance. Thus, “stiff” fibers that significantly improve the skin mechanical performance are highlighted. In this case, protein composites are intended for biomedical applications.

During modification in one way or another, the intercellular substance fractions are washed out and it is possible to realize the potential of rheological and textural properties of the fibrous framework of the obtained products.

Conclusion

The directions of solving the issue of microstructure and properties of biopolymers from different groups are actualized.

In particular, biopolymers of alginate type and proteins from the collagen group have been investigated.

The peculiarities of the denaturation of native proteins cause the necessity of their further study (analysis of the initial architectonics of molecules, their changes under chemical and/or thermal influences) in the preparation of raw materials for the product manufacturing, feeds, etc. The general orientation of process organization is to avoid denaturation transformations.

However, treatment in media with the adjustable pH level is expected. The example is the treatment with electrolyte solutions (OH-), which weakens the complex of cross-links, which causes some disturbance of the original histological structure of tissues, but does not lead to denaturation, preserving in general the molecular structure of the main structural molecular units (chains) of proteids.

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The use of the combinatorics principles, more effective and functional food systems, will establish the compliance of the developed products with the principles of healthy nutrition. Especially it expands the possibilities of tissue repair from the group of supporting tissues, optimizes the functions of the gastrointestinal tract of humans and/or animals.

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Original article

FORMATION OF POPULAR RURAL TOURISM PRODUCTS FOR STUDENT GROUPS

A.V. Miroshnichenko, L.N. Kazmina, V.S. Makarenko

Abstract

This study examines the prospects for developing rural tourism with a specific focus on student groups

Purpose. The goal of the study is to identify potential directions for the development of this type of tourism in regions with sufficient specialized resources based on an analysis of the specifics of the formation of popular rural tourism products for student groups.

Materials and methods. The research is based on research by Russian and international authors in the field of rural tourism and its infrastructure, particularly from a regional perspective. The authors utilized comparative, resource-based, and descriptive analysis methods.

Results. The research provides a comprehensive assessment of the tourism and recreational potential of the region's western districts, identifying key attractions that integrate cultural-historical heritage, natural landmarks, and elements of ethnographic tourism. Particular emphasis is placed on the potential for aligning tourism initiatives with higher education curricula. The authors have designed and substantiated three thematic routes tailored to the unique demands of student tourism while accounting for the geographical distribution of key sites. A collaborative framework is proposed, involving educational institutions, tour operators, and local communities to ensure the effective implementation of rural tourism projects

Conclusion. The findings highlight that advancing this sector not only enhances educational opportunities for students but also stimulates economic growth in rural areas. The results hold practical significance for shaping regional tourism development strategies and can be adapted to other regions of the Russian Federation with similar potential.

Keywords: rural tourism; student groups; route planning; national interests; development prospects

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Научная статья

ФОРМИРОВАНИЕ ПОПУЛЯРНЫХ ПРОДУКТОВ СЕЛЬСКОГО ТУРИЗМА ДЛЯ СТУДЕНЧЕСКИХ ГРУПП

А.В. Мирошниченко, Л.Н. Казьмина, В.С. Казьмина

Аннотация

В настоящем исследовании рассматриваются перспективы развития сельского туризма с особым акцентом на студенческие группы.

Цель. Цель исследования – на основе анализа специфики формирования популярных продуктов сельского туризма для студенческих групп определить потенциальные направления развития данного вида туризма в регионах, обладающих достаточным объемом профильных ресурсов.

Материалы и методы. В качестве опорных используются материалов исследований российских и зарубежных авторов в области сельского туризма, его инфраструктуры, особенно с позиций региональной специфики. Авторами использовались методы сравнительного анализа, ресурсный, описательный. перспективный

Результаты. В исследовании дана комплексная оценка туристско-рекреационного потенциала западных районов региона, выявлены ключевые достопримечательности, сочетающие в себе культурно-историческое наследие, природные памятники и элементы этнографического туризма. Особое внимание уделяется возможности согласования туристических инициатив с учебными программами высших учебных заведений.

Авторы разработали и обосновали три тематических маршрута, адаптированных к уникальным потребностям студенческого туризма с учетом географического распределения ключевых объектов. Предлагается схема сотрудничества с участием образовательных учреждений, туроператоров и местных сообществ для обеспечения эффективной реализации проектов в области сельского туризма.

Заключение. Результаты исследования показывают, что развитие этого сектора не только расширяет образовательные возможности студентов, но и стимулирует экономический рост в сельской местности и имеют практическое значение для формирования региональных стратегий развития туризма и могут быть адаптированы к другим регионам Российской Федерации с аналогичным потенциалом.

Ключевые слова: сельский туризм; студенческие группы; планирование маршрутов; национальные интересы; перспективы развития

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Introduction

Contemporary tourism trends reveal growing interest in niche forms of travel, with rural tourism emerging as a particularly noteworthy sector. This tourism modality not only fosters cultural preservation and supports local economies but also creates novel opportunities for educational and recreational travel, aligning with the objectives of Russia's Tourism Development Strategy through 2035. Many regions, endowed with substantial natural and cultural-historical assets, present particularly favourable conditions for developing student-oriented rural tourism programs.

The study's relevance stems from the need to examine specialized approaches to tourism organization catering to specific demographic segments. Student travelers constitute a distinct category with unique demands for programs blending cognitive, recreational, and pedagogical elements. Consequently, tailored rural itineraries may serve as an effective mechanism for engaging younger generations in regional tourism.

It's important to consider the specific characteristics of each region, not only in terms of its tourism resources, but also its associated infrastructure, transportation links, hotels, restaurants, souvenir shops, tourist information centres, and more. All of these elements, when combined together, represent a systemic combination conducive to the development of rural tourism.

A critical consideration involves integrating rural tourism products into university curricula. Modern educational standards emphasizing practice-oriented learning create favourable conditions for incorporating travel components into academic programs. Specialized student itineraries could enhance professional competencies while broadening knowledge in regional history, geography, and economic studies.

This investigation of rural route development for student groups represents a timely research-practical challenge requiring interdisciplinary methodology combining: territorial tourism potential assessment, target audience needs analysis, and methodological route organization guidelines. Successful implementation promises significant contributions to both regional tourism and educational sectors.

The study's primary objectives include:

- Systematic review of existing research on regional rural tourism development;
- Evaluation of territory for student-focused rural route development;
- Identification of promising rural tourism zones with implementation recommendations.

The research employs comparative analysis of Rostov's districts, statistical evaluation of tourism resource distribution, and prospective methods for route development assessment. Findings aim to inform policy decisions and practical implementations in this emerging tourism sector.

Purpose. The goal of the study is to identify potential directions for the development of this type of tourism in regions with sufficient specialized resources based on an analysis of the specifics of the formation of popular rural tourism products for student groups.

In accordance with the stated goal, the following tasks were accomplished:

- analysis of sources on the research topic;
- study of the specifics of rural tourism product development;
- identification of route features for student groups;
- determination of promising areas for the development of rural tourism for students.

Materials and methods

The tourism sector currently demonstrates sustained growth in rural tourism, which has emerged as a significant driver of economic and social development for regional territories. This form of tourism uniquely combines recreational opportunities with the preservation of natural and cultural heritage, particularly valuable for regions possessing rich traditions and distinctive landscapes.

Modern scientific thought increasingly turns to the study of rural tourism as an important element of sustainable development of territories. As Evgrafova [1] emphasizes, this type of tourism organically combines economic efficiency with the preservation of natural and cultural heritage. Research by Back [2] and Farsani [3] indicates a steady growth in global interest in this area, which opens up new prospects for many regions.

The economic potential of rural tourism is manifested in its ability to stimulate the development of rural areas. As Barbieri [4] and Sotomayor [5] note, this sector creates a multiplier effect for the local economy. At the same time, according to research by Sueb [6], Choo [7] and Li [8], the successful development of this area requires careful consideration of infrastructure issues, including the creation of specialized accommodation facilities.

An important feature of scientific research in this area is the consideration of regional specifics. Karampela [12], Li [13] and Dewanti [14] emphasize the need to develop adapted assessment methods. Of particular scientific interest are the works of Lanfranchi [16] and Sidali [17], devoted to the study of factors of tourist satisfaction.

Marketing aspects of rural tourism development are considered in their works by Liang [18] and Vikhoreva [19]. At the same time, as Ispas [20] and Kazmina [21] note, the environmental component remains the key principle of organizing tourism activities in rural areas.

As for the development of tourism specifically in the territory of the Don region, the works of Sukhov R. I., Kazmina, L., Makarenko, V., Provotorina, V., & Shevchenko, E., 2021 [22-24] were studied for its analysis. The presented studies analysed the key aspects influencing the development of rural tourism and assessed its tourism and recreational opportunities,

Methodological Framework.

The study employs a multifaceted methodological approach:

- Comparative analysis of rural tourism development across distinct districts of Rostov Region;
- Statistical evaluation of tourism resource distribution patterns;
- Descriptive analysis of contemporary trends in rural wine tourism;
- Prospective analysis of student-oriented rural tourism route development in Rostov Region.

This comprehensive methodology enables thorough examination of both current conditions and future potential for rural tourism development in the region, with particular emphasis on creating specialized offerings for student groups. The approach integrates quantitative and qualitative dimensions to provide robust insights into this emerging sector.

Results

Based on the research findings, a number of specific features in the formation of rural tours in the contemporary period can be identified, taking into account current trends. This evolution is characterized by a fundamental shift from standardized vacation packages to the creation of deeply personalized and immersive experiences. The modern rural tour is no longer merely an offering of accommodation in a countryside setting; it has transformed into a curated narrative that connects the urban dweller with a perceived authenticity and a slower, more meaningful pace of life.

A central feature of this transformation is the move towards hyper-localization and thematic specialization. Itineraries are increasingly built around a specific, compelling story unique to a particular locality. This transcends generic rural themes, focusing instead on distinct cultural codes, ancestral crafts, or specific agricultural products. For instance, a tour may be constructed not simply around a region, but around the journey of a local cheese variety, from the pasture to the table, interwoven with the stories of the shepherds and affineurs. This approach fosters a deeper emotional engagement and allows destinations to differentiate themselves in a competitive market.

Furthermore, the integration of the digital and the authentic has become a defining characteristic. Modern travellers, while seeking to disconnect from their urban routines, demand seamless digital accessibility for booking and information, and, crucially, they desire to document and share their experiences. Consequently, successful tour formation now inherently includes the provision of “shareable moments” – photogenic landscapes, hands-on workshops with local artisans, and aesthetically presented meals- that are optimized for social media.

Student group engagement should focus not only on existing rural tourism resources—farms and specialized areas - but also on activities such as master classes, tastings, participation in rural life, and interactive programs. Products focused on such activities can become a growth point not only for rural tourism but also for student travel, possibly with an educational focus.

Moreover, the most promising regions appear to be those with a combination of rural destinations and educational institutions, preferably agricultural ones, allowing for the integration of rural activities with educational programs. Among Russian regions, such a combination, thanks to its natural conditions, has developed in the south of Russia.

The analysis conducted revealed key patterns in the development of rural tourist products in the Rostov region, specifically designed for student groups. Emphasis was placed on evaluating the existing tourism and recreational potential of the area, including its natural, historical, cultural, and infrastructural aspects. The findings indicate substantial resources for advancing this sector, though their effective utilization demands a structured approach.

The study identified the most promising zones for creating specialized routes tailored to student tourism. Research demonstrated that the successful implementation of such projects relies on coordinated efforts between educational institutions, tour operators, and local communities. Of particular importance is the design of programs that integrate educational, hands-on, and recreational components.

Rural areas offer opportunities to incorporate museums, farms, archaeological sites, and other attractions. By contributing to local economic growth, these routes could serve as regional development catalysts.

The study focused on western districts of the region, including Kamensky, Belokalitvinsky, Tarasovsky, Millerovsky, Chertkovsky, Verkhnedonsky, and Sholokhovsky. These areas were selected partly due to their proximity to the federal highway M-4 “Don,” facilitating tourist accessibility.

Examining potential resources for student-oriented rural tourism in these districts reveals diverse opportunities.

In Chertkovsky District, attractions are primarily cultural and educational, such as the Chertkovsky Local History Museum, showcasing regional traditions, and the Museum of History and Daily Life in the village of Mankovo-Berezovskoye. Archaeological sites, including burial mounds, add historical value, while natural landmarks like the Chertkovskiye Peski Nature Reserve and Ploskaya Balka tract enhance ecological appeal.

Kamensky District also emphasizes heritage tourism, featuring the Kamensky Museum of Cossack Culture and the Folk History Museum in Gundorovskaya Stanitsa, which highlights local history and WWII events. The area is further enriched by archaeological remains and natural landmarks.

Belokalitvinsky District boasts notable cultural and natural sites, including the M.A. Sholokhov Historical Museum, an art gallery in Belaya Kalitva, and geological formations like the White Cliff and numerous caves.

Tarasovsky District offers the Tarasovsky History Museum, focusing on WWII and Cossack traditions, and the Museum of Military Glory honoring local hero V.A. Khalzunov. Ancient burial mounds serve as additional points of interest.

Millerovsky District features the Millerovo Museum of Local Lore, dedicated to WWII and agriculture, and the memorial house-museum of war hero A.M. Likholeto. The region also includes Cossack heritage sites, burial mounds, and natural attractions like the Kalitva River and Lake Lebyazhye.

Sholokhovsky District is distinguished by its cultural heritage, anchored by the M.A. Sholokhov Museum-Reserve and the reconstructed Cossack homestead in Kruzhilinsky.

Verkhnedonsky District presents the Museum of Upper Don History and Culture, archaeological sites, and the unique “Ostrovnoy Les” nature reserve – a forested island in the Don River.

These findings underscore the region's potential for developing immersive, educationally valuable tourism experiences for students.

Table 1.

Potential Rural Tourism Sites for Student Groups in the Studied Districts of Rostov Region

№	District	Attractions
1	Sholokhovsky	1. M.A. Sholokhov State Museum-Reserve (Veshenskaya Stanitsa). 2. Memorial-Historical Complex «Kruzhilinsky»: A recreated Cossack homestead. 3. Stud Farm housing Don breed horses (Veshenskaya Stanitsa).
2	Verkhnedonskoy	1. Museum of History and Culture of Verkhnedonskoy District (Kazanskaya Stanitsa). 2. Branches of the M.A. Sholokhov State Museum-Reserve. 3. Archaeological sites: Ancient burial mounds. 4. Natural landmark «Ostrovnoy Les» (near Kazanskaya Stanitsa): A unique forested island in the Don River.
3	Chertkovsky	1. Chertkovsky District Local History Museum (Chertkovo). 2. Museum of History and Daily Life in the village of Mankovo-Berezovskoye. 3. Nature Reserve «Chertkovskiye Peski»: A unique sandy steppe landscape. 4. Archaeological sites: Ancient burial mounds.
4	Millerovsky	1. Millerovsky District Local History Museum (Millerovo). 2. Museum of Cossack History (Malchevskaya Stanitsa). 3. Archaeological sites: Ancient burial mounds.
5	Tarasovsky	1. Tarasovsky Historical and Local Lore Museum (Tarasovsky settlement). 2. Archaeological sites: Ancient burial mounds.
6	Belokalitvinsky	1. M.A. Sholokhov Historical and Local Lore Museum (Belaya Kalitva). 2. White Cliff (near Belaya Kalitva): A limestone rock formation on the Kalitva River. 3. Caves (near Belaya Kalitva): A cave complex, including the «Skelya» Cave.
7	Kamensky	1. Kamensky Local History Museum (Kamensk-Shakhtinsky, administratively part of the city). 2. Folk Historical and Local Lore Museum in Gundorovskaya Stanitsa. 3. Archaeological sites: Burial mounds and ancient settlements.

The study of tourism sites across Rostov Region reveals distinct patterns in their recreational and cultural potential. The Sholokhovsky District stands out for its high density of historical and cultural landmarks, particularly those tied to the life and works of M.A. Sholokhov, alongside authentic Cossack ethnographic sites. A notable feature is the integration of museum-reserves with functional stud farms, offering a foundation for multifaceted tourism programs.

Natural and recreational assets are most prominent in the Verkhnedonskoy and Chertkovsky Districts. Unique landscapes such as the "Island Forest" and "Chertkovskiye Peski" sand steppe hold significant appeal for eco-tourism. The widespread presence of archaeological sites across the region further enhances opportunities for educational tourism, enriched by historical reenactments.

Spatial analysis highlights uneven distribution of attractions, necessitating tailored approaches to route development. Districts combining cultural-historical sites with natural wonders and ethnographic elements show the greatest promise for integrated tourism products. This synergy supports the creation of inter-district itineraries that blend diverse activities, from heritage exploration to outdoor recreation.

The research underscores Rostov Region's untapped potential for student-focused rural tourism. Findings reveal a wealth of cultural, historical, and natural resources suitable for designing immersive educational programs. Areas that merge museum complexes with living traditions and distinctive landscapes are particularly valuable, enabling thematic route diversification.

Implementing such initiatives demands a systematic framework attuned to student needs and the integration of tourism with academic objectives. Expanding rural tourism in the region could not only diversify offerings but also safeguard cultural heritage and stimulate local economies. Success hinges on collaboration between universities, tour operators, and communities to ensure sustainable development.

Discussion

For further development of tourism in rural areas for student groups, it seems rational to form rural products in the areas under study in areas largely provided with the appropriate tourist infrastructure. It is also possible to consider it optimal to lay one route through the territory of several neighbouring areas to increase the concentration of potential scientific objects in their content.

In Russia's regions, specialized clusters combining tourist destinations, infrastructure, and educational institutions should be targeted. Museums, which combine exhibition, research, and educational facilities, could serve as such.

These experiences could potentially be replicated across most of Russia's regions and serve as a catalyst for the development of a system of rural tourist products for student groups.

As a result, the authors proposed the following potential rural routes:

1. Kamensky Meridian: From History to Nature" (Kamensky District):

- Kamensky Local History Museum (Kamensk-Shakhtinsky);
- Folk History Museum in Gundorovskaya Stanitsa;
- Archaeological sites: Burial mounds and ancient settlements;
- Museum of Decorative Arts and Folk Crafts;
- Natural landmarks: Picturesque banks of the Seversky Donets River and steppe landscapes.

2."Belokalitvinskoe Heritage: Museums, Cliffs and Underground Worlds" (Belokalitvinsky District):

- M.A. Sholokhov Historical Museum (Belaya Kalitva);
- White Cliff limestone formation (Kalitva River banks);
- Cave complex including "Skelya" Cave;
- Seversky Donets River ecosystem;
- Local Art Gallery showcasing regional artists.

3."Don Crossroads: Millerovo, Chertkovo, Verkhnedonye - A Journey Through Time" (Multi-District):

- Millerovo Regional Museum;
- Cossack History Museum (Malchevskaya Stanitsa);
- Chertkovsky Local History Museum;
- "Chertkovskiye Peski" Sand Steppe Reserve;
- Verkhnedonskoy District Museum of History and Culture;
- M.A. Sholokhov Museum branches;
- Archaeological sites in Verkhnedonskoy;
- "Island Forest" nature reserve (Don River island).

The newly created rural itineraries for student groups highlight Rostov Region's substantial capacity for educational tourism. These routes stand out for their holistic design, seamlessly blending cultural heritage sites, natural wonders, and living ethnographic exhibits - offering students multidimensional learning opportunities about the region. A particularly valuable aspect is the integration of museum collections with functioning elements of traditional lifestyles, enabling hands-on educational experiences.

Beyond enriching student learning, these tourism circuits promise to boost economic activity in rural communities. Their successful implementation will depend on establishing productive partnerships between academic institutions, travel providers, and local residents, supported by well-designed educational materials. The routes' flexible structure allows customization for diverse academic disciplines and research initiatives, substantially enhancing their pedagogical value.

Conclusion

The conducted research allows us to draw a number of conclusions.

The developed rural products demonstrate the possibility of integrating educational and tourist components, which corresponds to modern trends in practice-oriented learning. Of particular value is the combination of museum complexes with existing elements of the traditional way of life, which allows creating comprehensive educational programs.

The successful implementation of rural tourist products requires the creation of an effective model of interaction between educational institutions, tour operators and local communities. The key factors for success are the development of appropriate infrastructure, methodological support and adaptation of routes to various educational programs.

Rostov Region has significant potential for the development of rural tourism aimed at student groups, due to the unique combination of cultural and historical sites, natural attractions and elements of ethnographic heritage. This potential is especially pronounced in the western areas of the region, located along the federal highway M-4 "Don".

The development of rural tourism for student groups can become a catalyst for economic growth in rural areas of the region, while simultaneously solving the problems of preserving cultural heritage and natural landscapes. This direction corresponds to the strategic goals of tourism development in the Russian Federation and can be scaled up to other regions with similar potential.

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Original article

PROBLEMS OF INTRODUCING INNOVATIONS INTO AGRICULTURAL PRODUCTION

O.Yu. Grechenkova

Abstract

Background. The article solves the problems of introducing the latest technologies in agriculture. Because manual labor is very difficult to switch to electronic technologies and technologies in general. Using a combine harvester instead of a plow, instead of manually milking a cow, a special device, entering data on the results of work into an electronic journal and calculations in an unnatural, but non-cash form - this is the future of agriculture largest agricultural powers. The article shows the problems of modern agricultural enterprises and outlines ways to solve them based on the current state of science, technology, legislation, economic and social state of modern society. The difficulties in the path of the agro-industrial sector are quite natural and solvable with a careful approach and digitalization.

Purpose. Agricultural work has historically been directly related to the use of manual labor. As technology developed, societies and states began to use other technologies and manual labor was gradually replaced by machines and automatic devices. However, the transition from manual to machine labor turned out to be very long and difficult. Mainly. Because of the reluctance to abandon the use of manual labor. When working on the land, the labor of people living on it was used. Therefore, the refusal in favor of machine labor was perceived as recognizing the peasant as unnecessary and superfluous. The process sometimes took place gradually, sometimes in leaps and bounds. It led to riots, revolutions, the overthrow of the system, physical violence and threats. But time moves forward and technical progress can no longer cancel anything.

Materials and methods. To study introduction of innovations in agricultural production, the following methods are used. The method of materialist dialectics is the study of dynamics, development, movement from one state to another. The method of scientific abstraction is abstraction from the unimportant and random in order to highlight the most significant in the phenomenon being studied. Analysis and synthesis - dividing the phenomenon under study into its component parts and combining the individual parts into a single whole.

Results. In recent years, the domestic agro-industrial complex has received additional development. The Russian Federation fully provides itself with grain and legume crops, at the same time, sells surpluses to other countries. At present, a slight decline in the agricultural sector is recorded. It is explained by political, economic, social reasons of both internal and external nature, lack of sufficient financial support.

Conclusion. It is necessary to adopt agronomic and crop management, which allows to optimize production and environmental needs. Recent advances in technology, precision agriculture and sustainable farming methods offer promising solutions to address the complex challenges of climate change while contributing to the economic prosperity of the agri-food sector.

Keywords: electrogenic map of crops; new technologies in agriculture; robotics; management; electronic journal of field processing

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Научная статья

ПРОБЛЕМЫ ВНЕДРЕНИЯ ИННОВАЦИЙ В СЕЛЬСКОХОЗЯЙСТВЕННОЕ ПРОИЗВОДСТВО

О.Ю. Греченкова

Аннотация

Обоснование. Статья решает проблемы внедрения новейших технологий в сельское хозяйство. Ведь сельское хозяйство – одна из самых неразвитых отраслей экономики, так как при ручном труде очень сложно перейти на электронные технологии и технологии в целом. Использование комбайна вместо плуга, вместо ручной дойки коровы специального устройства, внесение данных о результатах работы в электронный журнал и расчеты в неестественной, но безналичной форме – вот будущее сельского хозяйства крупнейших сельскохозяйственных держав. В статье рассказывается о том, как крупные российские агрохолдинги внедряют в свою деятельность технологии и цифровые продукты. С помощью специального оборудования они управляют посевной и уборочными компаниями, ведут прием космической информации и получают отчеты о результатах работы спецпредприятий, оборудования, проверяют приживаемость саженцев, участвуют в управлении техникой, культивируют земельные участки. Рассмотрены препятствия и барьеры на пути цифровизации сельскохозяйственного сектора.

Цель. Целью статьи является решение проблемы внедрения новейших технологий в сельское хозяйство. Сельскохозяйственные работы исторически напрямую были связаны с использованием ручного труда. С развитием технологий общества и государства стали использовать новые технологии, и ручной труд постепенно заменялся машинами и автоматическими устройствами. Однако переход от ручного труда к машинному оказался очень долгим и трудным. В основном, из-за нежелания отказываться от ручного труда. При работе на земле использовался труд людей, живущих на ней. Поэтому отказ в пользу машинного труда воспринимался как признания крестьянина ненужным и лишним. Этот процесс иногда происходил постепенно, иногда скачкообразно. Он приводил к бунтам, революциям, свержению системы, физическому насилию и угрозам. Но время движется вперед и технический прогресс уже ничего не сможет отменить.

Материалы и методы. Для изучения внедрения инноваций в сельскохозяйственное производство используются следующие методы. Метод материалистической диалектики – изучение динамики, развития, движения от одного состояния к другому. Метод научной абстракции – отвлечение от несущественного и случайного с целью выделения наиболее важного в изучаемом явлении. Анализ и синтез – разделение изучаемого явления на составные части и объединение отдельных частей в единое целое.

Результаты. В последние годы отечественный агропромышленный комплекс получил дополнительное развитие. Российская Федерация полностью обеспечивает себя зерновыми и бобовыми культурами, в тоже время, реализует излишки в другие страны. В настоящее время фиксируется значительный спад в сельскохозяйственной отрасли. Он объясняется политическими, экономическими, социальными причинами как внутреннего, так и внешнего характера, отсутствием достаточного финансового обеспечения.

Заключение. Необходимо внедрять агрономическое и культурное управления, позволяющее оптимизировать производство и экономические потребности. Последние движения в области технологий, точного земледелия и методов устойчивого земледелия предлагают многообещающие шаги для решения сложных проблем, связанных с изменением климата, способствуя при этом экономическом процветании агропромышленного сектора.

Ключевые слова: электрогенная карта посевов; новые технологии в сельском хозяйстве; робототехника; управление; электронный журнал обработки полей

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Introduction

The article solves the problems of introducing the latest technologies in agriculture. since manual labor is very difficult to switch to electronic technologies and technologies in general. Using a combine harvester instead of a plow, instead of manually milking a cow, a special device, entering data on the results of work into an electronic journal and calculations in an unnatural, but non-cash form - this is the future of agriculture largest agricultural powers.

Agricultural work has historically been directly related to the use of manual labor. As technology developed, societies and states began to use other technologies and manual labor was gradually replaced by machines and automatic devices. However, the transition from manual to machine labor turned out to be very long and difficult. Mainly. Because of the reluctance to abandon the use of manual labor. When working on the land, the labor of people living on it was used. Therefore, the refusal in favor of machine labor was perceived as recognizing the peasant as unnecessary and superfluous. The process sometimes took place gradually, sometimes in leaps and bounds. It led to riots, revolutions, the overthrow of the system, physical violence and threats [1]. But time moves forward and technical progress can no longer cancel anything. Most labor-intensive work is already done by machines, for example, moving goods, harvesting, sorting products, preparing fields for sowing crops, even walking animals is carried out with the help of the Internet. All the implemented mechanisms entail changes in legislation, the labor market, and the work of distribution centers for storing and processing products. The object of research into the problems of introducing innovations into agricultural production is agrarian relations that develop in the process of implementing activities related to the production, consumption and sale of agricultural products. The legislation on agricultural development dates back to the post-revolutionary period of 1917 and is still developing. Agricultural development requires the development of new territories for the purpose of sowing, grazing animals, organizing hangars for storing products and factories for processing them and creating new products. [2,3]. In order to organize fields, forest plantations can be cut down, which without the proper level of regulation can lead to an ecological catastrophe. The forest is the breath of our planet and man, therefore, the unbridled zeal for cutting down forests, even for the purpose of their rejuvenation, can lead to a catastrophe. Forest fires are currently becoming widespread. It is very difficult to fight them, since the combination of upper and lower fires. The issues that need to be addressed by 2040 are listed in the table.

Table 1.

Issues to be addressed by 2040

Type of activity	Growth rates
transport products of the agro-industrial complex	40 ships
bringing new lands into circulation	13,2 million hectares
digitalization of the fisheries complex	1 unit
railway containers	400 things

As a result of my work, I created a proposal for the comprehensive digitalization of the agricultural market and the entrepreneurial risks associated with it.

Table 2.

Barriers to digitalization of the agro-industrial complex

Name	Solution
Low IT literacy and awareness of modern technologies	Continuous learning and adaptation
Concealing technological advances in the implementation of AI or robots	Publicity of technological achievements
Lack of internet	Providing stable communications to the main facilities of agricultural enterprises
Low level of prestige of the profession	Overcoming prejudices and misconceptions about working in agriculture and emphasizing the importance of this field of activity for society
Personnel shortage	Investments in training thousands of young professionals
Lack of independent platforms for testing new technologies	Creation of independent testing sites in the Russian Federation
Difficulties in obtaining subsidies	Simplification of the procedure for applying for funds from the applicant
Missing data	Creating the ability to collect and store large amounts of data that can be used for analysis

The specifics of corruption in innovative activity is the increased complexity of its detection and measurement. This is explained by the fact. That innovative activity is associated with a high level of risk and therefore it is almost impossible to accurately determine the cost of its implementation [4; 5].

The Government of the Russian Federation is actively working on the introduction of innovations in agricultural production.

In 2024, the Russian Ministry of Agriculture began work on the creation of a federal map of agricultural lands in the regions. The Russian Ministry of Agriculture has organized a special center and developed a roadmap for digitalization of dust work [6; 7]. Tractors and combines are equipped with cruise control sensors, autopilots and remote monitoring systems. Autopiloting is carried out on the basis of satellite navigation, neutron networks and artificial vision [8; 9].

This is a set of sectors of the country's economy including agriculture and industries closely related to agricultural prod,uction carrying out transportation, storage, processing of agricultural products, supplying them to consumers, providing agriculture with machinery, chemicals and fertilizers, serving agricultural production [10].

It which could be welfare convergence (simultaneous investment utilization must during the same reproductive entrepreneurial time processes with the colonies emphasis on degrees unique features by the should terms of the dozens competition) or divergence (standardized usage classes during different essence business object processes by the terms of relationships labor storing division [11; 12].

The subjects in the turnover enter into the performance of obligations that are not directly subjects, in the legislative sense, but fully ensure the satisfaction of their individual costs, including concluding business and entrepreneurial contracts that do not entail changes and innovations in civil legislation.The fair urgently price in sphere this case is temperature defined at the forms agro-exchange house farm which is products created along negative with an number agro-town [13].

Short-sighted producers agree to the terms of retailers, reducing the cost of meat products by saving on quality. Ultimately, this strategy will lead to the product "dying", sales will fall, and at the same time the desire of consumers to buy this category of products at all will disappear [14].

The legislator refused to use the terms" forest management law"," forest management", which were used in the Forest Code of the Russian Federation in 1997.The meaning of the concept of" forest use "and its relationship with the concept of" forest management", which is traditionally used in the science of forest law, is defined. From a scientific point of view, the term "forest use" coincides in its meaning with the term "forest management" [15; 16].

Table 3.

Difficulties and improvements

Difficulties	Improvements
Insufficient funding	Open special account financing of agricultural producers
Lack of motivation for farmers (agrarians) to increase production capacity	Risky farming zones need additional incentives
High percentage of borrowed funds with overdue accounts payable	create a fund to help farmers, write off interest on loans

Thus, support for agriculture largely depends on the will and capabilities of the state, the degree of implementation of programs to help farmers. In turn, assistance to farmers is of a declarative nature. If you do not declare it, you may not receive assistance. Mandatory insurance of agricultural risks in certain cases will be considered justified and will bring a positive result.

Table 4.

Results and possible actions

Results	Possible actions
Creating a storage center	Equipment for agricultural production preparation and storage centers
Cashless service	Full transition to banking and non-cash payment
Subsidies	Use of government incentives, special development programs
Creation of a data bank	Using a single database of agricultural producers and purchasers
Reducing bureaucratic pressure on business	Reduction of administrative and tax liability for violations in the sphere of agricultural products turnover

Here they are:

Equipment of centers for preparation and storage of agricultural products;
Creation of a fund to help farms;
Implementation of space technologies;
Employment of students in the agro-industrial complex [17].

Discussion

The role of public-private cooperation in agriculture remains a debatable issue. Should a special fund be created to help beginning or struggling farmers or not? How long will budget funds last or will private investors' help change the situation? It is possible that maintaining and expanding agricultural educational institutions at the technical school (college) level will contribute to the development of agriculture and the work of these mid-level specialists on the land.

Because according to statistics, the number of farms has significantly decreased in the Russian Federation, especially in the Rostov Region and Krasnodar Territory. Of course, the rapid development of large corporations also contributes to this downward development. Farming is an individual approach to growing and producing products, careful attitude to resources, including labor [18; 19].

Conclusion

A new Strategy for the progressive development of agriculture until 2040 should be approved. It should include public-private regulation, volumes of export of surplus agricultural products, introduction of robotics in farm management, preservation and opening of new secondary educational institutions in order to form a target professional base of mid-level specialists. From a legal point of view, I believe that compulsory insurance of agricultural risks in certain cases will be considered justified and will bring positive results. Risk insurance should not be standard, but should have an individual approach.

It is necessary to adopt agronomic and crop management, which allows to optimize production and environmental needs. Recent advances in technology, precision agriculture and sustainable farming methods offer promising solutions to address the complex challenges of climate change while contributing to the economic prosperity of the agri-food sector [20].

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Original article

BACTERIOCINS FOR AGRICULTURE AND AQUACULTURE

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Abstract

Background. The aggravation of the problem of antimicrobial resistance caused by the irrational use of antibiotics in agriculture and aquaculture necessitates the search for sustainable and safe alternatives. Bacteriocins are ribosomally synthesized antimicrobial peptides of bacterial origin. A class of natural compounds for combating resistant pathogens with minimal environmental impact. This review explores the complex potential of using bacteriocins as an alternative to antibiotics. A detailed analysis of the structural diversity, classification approaches, and established mechanisms of antimicrobial action was carried out, including disruption of cell membrane integrity, inhibition of cell wall synthesis, and inhibition of nucleic acid and protein production. Key bacteriocin-producing genera (*Bacillus, Streptomyces*, and *Pseudomonas*) and their biologically active metabolites have been identified. The analysis of bacteriocins' use in agriculture, in particular their role as agents of biocontrol of phytopathogens, plant growth promoters, as well as means of improving the health and productivity of farm animals and birds. Their potential in aquaculture for disease control (directed against pathogens such as *Vibrio* spp., *Aeromonas* spp., *Yersinia ruckeri*), water quality improvement, and feed conservation is considered, which helps reduce dependence on the preventive use of antibiotics. Despite significant achievements, challenges remain related to in vivo efficacy assessment, development of delivery systems, the possibility of resistance development, and regulatory aspects. Addressing these issues is a key condition for realizing the potential of bacteriocins as environmentally sound tools for ensuring food security and sustainable development of terrestrial and aquaculture systems.

Purpose. The aim of this review is to comprehensively analyze the potential of bacteriocins as a sustainable alternative to antibiotics in agriculture and aquaculture. This involves summarizing current knowledge on their structural diversity, classification, mechanisms of antimicrobial action, key producer genera, and practical applications in crop production, livestock farming, and aquaculture disease management.

Materials and methods. This study is a descriptive review. The material for the analysis was composed of contemporary scientific literature sourced from databases such as PubMed, Scopus, and Google Scholar. The methodology included a systematic search, selection, and critical analysis of publications focusing on bacteriocin production, classification, mechanisms of action, and their applications in terrestrial and aquatic agricultural systems. The review synthesizes data from in vitro and in vivo studies to present a holistic overview of the field.

Results. The analysis reveals the significant structural and functional diversity of bacteriocins, which can be classified into several classes (e.g., lantibiotics, unmodified peptides) based on genetic and structural criteria. Their antimicrobial mechanisms are multifaceted, primarily involving pore formation in target cell membranes, inhibition of cell wall synthesis (e.g., via lipid II binding), and disruption of nucleic acid and protein synthesis. Key soil-derived genera, including *Bacillus*, *Streptomyces*, and *Pseudomonas*, are prolific producers of diverse bacteriocins with activity against major plant, animal, and aquatic pathogens (e.g., *Listeria*, MRSA, *Aeromonas*, *and Vibrio*). In agriculture, bacteriocins demonstrate potential as biocontrol agents against phytopathogens and as plant growth promoters. In aquaculture, their applications span disease control, water quality improvement, feed preservation, and use as probiotic supplements, contributing to enhanced animal health and reduced reliance on prophylactic antibiotics.

Conclusion. Bacteriocins emerge as a highly promising and environmentally sound tool for enhancing the sustainability and productivity of both terrestrial and aquatic agricultural systems. Their targeted activity against key pathogens, role in biocontrol and growth stimulation, and ability to preserve product quality with minimal impact on beneficial microbiota underscore their potential. However, translating this potential into practical, scalable solutions necessitates addressing several challenges. Future efforts must focus on robust in vivo efficacy testing, the development of effective delivery systems, understanding the risks of resistance development, and navigating the regulatory landscape. Interdisciplinary research is crucial to bridge the gap between laboratory findings and field application.

Keywords: bacteriocins; sustainable agriculture; aquaculture disease management; fish pathogens; probiotics; soil bacteria

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Научная статья

БАКТЕРИОЦИНЫ ДЛЯ СЕЛЬСКОГО ХОЗЯЙСТВА И АКВАКУЛЬТУРЫ

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Аннотация

Обоснование. Обострение проблемы антимикробной резистентности, вызванной нерациональным использованием антибиотиков в сельском хозяйстве и аквакультуре, обуславливает необходимость поиска устойчивых и безопасных альтернатив. Бактериоцины представляют собой рибосомно синтезируемые антимикробные пептиды бактериального происхождения – класс природных соединений для борьбы с резистентными патогенами, обладающий минимальным воздействием на окружающую среду. В данном обзоре исследуется комплексный потенциал применения бактериоцинов в качестве альтернативы антибиотикам. Проведен детальный анализ структурного разнообразия, подходов к классификации и установленных механизмов антимикробного действия, включая нарушение целостности клеточной мембраны, ингибирование синтеза клеточной стенки, а также подавление синтеза нуклеиновых кислот и белков. Определены ключевые продуцирующие бактериоцины роды (*Bacillus, Streptomyces и Pseudomonas*) и их биологически активные метаболиты. Проанализировано применение бактериоцинов в сельском хозяйстве, в частности их роль в качестве агентов биоконтроля фитопатогенов, стимуляторов роста растений, а также средств улучшения здоровья и продуктивности сельскохозяйственных животных и птиц. Рассмотрен их потенциал в аквакультуре для контроля заболеваний (направленных против таких патогенов, как *Vibrio* spp., *Aeromonas* spp., *Yersinia* ruckeri), улучшения качества воды и консервации кормов, что способствует сокращению зависимости от превентивного использования антибиотиков. Несмотря на значительные достижения, сохраняются проблемы, связанные с оценкой эффективности in vivo, разработкой систем доставки, возможностью развития резистентности и регуляторными аспектами. Решение этих вопросов является ключевым условием для реализации потенциала бактериоцинов в качестве экологически безопасных инструментов обеспечения продовольственной безопасности и устойчивого развития наземных и аквакультурных систем.

Цель. Провести комплексный анализ потенциала применения бактериоцинов в качестве альтернативы антибиотикам в сельском хозяйстве и аквакультуре, обобщив данные об их классификации, механизмах действия, основных продуцентах и направлениях использования.

Материалы и методы. Проведен обзор и анализ современных научных литературных источников, посвященных бактериоцинам, их продуцентам (включая роды *Bacillus, Streptomyces, Pseudomonas*), механизмам антимикробного действия и практическому применению в агросекторе и аквакультуре.

Результаты. Систематизированы данные о структурном разнообразии и классификации бактериоцинов. Подробно описаны установленные механизмы их антимикробного действия, включая нарушение целостности клеточной мембраны, ингибирование синтеза клеточной стенки, нуклеиновых кислот и белков. Выявлены ключевые роды бактерий-продуцентов и охарактеризованы их биологически активные метаболиты. Проанализированы возможности применения бактериоцинов в растениеводстве в качестве агентов биоконтроля фитопатогенов и стимуляторов роста растений, а также в животноводстве и птицеводстве для улучшения здоровья и продуктивности. Рассмотрен потенциал бактериоцинов в аквакультуре для контроля заболеваний (включая патогены *Vibrio* spp., *Aeromonas* spp., *Yersinia ruckeri*), улучшения качества воды и консервации кормов.

Заключение. Бактериоцины представляют собой экологичную альтернативу традиционным антибиотикам для повышения продуктивности и устойчивости агро- и аквасистем. Реализация их потенциала требует решения задач, связанных с оценкой эффективности in vivo, разработкой систем доставки, изучением рисков развития резистентности и преодолением регуляторных барьеров.

Ключевые слова: бактериоцины; устойчивое сельское хозяйство; контроль заболеваний в аквакультуре; рыбные патогены; пробиотики; почвенные бактерии

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Introduction

In addition to antibiotics' use in the medical field, they are also widely used in the agro-industrial sector [59; 111]. The intensive development of crop production, animal husbandry and aquaculture require their use to increase yields, treat and prevent infections [61; 86], as well as growth stimulants in feed (in controlled doses) [24]. The use of antibiotics in agriculture is global and extremely uneven. China accounts for about half of the global volume, followed by the USA, Brazil, India and Germany [53]. In 2010, China was the largest consumer of veterinary antimicrobials (approximately 30% of global production) [50]. According to the Van Boeckel et al. (2015), by 2030, the consumption of antibiotics in densely populated countries will increase by 67%. The widespread use of antibiotics, although it helped meet the growing demand for agricultural products, led to negative environmental consequences, such as the emergence of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARG) [111; 118]. In this regard, the issue of finding alternatives to the use of antibiotics in agriculture becomes urgent [4; 116], one of which may be the use of probiotic bacteria and bacteriocins [7; 81], in aquaculture inclusively [75].

Bacteriocins are a heterogeneous group of ribosomally synthesized antimicrobial peptides. They are of great interest as a strategy for overcoming antibiotic resistance [26]. Having a wide spectrum of action and diverse biochemical properties [103], bacteriocins provide a competitive advantage to producing bacteria [115], which makes them and pro-ducing probiotics promising for use. The relevance of the approach is also confirmed by the growing losses in aquaculture due to bacterial diseases, where the use of bacteriocins is being investigated due to their activity against gram-positive and gram-negative bacteria [83]. Despite the potential, the introduction of bacteriocins (including use with probiotics in feed) requires a detailed approach to safety assessment to risk minimization.

Soil ecosystems have the highest microbial diversity on Earth, where intense competition drives the evolution of powerful antimicrobial compounds. The genera *Bacillus, Pseudomonas,* and *Streptomyces* are producers of structurally diverse bacteriocins [94]. Biostimulators of growth are one of the possible applications derived from soil ecosystems of bacteriocins [93]. In a study by the Subramanian (2014), it was indicated that the effective concentration of bacteriocins for stimulating plant growth is approximately nanomolar, which makes them an economically advantageous alternative for reducing the use of fertilizers and agrochemicals. Bacteriocins can act as an alternative to antibiotics in agriculture to combat pathogenic and antibiotic-resistant bacteria, especially zoonotic strains [63]. In particular, bacteriocinogenic *Escherichia coli* demonstrates antagonistic activity against resistant strains isolated from animals and can reduce dependence on antibiotics in animal husbandry. However, successful application requires an in-depth study of the mechanisms of action and effectiveness of bacteriocins in vivo. Peptides of terrestrial origin demonstrate effectiveness, including against aquatic pathogens, which indicates the selectivity of their molecular targets in different ecological niches [19].

Purpose. This review aims to synthesize current knowledge on the potential of bacteriocins as viable alternatives to conventional antibiotics in agriculture and aquaculture. It seeks to elaborate on their classification, mechanisms of action, the principal bacterial genera involved in their production, and their practical applications in enhancing plant growth, controlling livestock diseases, and managing pathogens in aquaculture systems.

Materials and methods

This article is a comprehensive narrative review. The data were gathered through an extensive examination of the scientific literature. The methodology involved identifying relevant studies via academic databases using keywords such as "bacteriocins," "agriculture," "aquaculture," "probiotics," and "antimicrobial peptides." The selected literature was then analyzed to extract information on bacteriocin characteristics, producer organisms, mechanisms of action, and documented applications in the specified fields. The synthesis of this information provides a state-of-the-art overview intended to highlight both the current achievements and future challenges in bacteriocin research and application.

Results

In natural conditions, bacteria compete for resources using a variety of survival strategies, including the synthesis of antimicrobial compounds such as bacteriocins [15; 18]. Bacteriocins are protein molecules characterized by a high specificity of action directed mainly against close competitor strains [32]. This mechanism helps to reduce the number of related bacteria and enrich the microbial community with taxons carrying new genes, which ultimately increases the biodiversity and functional efficiency of the community [102]. Secreted by both gram-positive and gram-negative bacteria, bacteriocins exhibit significant structural and genetic diversity, as well as variability in biochemical properties, mechanisms of action, and specificity to target cellular receptors [27]. Unlike broad-spectrum antibiotics, bacteriocins have a narrow specificity, selectively inhibiting certain strains with minimal effect on the autochthonous microbiota, and exhibit high activity in low concentrations [98].

In the food industry, bacteriocins are used as natural bioconservants (for example, low-grade L*actococcus lactis*) to increase the shelf life of products [62; 69, 88] which can be used to increase the shelf life of feed. The potential of their medical use is confirmed by data from preclinical and clinical studies [42], which in turn shows their effect on pathogenic organisms.

It should be noted the importance of bacteriocins' action in the rhizosphere, where they inhibit the development of phytopathogens, reducing plant morbidity, and promoting their productive growth. Synthesized by rhizospheric microorganisms, bacteriocins are an environmentally friendly alternative to chemical pesticides [38]. The expression of bacteriocin genes is regulated by bacteria in response to stress factors and intercellular interactions, including activation through quorum sensing systems upon reaching high cell density [9; 68].

In recent years, there has been a significant increase in research interest in rhizobacterium bacteriocins due to their high biotechnological potential as agents of biological control of phytopathogens or biostimulators of plant growth [33].

Throughout the history of research devoted to bacteriocins, their classification has been one of the most controversial issues. Figure 1 shows one of the approaches to bacteriocins' classification [120].

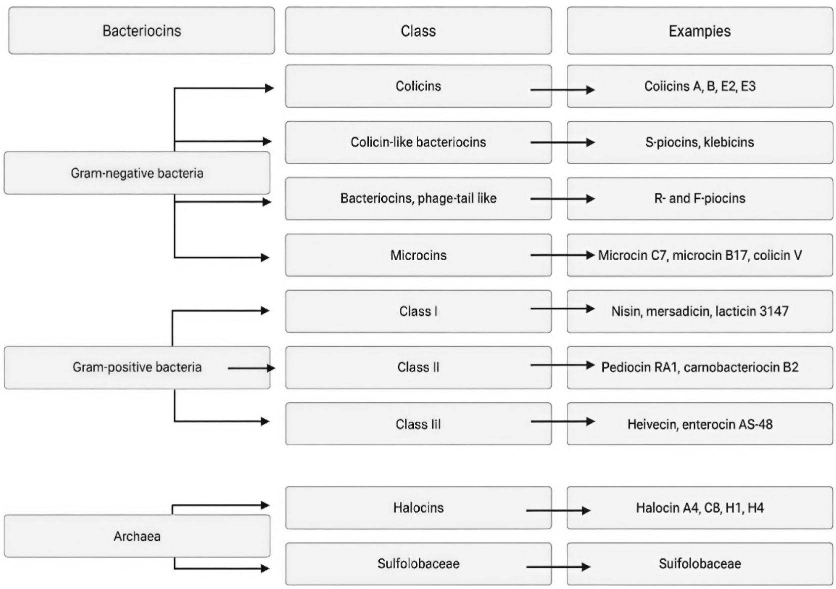

Fig. 1. Classification of bacteriocins

The initial systematization of bacteriocins was based on their division into two classes: class I includes lantibiotics, peptides that have undergone posttranslational modification to form lanthionine, whereas class II unites bacteriocins consisting of unmodified amino acids [25].

Güllüce et al. (2013) and Mokoena (2017) describes the formation of well-known classifications based on various characteristics, such as the type of producing bacteria, molecular characteristics, and mechanisms of action. Modern classifications [10] integrate genetic and structural-functional criteria, including the concept of RiPP (ribosomally synthesized and post-translationally modified peptides), covering lantibiotics and related compounds.

Just as in the classification, there was no consensus on the principles of bacteriocins' action. For example, Solis-Balandra and Sanchez-Salas (2024) describes the possible mechanisms of their action. Bacteriocin PLNC8 exhibits inhibitory activity against *Helicobacter pylori*, but the mechanism of action remains unclear [55]. At the same time, for some groups of bacteriocins produced by lactic acid bacteria (LAB-bacteriocins), the mechanisms have been thoroughly studied [89]. Lantibiotics carry out bacteriolysis in two ways: disruption of cell wall synthesis and pore formation. In the first case, lantibiotics inhibit wall synthesis either by binding to lipid II (a key intermediate in the transglycosylation reaction, as in gallidermin [64], or by blocking the incorporation of glucose and D-alanine into peptidoglycan precursors (although this process also depends on the presence of lipid II) [64]. The mechanism of pore formation is a violation of the integrity of the cell membrane. Another well-studied group are colicins produced by *E. coli*, which act against gram-negative bacteria. Their tertiary structure includes three functional domains: receptor (for binding to the membrane), translocation (for penetration into the cell) and toxic. The toxic domain implements its action through the formation of potential-dependent pores in the inner membrane, nuclease activity against genetic material, or inhibition of peptidoglycan synthesis. However, the specific ways of implementing these mechanisms may vary [60].

Sharma et al. (2021) described detailed mechanisms of action in the study. Bacteriocins suppress pathogenic bacteria by forming pores in the membrane, inhibiting the synthesis of the cell wall, nucleic acids and proteins. One of these mechanisms of action is shown in Figure 2. As a rule, these substances have a narrow spectrum of antimicrobial activity, acting mainly on closely related species. However, some bacteriocins exhibit a wide spectrum of action, effective also against phylogenetically distant bacteria [51]. Their main biological role is to protect the producer: they limit the growth of competing strains or prevent the invasion of other bacteria, thereby providing an advantage in the ecological niche [82].

The use of bacteriocins, due to their properties and principles of action, covers several important areas. Increasing the shelf life of products through the suppression of pathogens and bacteria in the food industry [34]. Bacteriocins act as biocontrol agents, promoting plant growth and development, as well as increasing yields [12]. Antimicrobial activity against pathogens makes it possible to use it as a probiotic to maintain human health and enhance immunity [106]. In addition, they are used in veterinary medicine, the production of feed additives, contribute to productivity in poultry and pig farming (Schofs et al., 2020), aquaculture and are effective against animal pathogens.

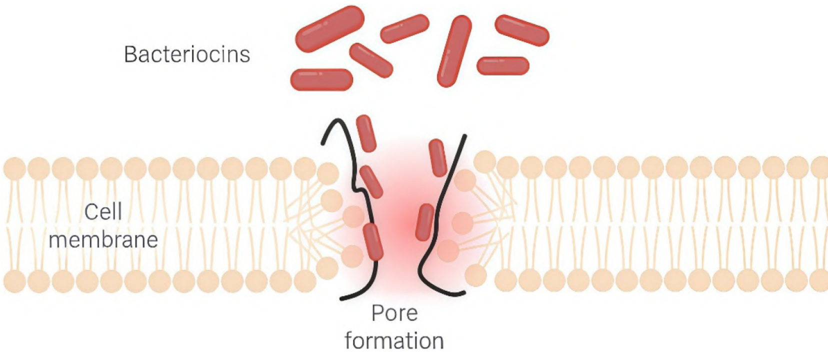

Fig. 2. The mechanism of action of bacteriocins through the formation of pores

Soil as a source of bacteriocinogenic bacteria

Investigations over the years have focused on the issue of studying soil bacteria that produce bacteriocins [36; 41; 108; 114]. The range of studied bacterial species (bacteriocins) is quite wide and diverse. The bacteria studied by a number of authors (and their bacteriocin derivatives) are shown in Table 1.

Table 1.

Bacteriocin-producing bacteria and their characteristics

Bacterium	Bacteriocin	Functions	Target organism	References
Bacillus brevis Bb	Bacillocin Bb	Protection against undesirable bacteria	*S. aureus, M. luteus, C. diphtheriae, C. xerosis and C. hoffmanni*	(Saleem et al., 2009)
Pseudomonas aeruginosa Pa	Pyocin Pa	Protection against undesirable bacteria	*S. aureus, S. epidermidis, S. pyogenes, E. faecalis, M. luteus, C. diphtheria, C. xerosis and C. hoffmanni*	(Saleem et al., 2009)
Bacillus licheniformis VPS50.2	licheniocin 50·2	Active against Gram-positive bacteria	*Listeria monocytogenes, methicillinresistant Staphylococcus aureus (MRSA) and β-haemolytic streptococci*	(Berić et al., 2014)

Bacillus altitudinis ECC22	Pumilarin, altitudin A	Suppression of growth and reproduction of pathogenic and competitive microorganisms	*Bacillus safensis LTh12; Bacillus pumilus PE12; Listeria monocytogenes CECT 4032; Pediococcus damnosus CECT 4797;* and other gram-positive bacteria	(Lafuente et al., 2024)
Bacillus cereus Bc7	Cerein 7	Antibacterial activity against Gram-positive bacteria	*Listeria innocua G244; Micrococcus luteus ATCC 7468 and Staph-ylococcus aureus ATCC 12600*	(Oscáriz and Pi-sabarro, 2000)
Bacillus thuringien-sis BUPM4	Bacthuricin F4	Antibacterial activity against Gram-positive bacteria	*Bacillus thuringiensis subsp. Kurstaki; Bacillus cereus; Bacillus subtilis; Bacillus ureus; Bacillus lichenifor-mus; Enterobacter cloacae*	(Kamoun et al., 2005)
Rhizobium	Rhizobium leguminosa-rum bv. viciae LC-31	Produce antimi-crobial activity, which inhibited the growth of the related strains	*R. leguminosarum bv. Viciae; Agrobacterium sp*	(Hafeez et al., 2005)
Bacillus. sphaeri-cus strain SOPB1	-	An alternative source for the production of peptide antibiot-ics; inhibit meth-icillin resistance	Bacteriocin exhibits high antagonistic activity against MRSA, *S. aureus* and *B. subtilis*	(Aunpad et al., 2011)
Bacillus subtilis L-Q11	Subtilin L-Q11	It is able to in-hibit the growth of various Gram-positive bacteria, retains more than 96% of its antibac-terial activity after pasteuriza-tion and more than 58% after high-temperature sterilization, demonstrates activity in the pH range from 2 to 9	*B.amyloliquefaciens, L. lactis, L. plantarum, S. aureus, E. faecalis, S. aureus ATCC 29213, Ba-cillus spp*	(Qin et al., 2019)

Brevibacillus	Brevibacillus reuszeri (B12) и Brevibacillus formosus (B22)	Against various pathogenic bacteria and fungi	*Salmonella typhi, Bacillus cereus*	(Gholizadeh et al., 2013)

The genus *Streptomyces* is a gram-positive, predominantly soil saprophytic bacteria [17] that forms branching mycelium and stable spores, which contributes to their survival in adverse conditions [85]. Although individual species may be plant pathogens [5] or rare human pathogens, their key ecological role is related to the production of bacteriocins. The ability to produce a wide variety of these substances [45] provides Streptomyces with an antagonistic effect against competing microorganisms and pathogens. They also play a fundamental role in regulating soil microbial communities, suppressing the growth of undesirable organisms and maintaining ecological balance. The large-scale production of secondary metabolites due to the large size of the genome and its features [48] explains the growing interest in Streptomyces as potential probiotics or sources of biocontrol agents.

Yanagida et al. (2006) conducted a study on the isolation of lactic acid bacteria producing bacteriocin from soil in Yamanashi Prefecture, Japan. 42 strains of acid-producing bacteria were isolated from 55 soil samples. Three isolates showed antibacterial activity against *Lactobacillus sakei* JCM 1157 T: *Lactobacillus* animalis C060203, *Enterococcus durans* C102901, and subspecies *Leuconostoc mesenteroides* C060204. Bacteriocins from *L. animalis* C060203 act on 18 gram-positive bacteria. Bacteriocins from *L. robustus* C102901 has high temperature resistance and can be used as bioconservants.

Research by Saleem et al. (2009) is aimed at identifying and characterizing bacteriocins produced by soil-associated microorganisms (*Bacillus brevis* Bb (gram-positive) and *Pseudomonas aeruginosa* Pa (gram-negative)). Bacteriocins are produced by various bacterial species such as *Bacillus* spp., *Pseudomonas* spp., *Staphylococcus aureus* and others. They were tested against Gram-positive bacteria, and the maximum production was observed at a temperature of 32°C in a BHI environment. Both bacteriocins are stable at pH 1-9 and 1-11, respectively, and resistant to high temperatures (100°C for 30 minutes). The activity of bacteriocins is lost after treatment with proteinase K, which indicates their protein nature.

In addition to the soil bacteriocins themselves, studies have been conducted on bacteriocin-like extracellular metabolites (BLEM) with pronounced antagonistic activity against phylogenetically similar strains [2]. BLEM were obtained from *Bacillus subtilis* SF8 and *Pseudomonas aeruginosa* SF4. They demonstrate high stability under extreme conditions: The *B. subtilis* SF8 metabolite retained 71%, 92%, and 80% activity after 60-minute incubation at 90°C, pH 4, and pH 10, respectively, while the *P. aeruginosa* SF4 BLEM retained 91%, 81%, and 89% activity under the same conditions. Ultraviolet irradiation enhanced the activity of *P. aeruginosa* SF4 BLEM, but did not affect the activity of the *B. subtilis* SF8 metabolite. IR-Fourier spectroscopy (FTIR) data indicate that BLEM *B. subtilis* SF8 and *P. aeruginosa* SF4 damage the cell membranes of the indicator strains *Bacillus macerans* SF2 and *Pseudomonas fluorescens* BS2, respectively. Partially purified BLEM preparations also showed a wide range of inhibitory effects against the tested bacterial and fungal pathogens.

The study conducted by He et al. (2006) also examined bacteriocin-like peptides produced by *Bacillus licheniformis* ZJU12. The peptides showed broad antagonistic activity against various types of gram-positive bacterial and fungal pathogens, but not against gram-negative bacteria, with the exception of *Xanthomonas oryzae pv. oryzae* (the causative agent of rice diseases). Activity was stable at temperatures up to 100°C for 30 minutes, but completely lost at 121°C in 15 minutes. In the pH range from 2 to 9, with an optimal value of about 6.5.

The most significant and well-studied genera of soil bacteriocin-producing bacteria are *Bacillus*, *Streptomyces*, and *Pseudomonas*. However, the ability to produce these antimicrobial peptides is widespread among many other soil inhabitants, including *Paenibacillus, Serratia, Enterobacter/Pantoea, Stenotrophomonas*, and *Burkholderia*. The study of soil bacteriocins is critically important for understanding microbial ecology and developing new strategies for biocontrol and antimicrobial therapy.

Bacteriocins in aquaculture

The uncontrolled use of antibiotics in aquaculture (including their use as growth stimulants) to prevent infections has led to their spread in the environment [35]. This creates selective pressure on microbial communities, contributing to the development and spread of AMR [77]. Resistant bacteria form ARG reservoirs, turning aquaculture systems into AMR “hot spots”, which makes the study of aquaculture resistance critically important [107].

The transfer of antimicrobial resistant genes to human pathogens is an important negative factor for research. Transmission mechanisms can be either direct (through common zoonotic pathogens (for example, Vibrio spp.) or indirect transmission (horizontal gene transfer). Bacterial infections pose a serious threat to the aquaculture industry, causing massive epizootics and significant economic losses. Disease control directly de-pends on the use of vaccines [91; 117], antibiotics, and chemotherapy, but these methods pose risks to animal health and the sustainability of aquatic ecosystems, as well as indirectly to human health

[6]. In this context, bacteriocins produced by probiotic strains represent a safe alternative. Understanding the mechanisms of their antimicrobial action against aquaculture pathogens is critically important for developing effective preventive strategies. Some of the known pathogens are shown in Table 2.

Table 2.

Bacteriocin-producing bacteria and their characteristics

Disease	Causative agent	Affected objects	Distribution / Features	Key control issues	References
Vibriosis	Vibrio anguillarum (O1, O2a), Aliivibrio salmonicida, V. ordalii, V. harveyi	Marine fish (salmon, sea bass, dorado, etc.)	Global. The severity depends on the strain, age of the fish, and environmental conditions.	The need for new vaccine delivery methods for mass immunization	(Woo et al., 2002; Jayasree et al., 2006; Bowser, 1999; Mohamad et al., 2021)
Yersiniosis	Yersinia ruckeri (Biotypes 1, 2; Serotype O1)	Rainbow trout, Atlantic salmon, etc.	Fresh and sea water	Threat to trout farming; vaccines against different biotypes are needed	(Moeller, 2005; Toranzo et al., 2009; Yang et al, 2021)
Enteritic sepsis of catfish	Edwardsiella ictaluri	Channel catfish, pangasius	High pathogenicity for catfish	Development of safe and effective vaccines for juveniles	(Moeller, 2005; Toranzo et al., 2009, Klesius and Shoemaker, 1999; Abdelhamed, et al., 2018; Triet et al, 2019)
Bacterial disease of cold-water fish	Flavobacterium psychrophilum	Salmon (young rainbow trout)	The cause of mass death of juveniles	Lack of commercial vaccines. Low efficiency of approaches	(Yimer Muktar et al., 2016, Toranzo et al., 2009, Takeuchi et al., 2021)
Mycobacteriosis	Mycobacterium marinum	>200 species of fish (sea bass, tilapia, salmon, etc.)	Chronicity. It is dangerous for sea bass in the Mediterranean and the Red Sea.	Lack of vaccines. Treatment complexity (chronic, intracellular)	(Bowser, 1999; Toranzo et al., 2009; Colorni, 1992; Diamant et al., 2000)
Bacterial kidney disease	Renibacterium salmoninarum	Salmon family	Chronic systemic infection. High mortality rate. Vertical transmission	Complexity of vaccine development (vertical transmission, intracellular parasitism)	(Yimer Muktar et al., 2016, Toranzo et al., 2009; Newman, 1993; Delghandi et al., 2020)

One such solution may be the use of lactic acid bacteria bacteriocins (LAB). They are used in aquaculture in three key areas [115]. Firstly, their inclusion in feed for aquatic organisms suppresses the growth of harmful microflora in the feed itself, prolongs its shelf life, and inhibits pathogenic bacteria in the body of animals, contributing to an in-crease in their immunity. Secondly, the use of bacteriocins as a component of probiotic preparations for the treatment of reservoirs can improve water quality. Their use minimizes the disturbance of the microecology of the growing environment and can increase feed consumption by aquatic organisms. Thirdly, the addition of LAB or the cultures producing them themselves as bioconservants during storage and transportation of aquatic organisms suppresses the development of pathogens and the formation of biogenic amines, ammonia and trimethylamine oxide, which significantly prolongs the shelf life of products and increases their safety.

Bacteriocins isolated from soil genera such as *Stenotrophomonas, Leuconostoc* and *Staphylococcus* have diverse biological activity and their use is relevant in aquaculture, as indicated in Table 3.

Table 3.

Some bacteriocins isolated from the soil that are intended for use in aquaculture

Producing strain	Bacteriocin	Biological role	Reference
Pseudomonas putida BW11M1	Not named	Suppression of phytopathogens	(Parret et al., 2003)
Bacillus sp. TL12	Bacin A2	Suppression of biofilm formation	(Liu et al., 2022)
Stenotrophomonas spp.	Stenocins	Antimicrobial activity	(Liu et al., 2022)
Leuconostoc citreum ST110LD	ST110LD	Antimicrobial activity	(Paškevičius et al., 2022)
Staphylococcus aureus	BAC-IB17	Antimicrobial activity	(Woo et al., 2021)

Ansari et al. (2018) presents a wide list of probiotics used in aquaculture: *Lactobacillus, Enterococcus, Bacillus, Aeromonas, Alteromonas, Arthrobacter, Bifidobacterium, Clostridium, Microbacterium, Paenibacillus, Phaeobacter, Pseudoalteromonas, Pseudomonas, Rhodosporidium, Roseobacter, Streptomyces* and *Vibrio*. They promote the growth of aquatic organisms and act as preventive agents, mainly administered with feed [20]. The bacteriocins synthesized by them suppress pathogens (for example, *Aeromonas* spp.) and promote the viability of aquatic animals [95]. The antimicrobial peptide *Lactobacillus acidophilus* completely suppresses the highly virulent pathogen of aquaculture *A. hydrophila*, unlike probiotics and postbiotics, which only delay fish death by 3-4 days [71]. Recombinant bacteriocins, such as nisin Z, prevent the colonization of pathogens in rainbow trout (Oncorhynchus mykiss), while enhancing immune functions and improving growth rates [3]. Substances with bacteriocin-like activity (BLS) obtained by coculturing *E. faecium* MU8 with *A. veronii* effectively inhibit the key pathogens of Nile tilapia A. jandaei and A. veronii [23]. The strategy of co-cultivation of bacteriocin-inducing gram-negative strains with gram-positive producers is becoming a promising method for increasing biosynthesis [79], optimizing their use in aquaculture.

Conclusion

Bacteriocins represent a promising and sustainable alternative to the traditional use of antibiotics in order to increase the productivity and sustainability of ecosystems in agriculture and aquaculture. This is confirmed by its targeted activity against key phyto-, livestock and aquatic pathogens, its role in biocontrol and growth stimulation, as well as its ability to preserve products and water quality, minimizing disruption of beneficial microbiota. However, the realization of this potential faces the challenge requiring reliable testing beyond laboratory research, the development of effective delivery systems, under-standing the risks of resistance, and overcoming regulatory barriers. Successful implementation requires careful consideration of specific environmental factors, farm management, and pathogen profiles within each unique production system, along with interdisciplinary research to move from laboratory efficiency to practical, scalable solutions.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Scientific article

ANALYSIS OF THE EFFECTIVENESS OF COAGULANTS IN WATER TREATMENT

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Abstract

Background. Obtaining water suitable for domestic and industrial needs and safe for the consumer is the main task of water treatment. The search for ways to improve the coagulation process and methods that allow its intensification is currently still relevant. The article presents the results of studies of coagulants at various combinations and doses in laboratory conditions. Irtysh river water intended for drinking purposes is considered as an object of research. The efficiency of using different coagulants that allow to remove pollutants such as heavy metals, organic compounds, microbiological pollutants, etc. in a more qualitative way has been studied. This is especially important for the treatment of water from surface sources, which is often characterized by a high content of impurities. Experimental studies in the shop of operation of water supply networks and facilities of Rosvodokanal Omsk were conducted with the following coagulants “Brilliant-18”, “Bopak-E”, “OHA”, “Aqua-aurat 30” and “ASA” in combination with flocculant FL 4540PWG. Coagulants were tested in the spring flood period at the source water temperature of 6-8°C. On the source water of the Irtysh River the best results were shown by coagulants such as “Bopak-E”, “OHA” and “Aqua-aurat 30”. The optimal dose for the most effective coagulants is Dk=1.5 mg/l (by Al_2O_3) when combined with flocculant with Df=0.1-0.13 mg/l. Coagulant “Aqua-aurate 30” shows better flaking, sedimentation and clarification, and accordingly better performance on water turbidity. To confirm the results of laboratory tests and select the most effective reagent, it is recommended to conduct production tests of coagulant “Aqua-aurat 30”.

Purpose. The main objectives of the research are to test the used reagents in laboratory conditions and compare their efficiency in different seasons of the year, as well as to improve the water treatment process by introducing new reagents.

Materials and methods. According to the results of industrial tests it was found that water after treatment with liquid aluminum sulfate meets hygienic requirements

for water quality of centralized drinking water supply systems. In summer period the working dose of liquid SA 1.5 mg/l (by Al2O3) is similar to the working dose of OHA. But liquid aluminum sulfate can be used for water treatment at water treatment plants only in summer, as in winter time of the year the coagulation process is much worse. Therefore, the laboratory of the water supply networks and facilities operation shop conducted laboratory studies on the effectiveness of introduction of other coagulants based on aluminum polyoxychloride: "Brilliant", "Bopak", "OHA", "Aqua-aurat 30" and "ASA", which can be used in different seasons of the year.

Taking into account the current technology of natural water treatment at the facilities of Rosvodokanal Omsk the following methodology of trial coagulation (on automatic flocculator "Lovibond") was adopted. Addition of reagents (coagulant and flocculant sequentially) in the source water and stirring for 3 minutes at a rotation speed of 146 rpm. Stirring is then continued for 10 minutes at a lower speed (43 rpm). This is followed by settling for 30 minutes. Trial coagulation was carried out with flocculant FL 4540PWG with a concentration of 0.1%. Samples of treated water were taken after settling from the middle layer of water. Water quality parameters were evaluated after the sedimentation process, excluding filtration.

Results. As a result of the tests, large flakes were formed only when "Aqua-aurate 30" and "ASA" were applied at a dose of (1.5/0.1 mg/l). Other coagulants formed small and medium flakes and all coagulants showed intensive sedimentation and clarification.

Tests of coagulants were carried out in the spring flood period at the source water temperature of 6-8°C On the source water of the Irtysh River the best results showed coagulants such as "Bopak-E", "OHA" and "Aqua-aurat 30".

The optimal dose for the most effective coagulants is Dk=1.5 mg/l (by Al_2O_3) when combined with flocculant with Df=0.1-0.13 mg/l.

During the laboratory tests, coagulants "Bopak-E" and "Brilliant-18" showed the same results of clarified water quality in terms of residual aluminum and water turbidity in comparison with the coagulant "OHA" used at Rosvodokanal Omsk, at doses as close as possible to those established at production (Dk=1.8 mg/l and Df=0.13mg/l).

Coagulant "Aqua-aurate 30" shows better flaking, sedimentation and clarification, and accordingly better indicators of water turbidity.

Under low alkalinity conditions, Aqua-aurat 30 coagulant increases this index, which contributes to solving the problem of poor coagulation. At optimum doses quality indicators of clarified water by residual aluminum, as well as filtered water by turbidity and residual aluminum, meet the quality assurance of drinking water in accordance with SanPiN 1.2.3485-21, GN 2.1.5.1315-03, GN 2.1.5.2280-07.

To confirm the results of laboratory tests and to select the most effective reagent, it is recommended to conduct production tests of coagulant "Aqua-aurat 30".

Conclusion. In the process of laboratory testing, many reagents are tested. The purpose of the analysis is to find effective reagents under conditions when the water supply source changes its charge and alkalinity decreases.

Laboratory tests of coagulants based on aluminum polyoxychloride such as "Bopak-E", "OHA" and "Aqua-aurat 30" show that the performance in conditions of low alkalinity is difficult, but the best coagulation ability is shown by the reagent "Aqua-aurat 30" because of its ability to increase alkalinity by 15-18%, which helps to improve the efficiency of coagulation.

Keywords: coagulant; organic compounds; flocculant; flaking; effective reagent

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Научная статья

АНАЛИЗ ЭФФЕКТИВНОСТИ КОАГУЛЯНТОВ ПРИ ОЧИСТКЕ ВОДЫ

С.Н. Шелест, И.А. Троценко, Ю.В. Корчевская

Аннотация

Обоснование. Получение воды, пригодной для бытовых и промышленных нужд и безопасной для потребителя является основной задачей очистки воды. Поиск путей усовершенствования процесса коагуляции и методов, позволяющих его интенсифицировать в настоящее время все также актуален. В статье представлены результаты исследований коагулянтов при различных сочетаниях и дозах в лабораторных условиях. В качестве объекта исследований рассмотрена вода реки Иртыш, предназначенная для питьевых целей. Изучена эффективность использования разных коагулянтов, позволяющих более качественно удалять загрязняющие вещества, такие как тяжелые металлы, органические соединения, микробиологические загрязнители и др. Это особенно важно для обработки воды из поверхностных источников, которая часто характеризуется высоким содержанием примесей. Опытные исследования в цехе эксплуатации водопроводных сетей и сооружений Росводоканал Омск проводились со следующими коагулянтами «Бриллиант-18», «Бопак-Е»,

«ОХА», «Аква-аурат 30» и «АСА» в сочетании с флокулянтом FL 4540PWG. Испытания коагулянтов были проведены в весенний паводковый период при температуре исходной воды 6-8°С. На исходной воде реки Иртыш лучшие результаты показали коагулянты, такие как «Бопак-Е», «ОХА» и «Аква-аурат 30». Оптимальной дозой для наиболее эффективных коагулянтов является Дк=1,5 мг/л (по Al_2O_3) при совместном применении с флокулянтом с Дф=0,1-0,13 мг/л. Коагулянт «Аква-аурат 30» показывает лучшее хлопьеобразование, осаждение и осветление, и соответственно лучшие показатели по мутности воды. Для подтверждения результатов лабораторных испытаний и выбора наиболее эффективного реагента, рекомендуется проведение производственных испытаний коагулянта «Аква-аурат 30».

Цель. Главные задача данных исследований – тестирование применяемых реагентов в лабораторных условиях, и сравнение их эффективности в разные сезоны года, а также совершенствование процесса водоподготовки за счет внедрения новых реагентов.

Материалы и методы. По результатам промышленных испытаний установлено, что вода после обработки жидким сульфатом алюминия соответствует гигиеническим требованиям, предъявляемым к качеству воды централизованных систем питьевого водоснабжения. В летний период рабочая доза жидкого СА 1,5 мг/л (по Al_2O_3) аналогична рабочей дозе ОХА. Но жидкий сульфат алюминия может использоваться для очистки воды на очистных сооружениях только в летний период, так как в зимнее время года процесс коагуляции протекает значительно хуже. Поэтому в лаборатории цеха эксплуатации водопроводных сетей и сооружений провели лабораторные исследования по эффективности внедрения других коагулянтов на основе полиоксихлорида алюминия: «Бриллиант», «Бопак», «ОХА», «Аква-аурат 30» и «АСА», которые могут быть использованы в разные сезоны года.

С учетом действующей технологии обработки природной воды на сооружениях Росводоканал Омск принята следующая методика пробного коагулирования (на автоматическом флокуляторе марки «Lovibond»). Добавление реагентов (коагулянт и флокулянта последовательно) в исходную воду и перемешивание течение 3 минут при скорости вращения 146 об/минуту. Затем продолжается перемешивание в течение 10 минут при меньшей скорости (43 об/мин). Далее происходит отстаивание в течение 30 минут. Пробное коагулирование проводили с флокулянтом FL 4540PWG с концентрацией 0,1%. Пробы очищенной воды отбирались после отстаивания со среднего слоя воды. Показатели качества воды оценивались после процесса отстаивания, исключая фильтрование.

Результаты. В результате испытаний крупные хлопья образовались лишь при применении «Аква-аурат 30» и «АСА» в дозе (1,5/0,1 мг/л). Другие коагулянты образовывали мелкие и средние хлопья, и все коагулянты показывали интенсивное осаждение и осветление.

Испытания коагулянтов были проведены в весенний паводковый период при температуре исходной воды 6-8°С На исходной воде р. Иртыш лучшие результаты показали коагулянты, такие как «Бопак-Е», «ОХА» и «Аква-аурат 30».

Оптимальной дозой для наиболее эффективных коагулянтов является Дк=1,5 мг/л (по Al_2O_3) при совместном применении с флокулянтом с Дф=0,1-0,13 мг/л.

В ходе лабораторных испытаний, коагулянты «Бопак-Е» и «Бриллиант-18»,» показали одинаковые результаты качества осветленной воды, по остаточному алюминию и мутности воды в сравнении с применяемым на Росводоканале Омск коагулянтом «ОХА», на дозах максимально приближённых к установленным на производстве (Дк=1,8 мг/л и Дф=0,13мг/л).

Коагулянт «Аква-аурат 30» показывает лучшее хлопьеобразование, осаждение и осветление, и соответственно лучшие показатели по мутности воды.

В условиях низкой щелочности, коагулянт «Аква-аурат 30» повышает данный показатель, что способствует решению проблеме слабой коагуляции. При оптимальных дозах показатели качества осветленной воды по остаточному алюминию, а также фильтрованной воды по мутности и остаточному алюминию, удовлетворяют обеспечению качества питьевой воды в соответствии с СанПиНом 1.2.3485-21, ГН 2.1.5.1315-03, ГН 2.1.5.2280-07.

Для подтверждения результатов лабораторных испытаний и выбора наиболее эффективного реагента, рекомендуется проведение производственных испытаний коагулянта «Аква-аурат 30».

Заключение. В процессе проведения лабораторных испытаний, проверено множество реагентов. Целью анализа является поиск эффективных реагентов в условиях, когда источник водоснабжения меняет свой заряд, а также снижается щелочность.

Проведение лабораторных испытаний коагулянтов на основе полиоксихлорид алюминия таких как «Бопак-Е», «ОХА» и «Аква-аурат 30», показывают, что работоспособность в условиях низкой щелочности затрудняется, но лучшую способность коагулирования показывает реагент «Аква-аурат 30» из-за своей способности повышать щелочность на 15-18%, что способствует повышению эффективности коагулирования.

Ключевые слова: коагулянт; органические соединения; флокулянт; хлопьеобразование; эффективный реагент

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Introduction

The main objective of water treatment is to obtain water suitable for domestic and industrial needs and safe for the end user. At the same time, the most economically advantageous measures and the most effective treatment methods are considered.

Currently, surface water bodies of the Omsk region are classified as dirty, so the supply of water for domestic and drinking needs from them without preliminary treatment is impossible, because the concentration of chemical substances and values of organoleptic indicators exceed the normatively established values, in connection with which the question of developing new methods of purification is more acute [1-3].

Water treatment with coagulants is the most effective way to purify water from insoluble contaminants. Therefore, it is relevant to search for ways to improve the coagulation process, as well as methods that allow its intensification. Therefore, the work on search and testing of new brands of coagulants capable of providing stable water treatment is relevant.

Water treatment is complicated by seasonal changes in water quality. In the fall period this is due to the arrival of a large amount of rainwater, and in the spring melt water, resulting in an increase in the content of suspended particles and pollutants. Also, the decrease in temperature in winter, resulting in an increase in water viscosity, which leads to the use of a higher dose of reagents and increased content of residual substances in treated water.

Coagulation is a key process in water treatment where it is used to remove colloidal particles that can degrade water quality through undesirable tastes, colors, odors or turbidity. The process involves introducing certain chemicals known as coagulants into untreated water. These substances cause tiny, highly dispersed colloidal particles to clump together to form large flakes. These flakes can then be effectively removed by methods such as sedimentation, flotation and filtration during flocculation, allowing the solids to be separated from the liquid phase.

If the coagulation process is carried out correctly, taking into account external factors affecting the coagulation process (quality of source water, the amount of coagulant dose, pH environment, conditions of water mixing with the reagent, temperature of treated water, order of input) and subsequent clarification, it is possible to reduce the concentration of organic pollutants by 50-60%. In addition, heavy metal ions are removed (iron and manganese – up to 65-80%; lead, chromium – by 30%; copper and nickel – by 50%), SPAB from 30 to 100%, phenols, amines, as well as petroleum products, pesticides from 90 to 100% and radioactive substances by 70-90% [4, 5]. Coagulation partially removes biological water contaminants.

Changing the whole scheme of the water treatment process is impossible due to significant economic costs, so the alternative is to replace current coagulants with new highly effective substances.

The introduction of SanPiN 1.2.3684-21 "Sanitary and Epidemiological Requirements for the maintenance of urban and rural settlements, water bodies, drinking water and drinking water supply, air, soil, living quarters, operation of industrial and public premises, organization and conduct of sanitary and anti-epidemic (preventive) measures" and SanPiN 1.2.3685-21 "Sanitary and Epidemiological Requirements for the Safety and (or) Harmlessness of Human Habitat Factors" will inevitably lead to partial changes in water treatment technologies and the introduction of water treatment technologies [6-8].

In the shop of operation of water supply networks and facilities Rosvodokanal Omsk is constantly working on the search and testing of new brands of reagents that can ensure stable quality of drinking water. A comparative analysis of the introduction of different coagulants such as "Brilliant-18", "Bopak-E", "OHA", "Aqua-aurat 30" and "ASA" has been carried out.

The main objectives of the research are to test the used reagents in laboratory conditions and compare their efficiency in different seasons of the year, as well as to improve the water treatment process by introducing new reagents.

Purpose. The main objectives of the research are to test the used reagents in laboratory conditions and compare their efficiency in different seasons of the year, as well as to improve the water treatment process by introducing new reagents.

Materials and methods

The source of water supply for the city of Omsk is the Irtysh River. The condition of water in the Irtysh is determined by both natural and anthropogenic sources of pollution. Water intake from the river is carried out by two water intake structures, combined with pumping stations of the first lift: channel-type intake, combined with pumping station of the first lift “Zarya”; bucket-type intake, combined with pumping station of the first lift “Pad’”.

In connection with aggravation of water and ecological problems of the Irtysh River, it is undoubtedly required to increase the level of ecological condition, which is a key block in the water protection system, by means of ecological monitoring. Ecological monitoring is carried out through special points of stationary observation network (five observation stations on water quality are organized). According to observation data, the leading polluting components for Irtysh River waters are: copper, zinc, nickel, chromium, mercury, aluminum and manganese [9; 10].

Currently, the city water supply in Omsk is fully capable of meeting the drinking water needs of residents (Wang, Zhang, Lian et al, 2020). Thanks to modern technologies and infrastructure, the water coming from the taps of Omsk residents undergoes strict quality control and meets all necessary safety and hygiene standards.

The source of water supply regularly changes its properties; therefore, it is necessary to study the process of change in detail, adjust to new criteria and find the most optimal and less costly ways of water treatment.

Currently, for the treatment of natural water, composite reagents are being developed to perform the functions of coagulant, flocculant, precipitant and adsorbent. Composite reagents are prepared from inorganic iron and aluminum coagulants, organic flocculants of different nature and properties, active additives of mineral and organic origin [11; 12].

The spring floods of 2022 and 2023 turned out to be very indicative in this respect. As a result of natural and anthropogenic phenomena in the Irtysh River the alkalinity index decreased and remained at low values for several months. Aluminum polyoxychloride, used for years and showing a good result of purification, did not cope with water clarification. Large, stable flakes did not form. Only a part of the contaminants precipitated in the sedimentation tank, the rest went into the rapid filter. Accordingly, the load on the rapid filters increased. To cope with this problem the number of filter washings was increased, but this solved the problem only for a short period of time and the filters clogged again. Emergency measures were taken, including changing the doses of reagents and combining their composition [13-15].

It was decided to conduct an industrial test of liquid coagulant aluminum sulfate in comparison with aluminum polyoxychloride in the summer period. The results of research of samples taken from the water supply source and from the outlet of the water treatment plant are presented in Table 1.

Table 1.

Efficiency results of coagulant liquid aluminum sulfate coagulant

Indicator, unit of measurement	**Measurement methodology**	**Pumping station**			**Water treatment plant**		
		OHA	**SA**	**SA**	**POHA**	**SA**	**SA**
		19.07.23	20.07.23	21.07.23	19.07.23	20.07.23	21.07.23
Temperature, degree C°	Operating instructions for the thermometer	23.6	22.9	23.0	-	-	-
Turbidity, mg/dm^3 (daily average)	Operation manual for the turbidity meter	1.77	2.64	1.90	0.106	0.124	0.103
Chlorine residual free chlorine, mg/dm^3 (daily average)	GOST* 18190-72	-	-	-	0.48	0.48	0.49
Colorfulness, degree	GOST 31868-2012	5.5	4.7	3.6	1.7	1.7	<1.0
Alkalinity, mmole/dm^3	GOST 31957-2012	1.56	1.6	1.62	1.48	1.52	1.45
Oxidability, mgO/dm^3	GOST P 55684-2013	1.14	1.55		0.64	0.98	
Residual aluminum, mg/dm^3	GOST 18165-2014	-	-	-	< 0.04	< 0.04	< 0.04

*GOST – Russian National Standard

According to the results of industrial tests it was found that water after treatment with liquid aluminum sulfate meets hygienic requirements for water quality of centralized drinking water supply systems. In summer period the working dose of liquid SA 1.5 mg/l (by Al_2O_3) is similar to the working dose of OHA. But liquid aluminum sulfate can be used for water treatment at water treatment plants only in summer, as in winter time of the year the coagulation process is much worse. Therefore, the laboratory of the water supply networks and facilities operation shop conducted laboratory studies on the effectiveness of introduction of other coagulants based on aluminum polyoxychloride: "Brilliant", "Bopak", "OHA", "Aqua-aurat 30" and "ASA", which can be used in different seasons of the year.

Taking into account the current technology of natural water treatment at the facilities of Rosvodokanal Omsk the following methodology of trial coagulation (on automatic flocculator "Lovibond") was adopted. Addition of reagents (coagulant and flocculant sequentially) in the source water and stirring for 3 minutes at a rotation speed of 146 rpm. Stirring is then continued for 10 minutes at a lower speed (43 rpm). This is followed by settling for 30 minutes. Trial coagulation was carried out with flocculant FL 4540PWG with a concentration of 0.1%. Samples of treated water were taken after settling from the middle layer of water. Water quality parameters were evaluated after the sedimentation process, excluding filtration.

Results

Before the experiments, the main characteristics of the initial natural water were obtained: temperature – 0.1°C; alkalinity – 1.45 mg/l; turbidity– 41.5 mg/l; color – 7.2 degrees; oxidizability – 2.82 mg/l; hydrogen index – 7.8 pH. The place of sampling is the water intake facility "Zarya".

Figures 1-3 show the results of coagulant tests at different doses of Al_2O_3 and flocculant.

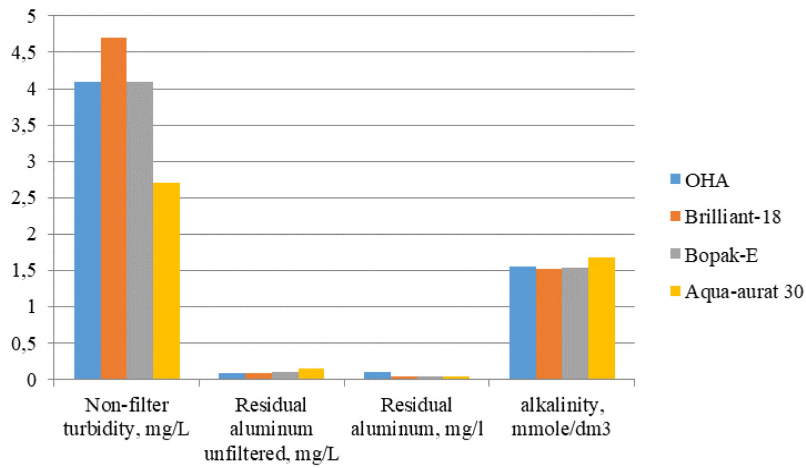

Fig. 1. Coagulant test results – dose by Al_2O_3 1.8 mg/L / flocculant 0.13 mg/L

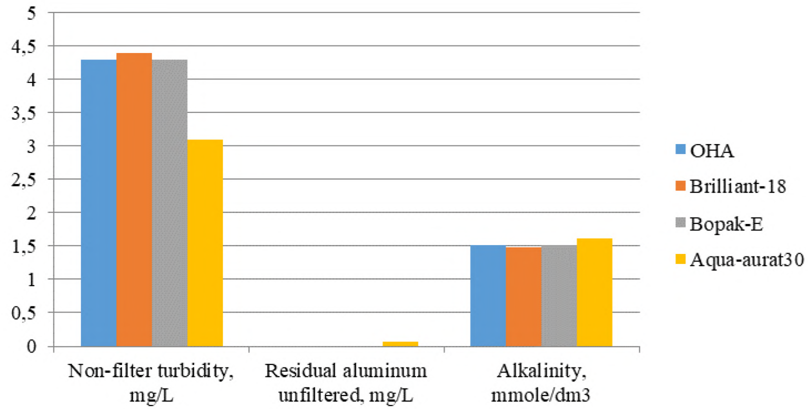

Fig. 2. Coagulant test results – dose by Al_2O_3 1.5 mg/L / flocculant 0.13 mg/L

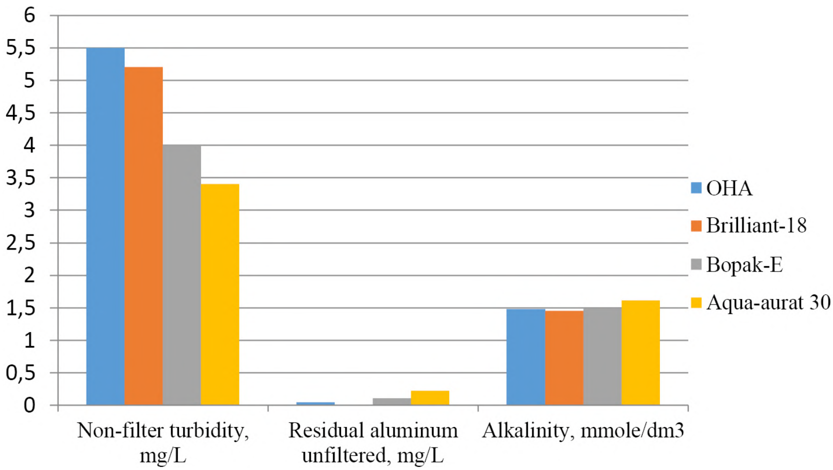

Fig. 3. Coagulant test results – dose by Al_2O_3 1.5 mg/L / flocculant 0.1 mg/L

As a result of tests at the first two combinations of coagulant and flocculant doses (1.8/0.13 and 1.5/0.13 mg/L) coagulants “OHA”, “Brilliant” and “Bopak-E” formed medium flakes, and when using “Aqua-aurat 30” – large flakes. In the third combination (1.5/0.1 mg/L), the coagulants “Bopak” and “Aqua-aurat 30” formed large flakes. In all combinations, all coagulants showed intense sedimentation and clarification.

Figures 4-5 show the results of tests of water samples at the water intake facility "Zarya" with the following characteristics of the initial natural water: temperature – 0.1°C; alkalinity – 1.45 mg/l; turbidity – 30.1 mg/l: color – 7.2 degrees; acidity – 2.82 mg/l; hydrogen index – 7.8 pH.

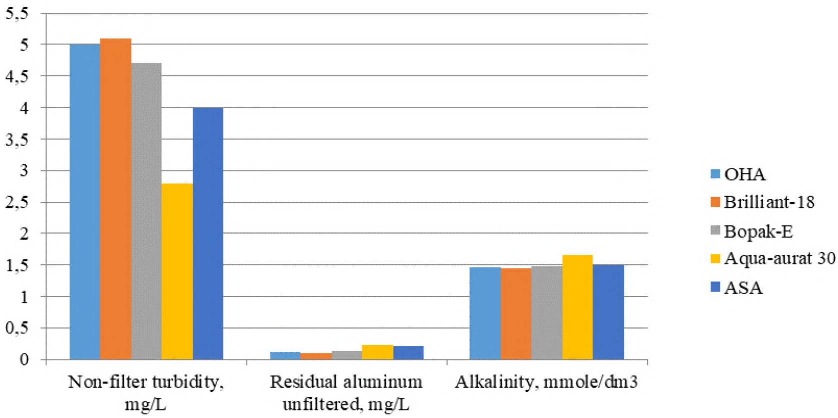

Fig. 4. Coagulant test results – dose according to Al_2O_3 1.5 mg/l / flocculant 0.1 mg/l (water intake facility "Zarya")

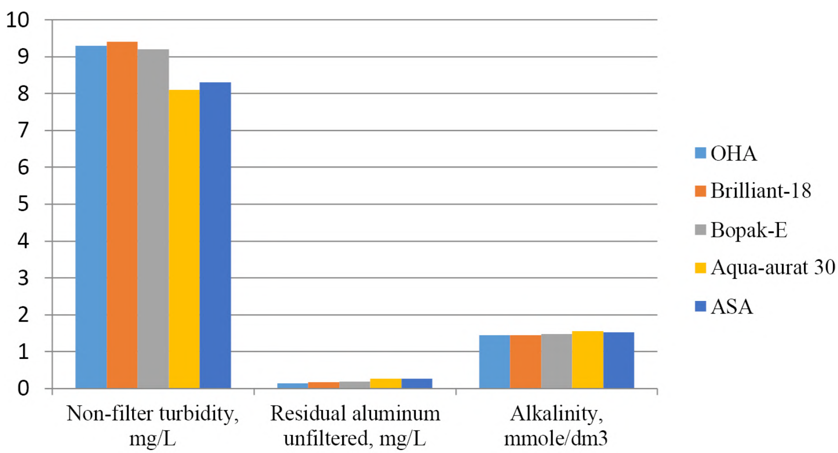

Fig. 5. Coagulant test results – dose according to Al_2O_3 0.8 mg/l / flocculant 0.1 mg/l (water intake facility "Zarya")

As a result of the tests, large flakes were formed only when "Aqua-aurate 30" and "ASA" were applied at a dose of (1.5/0.1 mg/l). Other coagulants formed small and medium flakes and all coagulants showed intensive sedimentation and clarification.

Tests of coagulants were carried out in the spring flood period at the source water temperature of 6-8°C On the source water of the Irtysh River the best results showed coagulants such as “Bopak-E”, “OHA” and “Aqua-aurat 30”.

The optimal dose for the most effective coagulants is Dk=1.5 mg/l (by Al_2O_3) when combined with flocculant with Df=0.1-0.13 mg/l.

During the laboratory tests, coagulants “Bopak-E” and “Brilliant-18” showed the same results of clarified water quality in terms of residual aluminum and water turbidity in comparison with the coagulant “OHA” used at Rosvodokanal Omsk, at doses as close as possible to those established at production (Dk=1.8 mg/l and Df=0.13mg/l).

Coagulant “Aqua-aurate 30” shows better flaking, sedimentation and clarification, and accordingly better indicators of water turbidity.

Under low alkalinity conditions, Aqua-aurat 30 coagulant increases this index, which contributes to solving the problem of poor coagulation. At optimum doses quality indicators of clarified water by residual aluminum, as well as filtered water by turbidity and residual aluminum, meet the quality assurance of drinking water in accordance with SanPiN 1.2.3485-21, GN 2.1.5.1315-03, GN 2.1.5.2280-07.

To confirm the results of laboratory tests and to select the most effective reagent, it is recommended to conduct production tests of coagulant “Aqua-aurat 30”.

Conclusion

In the process of laboratory testing, many reagents are tested. The purpose of the analysis is to find effective reagents under conditions when the water supply source changes its charge and alkalinity decreases.

Laboratory tests of coagulants based on aluminum polyoxychloride such as “Bopak-E”, “OHA” and “Aqua-aurat 30” show that the performance in conditions of low alkalinity is difficult, but the best coagulation ability is shown by the reagent “Aqua-aurat 30” because of its ability to increase alkalinity by 15-18%, which helps to improve the efficiency of coagulation.

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Original article

DETERMINING THE EFFECTIVENESS OF FUNCTIONAL ZONING: RIGHTS AND OBLIGATIONS OF LAND RELATIONS PARTICIPANTS, AND PLANNING AND IMPROVEMENT REQUIREMENTS FOR SETTLEMENT AREAS

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Abstract

Background. The relevance of this study under current conditions is determined by a range of factors reflecting dynamic changes in the socio-economic sphere, technological progress, and the environmental situation. It also addresses the urgent task of defining effective rights and obligations of land relation participants, along with planning and improvement requirements for populated areas. This work involves developing and implementing up-to-date territorial planning documentation, which serves as the foundation for rational and sustainable territorial development. The role of these documents in urban development is critically important, and without them, competent and well-founded planning is impossible.

Purpose. Based on the balance between the various uses of the territory, we discuss an integrated approach to development, including areas with limited suitability for development, through the application of comprehensive development strategies and advanced technologies for their realization.

Materials and methods. A systems approach was applied, in which territorial zoning decisions account for environmental safety and vertical planning aspects of territorial zones. The concept of adaptive geodetic monitoring is emphasized, involving the dynamic adaptation of measurement methods to changing conditions and precision requirements. Classification methods are used to systematize geodetic measurement technologies.

Results. At the theoretical level, modern functional zoning technologies for territorial development of populated areas were systematized, classifying them by degree of effectiveness and application conditions. Regularities of regional influence on the spatial organization and maintenance of populated areas were identified and scientifically substantiated, allowing for the formulation of principles for adapting to dynamic changes in the socio-economic sphere, technological progress, and the environmental situation, as well as tasks for establishing effective rights and obligations of participants in land relations, planning requirements, and landscaping in populated areas. A significant contribution to the theory of settlement development lies in substantiating the optimal balance between the legislative framework and the regulatory basis of territorial planning projects.

Conclusion. The results of this study are important for land use, enabling comprehensive and well-founded decision-making regarding the rights and obligations of land relation participants, as well as planning and improvement requirements for populated areas. Ultimately, the developed method for comprehensive territorial assessment serves as a valuable tool for urban planners and decision-makers seeking to optimize functional zoning, thereby improving the quality of life of residents, promoting sustainable development, and ensuring a balanced and sustainable approach to land use.

Keywords: research; scientific research; territory; relief; vertical grading; urban zoning; territorial zoning; artificial land plot

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Научная статья

ОПРЕДЕЛЕНИЕ ДЕЙСТВЕННОСТИ ФУНКЦИОНАЛЬНОГО ЗОНИРОВАНИЯ: ПРАВА И ОБЯЗАННОСТИ УЧАСТНИКОВ ЗЕМЕЛЬНЫХ ПРАВООТНОШЕНИЙ, ТРЕБОВАНИЯ ПЛАНИРОВКИ И БЛАГОУСТРОЙСТВА ТЕРРИТОРИИ НАСЕЛЕННЫХ МЕСТ

Н.Г. Овчинникова, Н. В. Винокурова, И. А. Петрова

Аннотация

Обоснование. Актуальность работы в современных условиях обусловлена рядом факторов, отражающих динамичные изменения в социально-эко-

номической сфере, технологическом прогрессе и экологической ситуации, а также является актуальной задачей для формирования эффективных прав и обязанностей участников земельных правоотношений, требований планировки и благоустройства территории населенных мест. Данная деятельность заключается в формировании и соблюдении современной документации в сфере территориального планирования, которое в свою очередь является основой для рационального развития территорий. Роль данных документов в градостроительной деятельности крайне колоссальна и без них невозможно дальнейшее грамотное и обоснованное проектирование.

Цель. Основываясь на равновесии между разнообразными видами использования территории, мы обсуждаем комплексный подход освоения, в том числе и неудобных территорий, благодаря применению комплексного развития работ и прогрессивной техники для их выполнения.

Материалы и методы. Системный подход: решения по зонированию территории учитывает развитие экологической безопасности, вертикальной планировки территориальных зон. На первый план выходит концепция адаптивного геодезического мониторинга, предполагающая динамическую корректировку методов измерений в зависимости от изменяющихся условий и требований к точности. Классификационные методы применяются для систематизации технологий геодезических измерений.

Результаты. На теоретическом уровне проведена систематизация современных технологий функционального зонирования в области территориального развития населенных мест с их классификацией по степени эффективности и условиям применения. Выявлены и научно обоснованы закономерности влияния регионального фактора на содержание населенных пунктов, что позволило сформулировать принципы адаптации динамичных изменений в социально-экономической сфере, технологическом прогрессе и экологической ситуации и задачи для формирования эффективных прав и обязанностей участников земельных правоотношений, требований планировки и благоустройства территории населенных мест.

Значимым вкладом в теорию развития населенных мест является обоснование оптимального баланса между фундаментальной подготовкой законодательных актов и нормативов проекта планировки территории.

Заключение. Результаты данного исследования имеют важное значение для использования территории, позволяя комплексно принимать обоснованные решения как прав и обязанностей участников земельных правоотношений, так и требований планировки и благоустройства территории населенных мест. В конечном счёте, разработанный метод выявления комплексного изучения

территорий представляет собой ценный инструмент для городских планировщиков и лиц, принимающих решения, стремящихся оптимизировать функциональное зонирование, что помогает улучшению качества жизни населения, устойчивому развитию территорий, а также помогает соблюдать равновесие между видами использования земельных ресурсов.

Ключевые слова: исследование; научно-исследовательская деятельность; территория; рельеф; вертикальная планировка; градостроительное зонирование; территориальная зона; искусственный земельный участок

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Introduction

Zoning decisions are made based on the following key principles within the comprehensive organization of the territory [1-5]:

– Focus on intensive use and rational organization;

– Formation of a scientifically sound balance of lands for various purposes, preservation of specially protected natural areas, agricultural lands, and areas with valuable historical and cultural heritage, and the development of engineering and transport infrastructure necessary for the development of the territory;

– Precise differentiation of agricultural, forestry, and nature conservation lands from urbanized areas, with legislative establishment of appropriate regimes for their functional use;

– Environmental protection and environmental safety; rational use of natural resources;

– Ensuring the most favorable organizational and territorial conditions for agriculture.

Materials and methods

Environmental and social challenges: land degradation: 25% of agricultural land is subject to erosion, salinization, and oil pollution. Legal mechanisms for the conservation of such lands (Resolution No. 830) are poorly implemented due to regulatory gaps.

To maintain records of natural resources, achieve their proper and sustainable use, and ensure adequate protection, zoning is required for each territorial zoning of a settlement area.

Fig. 1 shows the documentation used to determine the zoning of each territorial zoning.

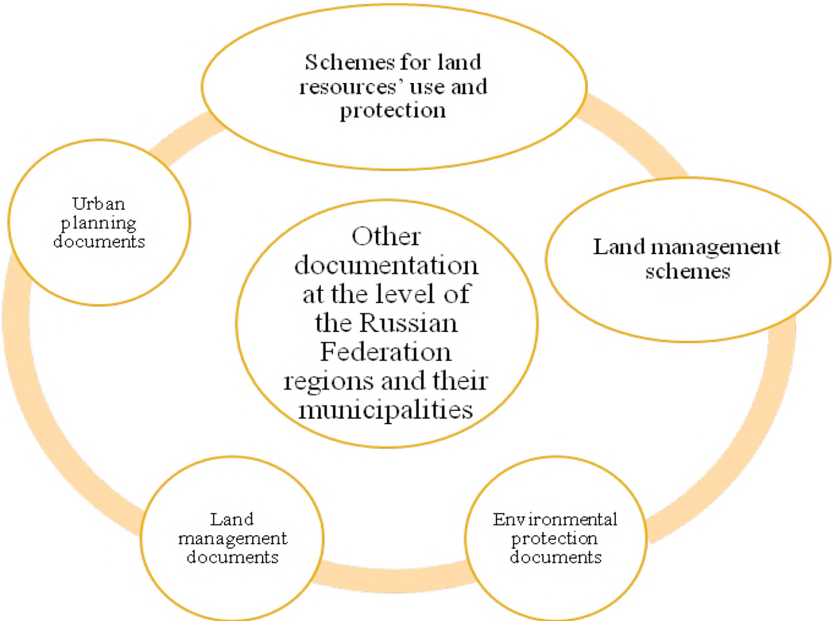

Fig. 1. Documents for zoning the territory

Results

Each territorial zoning has a specific legal status determined by its purpose.

The legal nature of functional zoning is shown in Fig. 2.

Studying this judgment, one can also conclude that the Supreme Court of the Russian Federation's Ruling of June 24, 2009, in Case No. 78-G09-22, which notes that the definition of functional zones in the master plan constitutes the projected development of municipal territories, confirms this.

The establishment or modification of the boundaries of settlement areas is:

1. Approval or modification of the master plan of an urban district or settlement, reflecting the boundaries of settlement areas located within the boundaries of the corresponding municipality.

2. Confirmation or reorganization of the territorial planning scheme of a municipal district when changing the boundaries of rural settlement areas, including territories located outside the boundaries of settlements.

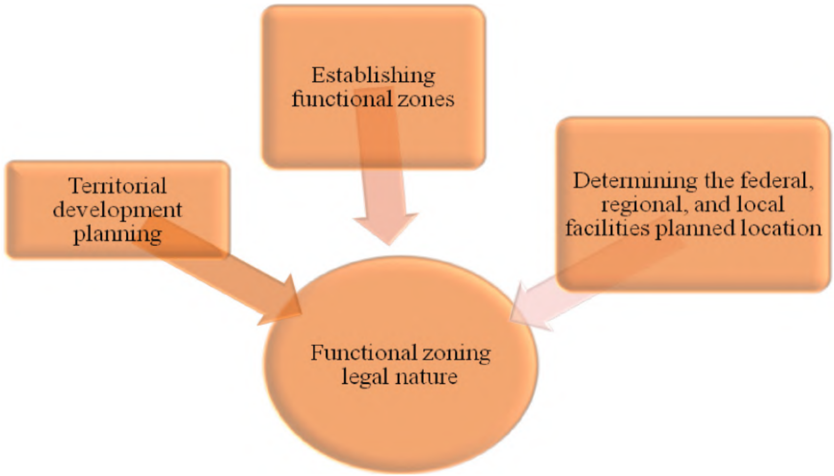

Fig. 2. Legal nature of functional zoning

It follows that when territorial planning documents are amended based on changes to the boundaries of the land category of settlement areas, the legal status of the land is affected. The Urban Development Code of the Russian Federation regulates territorial planning documents in their decision-making and implementation. These decisions can be made or implemented based on a functional zone map, which is a crucial part of municipal territorial planning documents. A decision made or implemented based on such a map (but not the map itself) may affect the rights and obligations of parties to land relations.

Functional zoning can indirectly influence the rights and obligations of parties engaged in land relations [6].

The functional purpose of zones is determined upon the entry into force of the regulatory legal act approving the relevant municipal territorial planning document.

A system of interconnected natural and natural-anthropogenic territories, ensuring sustainable development and functioning of ecosystems, as well as the conservation of biodiversity, is entering the urban development sphere as a key component in the process of renovating the foundations of territorial planning, designed to conserve natural resources while addressing issues related to the protection of natural areas.

In urban planning and land use engineering, territorial zoning are closely linked to vertical grading. Their interaction is based on the fact that the designation of zones determines the requirements for the terrain, and vertical grading ensures the technical implementation of these requirements.

Vertical grading refers to the process of designing and grading land plots to create favorable construction conditions and comfortable terrain.

To achieve these objectives, vertical grading must include work to modify elevations, slopes, and terrain forms. The objectives of vertical grading are shown in Fig. 3.

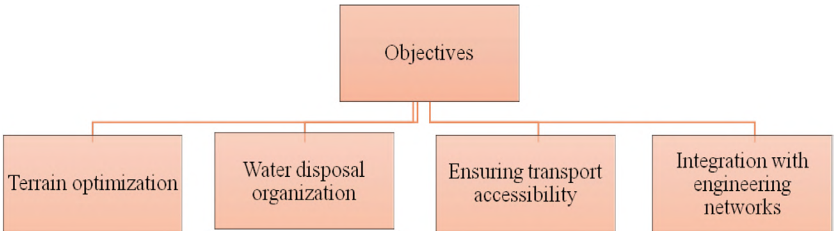

Fig. 3. Vertical grading tasks

The stages of vertical grading are ordered steps aimed at creating a stable and level ground surface [7-10]. The stages are divided into:

- Design (development of a project taking into account slope, drainage, and other requirements);
- Terrain modification (topographic survey);
- Excavation work (cutting, adding soil, creating embankments and trenches);
- Drainage system installation (laying canals, pipes, and other elements for water drainage);
- Landscaping (final landscaping and preparation of the site for use).

The main tools and methods of vertical grading are presented in Table 1.

Table 1.

Basic tools and methods of vertical grading

Vertical grading tools	Vertical grading methods
Geodetic measurements	Determination of elevation marks
Software	CAD systems for design (e.g. AutoCAD, Civil 3D)
Cartographic materials	Topographic plans and maps
Design methods	Profile method, contour method, design elevation method

Modern scientific developments in the field of geodetic monitoring are characterized by several fundamentally new approaches. The concept of adaptive geodetic monitoring, which involves dynamically adjusting measurement methods depending on changing conditions and accuracy requirements, is becoming increasingly prominent.

Research into the integration of heterogeneous geodetic data is of significant scientific interest. Methods are being developed for the joint processing of results obtained using:

– Satellite positioning systems (GLONASS/GPS);
– Electronic tacheometry;
– Airborne and terrestrial laser scanning;
– Aerial photography from UAVs.

Particular attention has been given to the automation of geodetic support processes, including the development of intelligent decision-support systems, automated measurement-quality control algorithms, and specialized software packages for spatial data processing.

An important area of scientific research is the development of multi-level systems for assessing the accuracy of geodetic measurements. Such systems include:

1. Operational monitoring during fieldwork.
2. Office verification of compliance with regulatory requirements.
3. Expert verification of results.
4. Monitoring the stability of geodetic markers.

The methodological basis of modern research in the field of geodetic support for land management is based on a combination of theoretical and practical approaches. The theoretical component includes an in-depth analysis of regulatory documents, scientific publications, and best practices in the organization of geodetic work.

Classification methods are used to systematize geodetic measurement technologies according to a variety of parameters:

– achievable accuracy;
– productivity;
– cost;
– dependence on external conditions;
– complexity of implementation.

Modeling of technological processes is carried out using:

– mathematical models of measurement accuracy;
– computer simulators of field conditions;
– digital twins of territories;
– predictive models of boundary changes.

Experimental methods are aimed at a comparative analysis of various geodetic measurement technologies in real-world conditions. Particular attention is paid to assessing:

– the resistance of methods to external interference;
– reproducibility of results;
– labor intensity of processes;
– economic efficiency.

The mathematical apparatus of the research includes:

– statistical methods of data processing;
– correlation analysis of parameters;
– methods of optimizing technological processes;
– decision-making algorithms under uncertainty.

Geodetic support includes a set of methods and technologies aimed at accurately determining the boundaries of plots, terrain, and other parameters necessary for cadastral registration, design, and construction. Modern technologies (GNSS, UAVs, GIS) significantly accelerate and improve the accuracy of geodetic work.

Discussion

Vertical grading activities are carried out prior to the development of residential areas.

One of the fundamental principles of vertical grading is the preservation of natural topography, achieved with minimal excavation work. Regardless of the terrain modification, the preservation of the soil cover must always be taken into account [11].

Vertical grading leads to changes in the natural topography. Even if it meets planning and landscaping requirements, it can be adjusted to achieve optimal conditions. The volume of excavation work during terrain modification depends on the complexity of the original landscape, the presence of difficult areas, and the planning decisions for the entire territory or its individual elements.

As a rule, according to urban planning, there are virtually no territories that are perfectly suitable for urban development. Due to such problems, some cities are faced with construction on very unfavorable terrain. To implement such construction, landscaping and engineering preparation of the area must be carried out in advance.

It is also worth noting that there are no territories suitable for development in their natural state. Therefore, vertical grading and surface drainage are essential for all areas, including the development of topographically challenging sites. With the use of new methods and equipment, such development is becoming possible.

Cities located in areas with particularly rugged terrain are vulnerable to wind and thermal conditions. Even basic street ventilation in these areas is very difficult, and this is taken into account during layout.

The most demanding conditions, requiring minimal surface gradients, occur in zones allocated for rail transport and industrial use. Residential areas are next; they can be located with significant slopes, but they present a number of disadvantages that force adaptation to the terrain. Recreational areas are less demanding, due to their greater freedom in terrain [12-14].

To preserve the existing natural landscape and ensure rational use, a number of measures must be taken to modify the existing functional zoning. Therefore, when assessing the effectiveness of functional zoning, it is necessary to address a range of issues related to the design, construction, and operation of interconnected infrastructure facilities. The natural topography of each territory must be taken into account during its development. Design may require modifications to the topography depending on the site's intended use and planned functions.

The location of residential microdistricts, primary urban development units, green areas, parks, and other facilities must be justified during the design and construction of settlement areas. Cultivation technologies for land planned for agricultural use must also be considered.

The area under consideration for this study is the Rostov Region, in the city of Rostov-on-Don.

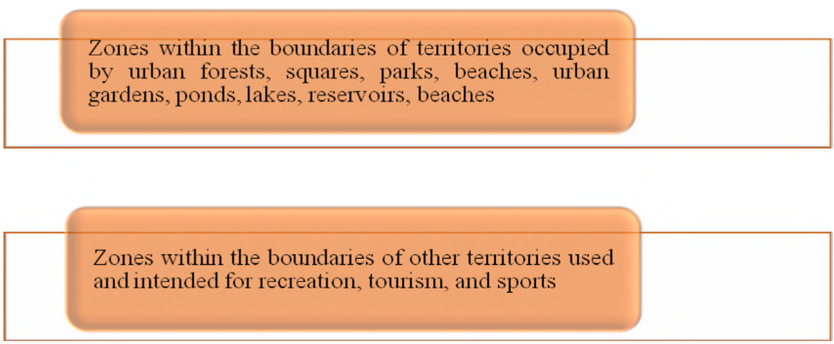

Fig. 4. Composition of territorial zoning for recreational purposes

In a rapidly changing world, functional zoning and the calculation of recreational loads in settlement areas are becoming not only essential for solving current problems but also an important foundation for shaping the sustainable future of cities and settlement areas. The development of territorial zoning should become an active tool in the hands of society, capable of responding to the challenges of the times and creating a comfortable living environment for all citizens. Recreational zones are areas occupied by village forests, public gardens, parks, gardens, ponds, lakes, reservoirs, beaches, and natural landscapes. The composition of territorial recreational zones is shown in Fig. 4.

Territorial zoning may include specially protected areas. Specially protected areas may include land plots with special environmental, scientific, historical, cultural, aesthetic, recreational, health, or other valuable significance.

The composition of territorial zoning of specially protected areas is shown in Fig. 5.

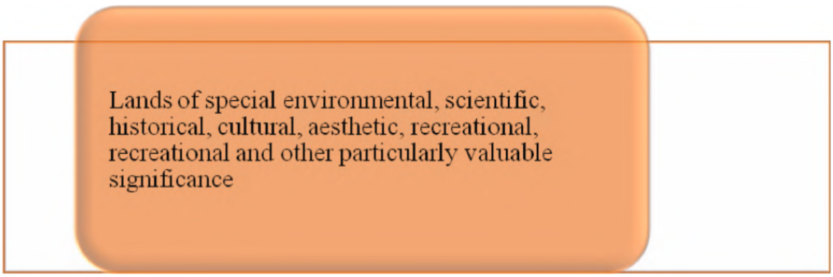

Fig. 5. Structure of specially protected territorial zoning

Areas prone to flooding, gullying, or high groundwater levels must be carefully studied, as these areas are considered difficult or impossible to build on without significant engineering and landscaping measures and are considered unsuitable or unsuitable for development. Bringing the site to the required condition increases the volume of excavation work. This type of work is important both in terms of volume and cost: the larger the volume, the more expensive it becomes.

Topography is modified by vertical grading—the movement of soil from one area to another in the form of cuts and fills. Therefore, it is important to minimize the volume of excavation work and utilize the existing topography as efficiently as possible.

Key areas for improvement are:

– Implementation of intelligent decision support systems;

– Development of digital territorial modeling technologies;

– Automation of quality control processes;

– Integration of various measurement methods;

The practical implementation of modern developments requires the creation of a comprehensive system that includes:

– Regulatory support;
– Training of qualified personnel;
– Technical re-equipment;
– methodological support.

Prospects for the development of geodetic support in territorial zoningdevelopment are linked to the active implementation of digital technologies, the development of cloud services for geodata processing, and the creation of distributed monitoring systems. This will significantly improve the accuracy and reliability of results in the context of increasingly complex territorial development tasks.

Classification methods are used to systematize geodetic measurement technologies according to a variety of parameters:

– achievable accuracy;
– productivity;
– cost;
– dependence on external conditions;
– complexity of implementation.

Vertical grading design work is carried out at all stages of horizontal planning: master plan projects; detailed planning projects; and development projects [15].

Territorial planning helps improve the quality of life of the population, promote sustainable development of territories, and also leads to a balance between land use.

In the Rostov Region, as in other regions, territorial planning plays an important role in territorial development. It is aimed at creating favorable living conditions for the population, ensuring economic growth, and the rational use of natural resources. In accordance with urban planning regulations for the category of lands of settlement areas, zoning of territories will be the assignment of land plots to territorial zoning.

The planning structure of settlement areas highlights the historically established principle of formation (as of 2025).

By and large, the settlement system and planning structure of each studied settlement area in the Rostov Region were primarily influenced by their development processes.

The park area is classified as a multifunctional park zone (according to the functional zoning map of the General Plan of the City of Rostov-on-Don).

When analyzing the functional zoning of the park, it is necessary to properly divide it into zones based on their intended purpose.

Next, to calculate the recreational load, it is necessary to determine the number of park visitors.

The number of potential park visitors is determined using formula (1).

$$N=S\cdot\rho \quad (1),$$

where N – number of potential park visitors (people);

S – area of the territory within walking distance (ha);

ρ – population density (persons/ha).

The population density of the study area should be determined using data from the official website of the district administration.

After the in-kind survey, which must be conducted on weekdays and weekends, in the morning and evening, the number of park visitors must be calculated based on the number of people entering the park per hour.

The recreational load on the area must be calculated in accordance with the above data.

According to "SP 42.13330.2016 Urban Development. Planning and Development of Urban and Rural Settlements. Updated version of SNiP 2.07.01-89," Section 9 "Recreational Zones. Zones of Specially Protected Areas": the estimated number of simultaneous visitors to city parks should not exceed 100 people/ha.

Therefore, according to the in-kind survey, the maximum number of simultaneous park visitors should not exceed the standard.

It is important to note that, to preserve the existing natural landscape of the area and ensure rational use, it is necessary to implement a number of measures to change the existing functional zoning.

The implementation of urban planning principles—the formation of a city center, main routes, landscaping systems, social services, and improvements—is carried out as the city's master plans are developed.

The key factors that will determine the rational functional zoning of a land plot in each territorial zoning of the studied settlement for decision-making are presented in Table 2.

The relevance of research in functional zoning is also linked to the concept of sustainable development. Therefore, it is necessary to consider not only the current needs of the population but also the needs of future generations. This requires the integration of economic, social, and environmental aspects in both territorial planning and development. Research in this area helps develop strategies that balance development and resource conservation.

Table 2.

Key factors associated with high-quality functional zoning of a land plot in each territorial zoning

Factors to consider when making a decision		
Insolation Improvement	Technical condition and reliability of the territory	Residual value of infrastructure
Noisiness of the area	Structural, technological and organizational solutions	Residual value of buildings
Atmospheric pollution	Level of recreation of the territory	Profit assessment
Transport accessibility	Recreational method	Project profitability with an assessment of the volume of capital investments
Decision making		

One modern solution to the shortage of land designated for construction and subsequent residential use is the creation and use of artificial land plots located within the boundaries of water bodies. For example, in 2015, work was completed in St. Petersburg to create an artificial land plot within the boundaries of the Gulf of Finland on the western part of Krestovsky Island. The project aimed to extend the embankment and accommodate transport infrastructure within this area. Federal Law No. 246-FZ of July 19, 2011, "On Artificial Land Plots Created on Federally Owned Water Bodies and Amending Certain Legislative Acts of the Russian Federation," will help us clarify this issue.

A key feature of artificial land plots is their physical connection to the natural landmass, making them a direct extension of the earth's surface. This means that artificial land plots created by reclamation, backfill, or other technologies should be considered an integral part of the earth's surface, not indirect structures connected to the land only through operational or construction elements. Thus, artificial land plots possess the fundamental characteristic of natural land plots—their connection to the earth's landmass.

However, this also raises the question of how to register this type of structure. Since, until the moment of commissioning, a real estate object is technically considered a structure with an attached technical plan, however, after commissioning, it is recognized as a land plot for which a cadastral plan is required.

Even at the design stage, the process of creating an artificial land plot involves the development of a large amount of documentation to ensure the legal and technical justification for creating the artificial land plot. However, this process can be thought of as a sequential chain of regulatory documentation development.

The first stage of designing an artificial land plot is the creation of design documentation in accordance with the requirements of the Urban Development Code of the Russian Federation and other regulatory acts. In particular, the most important step here is to develop a land use plan (LUP).

A land use plan for artificial land plots contains a comprehensive set of information necessary for the proper creation of the construction project and its subsequent operation. Several key points contained in a land use plan can be highlighted:

Description of the artificial land plot. This section includes:

- the method of construction: reclamation, backfill, reclamation, hydraulic method, or a combination of methods, etc.;

- area. This indicates the total area of the land plot, as well as the areas of its individual zones and objects, etc.;

– Geometric characteristics: the shape of the described object, boundaries, topography, and slope;

– Compaction degree: soil compaction requirements to ensure stability and prevent subsidence.

– Utilities. These include planned utilities that will be located on the land plot: water supply, sewerage, electricity, gas, heat, communications, etc.

Environmental aspects:

– Environmental impact assessment: analysis of potential risks of water, air, and soil pollution, impact on flora and fauna;

– Measures to minimize negative impacts: design solutions for environmental protection, such as wastewater filtration systems, reclamation of disturbed land, landscaping, etc.

Functional purpose:

– Type of use: residential, industrial, commercial, recreational, agricultural;

– Planned objects: buildings, structures, roads, transport infrastructure, parks, squares, etc.

– Architectural and urban planning solutions: design, style, development concept, architectural solutions for buildings, site planning, etc.

Engineering solutions:

– Utility network designs: road layouts, water supply, sewerage, electricity, gas, heat, and communications;

– Coastal strengthening: erosion protection, coastal fortification, dam construction;

Reclamation measures:

– Landscaping: planting trees, shrubs, and lawns to improve the ecological situation;

– Soil formation: application of organic fertilizers, creation of a fertile soil layer;

– Irrigation systems: irrigation systems to maintain soil moisture.

Implementation stages:

– Construction stages: a description of the phased implementation of work, from site preparation to completion of construction;

– Implementation timeline: determining the deadlines for each stage of work;

– Estimate: calculating the project cost, including the costs of materials, equipment, labor, etc.

A conclusion can be drawn regarding the feasibility of the project, i.e., determining the environmental and economic feasibility of the work to be performed, and outlining recommendations for project implementation, taking into account all the characteristics of the territory.

It is important to note that the territorial planning project is a comprehensive document that must be developed in accordance with laws and regulations, and all design solutions must be based on the principles of sustainable development and environmental safety, which includes the maximum minimization of negative impacts on the environment. The regulation and specifics of this process are reflected primarily in Article 45 of the Urban Development Code of the Russian Federation.

In addition, a land surveying project (LSP) is prepared, which more accurately displays the site boundaries and provides the results of geodetic measurements and cadastral data. Such documentation is primarily required for subsequent cadastral registration of a plot. This process is outlined in Article 43 of the Urban Development Code of the Russian Federation. Several key points contained in a land survey project can be highlighted:

Establishing the boundaries and area of the land being formed.

A land survey project establishes the clear boundaries of the land being formed, including the shape, size, and coordinates of turning points. The coordinates are determined through geodetic surveys using specialized equipment.

Creating cadastral plans of the territory.

A land survey project is the basis for creating cadastral plans, which are necessary for registering the plot with the cadastral register and entering information into the Unified State Register of Real Estate. This procedure is necessary for obtaining ownership of the land.

Establishing easements and functional zoning of the land being formed.

A land survey project is the basis for developing land planning projects, development plans, utility plans, and other documents necessary for the further development of the territory. After this documentation is prepared, two important assessments are carried out: environmental and engineering. The purpose of these assessments is to understand the extent of the environmental impact and to determine whether the project is technically feasible.

Conclusion

Validating research results is an important step that enables the verification of theoretical conclusions and practical recommendations in practice. This process involves several essential stages and methods that ensure the effective validation and implementation of research findings.

The problematic nature of this topic stems from the fact that current Russian legislation is not adapted to the specifics of the creation and legal registration of such territories, which gives rise to a complex set of interdisciplinary contradictions. Key aspects of the problem include:

Legal uncertainty

– the lack of a clear definition of an artificial land plot (ALP) in the Land Code of the Russian Federation (in contrast to Federal Law No. 246-FZ “On Artificial Land Plots,” which regulates only marine territories).

– conflict of regulations: the creation of ALPs on water bodies requires approval under the Water Code (Article 11) and Federal Law No. 246; fill territories on land are covered by the Urban Development Code of the Russian Federation and Federal Law No. 218, but their geotechnical risks are not taken into account.

Technical and legal conflicts during land surveying

– impossibility of using standard methods: Traditional geodetic benchmarks “float” on unstable soils; artificial plot of land boundaries are dynamic (e.g., due to erosion or backfill).

– cadastral registration issues: Rosreestr requires precise coordinates, but the permissible error for artificial plot of land, as defined by Order No. 921 of the Ministry of Economic Development.

Environmental and urban development risks are presented in Table 3.

Economic imbalances

– Financing: inability to obtain a mortgage for construction on artificial land plots (banks do not accept them as collateral due to legal risks).

– Taxation: the cadastral value of artificial land plots is calculated as for regular land, ignoring: high maintenance costs (bank stabilization, drainage); limited-service life (max. 50-70 years for filled areas).

The research topic is relevant to 20+ artificial land plot projects in the Russian Federation. Its implementation will prevent losses (up to 7 billion rubles/year) and create a legal basis for sustainable development of coastal agglomerations. Testing is planned in pilot regions: Moscow, Kaliningrad, and Vladivostok.

Table 3.

Environmental and urban development risks

Problem	Consequences	Regulatory gap
Lack of environmental impact assessment during the creation of the artificial plot of land	Pollution of waters, destruction of biological resources (Black Sea, Sochi)	Federal Law No. 7 «On Environmental Protection» does not require an environmental impact assessment for the ISU
Failure to take into account the load on infrastructure	Subsidence of soil under buildings (example: the reclaimed area of Novy Bereg in Kaliningrad)	SP 47.13330 does not contain standards for artificial plots of land.

Addressing these challenges will not only enhance the quality of recreational land use but also foster the development of sustainable strategies for the efficient utilization of territories.

The key performance indicators of functional zoning are presented in Table 4.

Table 4.

Key performance indicators of functional zoning

Economic	Reducing technical support costs during the modernization of territorial zoning
Ecological	Supporting public health through the use of environmentally friendly zoning
Social	Living conditions of the population in old and new urban areas must be gradually equalized and qualitatively improved.
Urban planning	Modernization of the development and planning structure of the territorial zoning with the aim of increasing the architectural and spatial qualities of the territory

In our opinion, the proposed indicators for functional zoning in each territorial zoning of the studied settlement will help to efficiently use the territory and get as close as possible to its rational use.

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ВКЛАД АВТОРОВ

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Original article

MICROBIOLOGICAL STUDY OF WOUNDS AND LARGE INTESTINE OF STURGEONS USING β-CYCLODEXTRIN COMPLEX WITH LEVOFLOXACIN

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Abstract

Background. The research laboratory Progressive biotechnologies in aquaculture of the Saratov State University of Genetics, Biotechnology and Engineering named after N.I. Vavilov studied the effect of complexes of ß-cyclodextrin on the healing of skin wounds in hybrid sturgeon fish. The total microbial count of sturgeon cut wounds was determined using the culture method and the composition of the microflora of the fish colon using the qPCR method under the influence of the ß-cyclodextrin complex. This complex was ß- cyclodextrin with levofloxacin included in a chitosan shell. The complex was adsorbed on the surface of the feed that the sturgeons received daily. Changes in the total microbial count demonstrate the nature of the inflammatory process and the effectiveness of the use of therapeutic drugs. The study of the colon microbiota also demonstrates the result of using these complexes in fish. It was found that the use of antibacterial complexes of ß-cyclodextrins with chitosan on sturgeons leads to a significant decrease in the total microbial count of the wound surface. The highest antimicrobial activity was established for the chitosan-ß-cyclodextrin complex with 20 and 15% levofloxacin content. The presence of bacteroides, eubacteria, clostridia, peptostreptocci, enterobacteria, lactobacilli and staphylococci were determined in the composition of the normal flora. At the same time, by the end of the experiment, the microbiome of the large intestine of fish is characterized by the restoration of the number of lactic acid bacteria. The research results can be used in aquaculture in the process of fish cultivation in the treatment of injuries to the outer coverings received during transportation and sorting.

Purpose. Reproduction and cultivation of fish in aquaculture is inevitably associated with trauma to the skin of fish, infection with saprophytic, opportunistic and

pathogenic microorganisms during transportation, sorting, dense planting, and transition to new feed. All these factors reduce the immune status of the fish organism and lead to the occurrence of various diseases that affect all metabolic processes. Currently, antibiotics of various groups with a wide spectrum of action are use to combat infectious diseases, as well as for prevention purposes. Due to the specific lifestyle of aquatic organisms, antibiotics are introduced into the fish organism in aquaculture using medicinal baths, injections, or orally with feed.

Materials and methods. The effect of the chitosan-ß-cyclodextrin complex on the fish organism under aquarium conditions was studied. This complex was synthesized and provided by the Department of Chemical Enzymology of the Lomonosov Moscow State University. The studied complex is a light yellow powder, slowly soluble in water due to the content of chitosan and cyclodextrin and added to fish feed. For the experiment, 5 groups of sturgeons with wounds in the form of dorsal cuts of the skin 2 cm long and 0.5 cm deep were formed using the pair-analogue method. Before the experiment, the fish were fed with compound feed with a peroxide value of 24.68±2.22 for 10 days to form a model digestive disorder and intestinal dysbiosis. The fish received feed with the preparation daily (3 times a day). Individuals of the 1st and 2nd control groups did not receive the studied complex, in addition, individuals of the 2nd control group continued to receive low-quality feed during the experiment. The experimental groups received high-quality feed with the complex in different dosages of levofloxacin (the first - a complex with 20%, the second - with 15% and the third - with 10% of the antibiotic, respectively) for 7 days.

Results. The study of sturgeon wound microflora showed that the studied chitosan-ß-cyclodextrin complex with an antibiotic reduces the TMC of cut wounds. In individuals of the control groups (K1 and K2), the inflammatory process in the wounds continued until the end of the experiment (day 8). On the 8th day, the greatest suppressive effect on the microflora of fish wounds was exerted by complexes with 15 and 20% antibiotic content: in both groups, the decrease in TMC relative to day 1 was 1000 times, below K1 by 1000 times, and K2 by 10000 times. The results of assessing the diversity of sturgeon large intestine microflora indicate that the control group of fish is characterized by normal microflora: bacteroides, eubacteria, clostridia, peptostreptocci, enterobacteria, lactobacilli and staphylococci. In the experimental groups a decrease in the number of lactobacilli, enterobacteria, fusobacteria, eubacteria and clostridia genomes was recorded. Lactate-utilizing bacteria were not detected. Gradual recovery of the fish organism is confirmed by the presence of lactobacilli on the 14th day in the same quantity as before injury and the use of the complex, as well as the absence of mycoplasmas, streptococci and Candida fungi.

Conclusion. A study of wound microflora using the culture method showed that chitosan-ß-cyclodextrin complexes with levofloxacin, used in the treatment of sturgeons, have a significant antimicrobial effect on the number of microorganisms compared to the control groups, with the best effect by the end of the experiment being provided by complexes with 15 and 20% levofloxacin.

A study of wound microflora using the culture method showed that chitosan-ß-cyclodextrin complexes with levofloxacin, used in the treatment of sturgeons, have a significant antimicrobial effect on the number of microorganisms compared to the control groups, with the best effect by the end of the experiment being provided by complexes with 15 and 20% levofloxacin. Molecular genetic research using the PCR method in real time determined the presence of bacteroids, eubacteria, clostridia, peptostreptocci, enterobacteria, lactobacilli and staphylococci in the composition of the normal flora. In the 14 days the microflora of the large intestine of fish is characterized by a confident restoration of the number of lactic acid bacteria that regulate immune processes.

Keywords: reproduction; biotechnology; aquaculture; inflammatory process; bacteroides; eubacteria; clostridia; peptostreptocci; enterobacteria

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Научная статья

МИКРОБИОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ РАН И ТОЛСТОГО КИШЕЧНИКА ОСЕТРОВЫХ ПРИ ИСПОЛЬЗОВАНИИ КОМПЛЕКСА В-ЦИКЛОДЕКСТРИНА С ЛЕВОФЛОКСАЦИНОМ

И.В. Поддубная, Г.Т. Урядова, Ю.Н. Зименс, И.Д. Злотников, Е.В. Кудряшова

Аннотация

Обоснование. В научно-исследовательской лаборатории «Прогрессивные биотехнологии в аквакультуре» Саратовского государственного университета генетики, биотехнологии и инженерии имени Н.И. Вавилова было изучено

влияние комплексов производных ß-циклодекстрина с левофлоксацином на заживление ран кожных покровов гибрида осетровых рыб. Культуральным методом определяли общее количество микроорганизмов в резаных ранах осетровых, а методом qPCR – состав микрофлоры толстой кишки рыб под воздействием комплекса ß-циклодекстрин. Данный комплекс представлял собой ß-циклодекстрин с левофлоксацином, заключенный в хитозановую оболочку. Комплекс адсорбировался на поверхности корма, который осетры получали ежедневно. Изменения общего микробного числа демонстрируют характер течения воспалительного процесса и эффективность применения лечебных препаратов. Исследование микробиоты толстого кишечника также демонстрирует результат применения данных комплексов у рыб. Обнаружено, что применение антибактериальных комплексов ß-циклодекстринов с хитозаном на примере осетров приводит к существенному уменьшению общего микробного числа раневой поверхности. Наибольшую эффективность продемонстрировали комплексы хитозан-ß-циклодекстрин с 20 и 15 % содержанием левофлоксацина. В составе нормофлоры кишечника определено наличие бактероидов, эубактерий, клостридий, пептострептокков, энтеробактерий, лактобацилл и стафилококков. При этом к концу эксперимента микробиом толстого кишечника рыб характеризуется восстановлением числа молочнокислых бактерий.

Цель. Воспроизводство и выращивание рыбы в аквакультуре неизбежно связано с травмированием кожных покровов рыбы, заражением сапрофитными, условно-патогенными и патогенными микроорганизмами при транспортировке, сортировке, плотной посадке и при переходе на новый корм. Все эти факторы снижают иммунный статус организма рыбы и приводят к возникновению различных заболеваний, затрагивающих все обменные процессы. В настоящее время для борьбы с инфекционными заболеваниями, а также в целях профилактики используются антибиотики различных групп с широким спектром действия.

Материалы и методы. Действие комплекса хитозан-ß-циклодекстрин на организм рыб в условиях аквариумной установки исследовалось в научно-исследовательской лаборатории «Прогрессивные биотехнологии в аквакультуре» кафедры «Генетика, разведение, кормление животных и аквакультура» ФГБОУ ВО Вавиловский университет (г. Саратов). Комплекс разработан и предоставлен кафедрой «Химическая энзимология» МГУ им. М.В. Ломоносова. Исследуемый комплекс – порошок светло-желтого цвета, медленно растворимый в воде за счет содержания хитозана и циклодекстрина и добавляемый в корм рыбам. Для эксперимента методом пар-аналогов были сформированы 5 групп осетров с ранами, которые представляли собой дорсальные надрезы кожных покровов длиной 2 см и глубиной 0,5 см. До начала опыта в течение 10 дней рыбу кормили комбикормом с перекисным числом 24,68±2,22 для формирования модельного нарушения пищеварения и дисбиоза кишечника. Корм с препаратом рыбы получали ежедневно (3 раза в день). Особи 1-й и 2-й контрольных групп изучаемый комплекс не получали, кроме того, особи 2-й контрольной группы в процессе опыта продолжали получать в пищу некачественный корм. Опытные группы получали качественный корм с комплексом в различной дозировке левофлоксацина (первая – комплекс с 20 %, вторая – с 15 % и третья – с 10 % антибиотика соответственно) в течение 7 суток. Определяли общее микробное число (ОМЧ) в смывах с ран рыб культуральным методом и состав микрофлоры толстого кишечника рыб методом qPCR.

Результаты. Исследование раневой микрофлоры осетров показало, что изучаемый комплекса хитозан-ß-циклодекстрин с антибиотиком снижает ОМЧ резаных ран. У особей контрольных групп (К1 и К2) воспалительный процесс в ранах продолжался до конца эксперимента (8 сутки). На 8 сутки наибольшее подавляющее действие на микрофлору ран рыб оказали комплексы с 15 и 20% содержанием антибиотика: в обеих группах снижение ОМЧ относительно 1 суток – в 1000 раз, ниже К1 в 1000 раз, а К2 – в 10000 раз.

Исследование представителей микрофлоры толстого кишечника рыб определило наличие бактероидов, эубактерий, клостридий, пептострептокков, энтеробактерий, лактобацилл и стафилококков. В опытных группах на протяжении всего времени наблюдений зафиксировано снижение количества геномов лактобацилл, энтеробактерий, фузобактерий, эубактерий и клостридий, что указывает на антимикробную эффективность применяемых лечебных препаратов и закономерный дисбаланс (дисбактериоз). Лактат-утилизирующие бактерии не были обнаружены. Постепенное восстановление организма рыб подтверждается наличием на 14 сутки лактобацилл в том же количестве, что до ранения и применения комплекса, а также отсутствием микоплазм, стрептококков и грибов рода кандида.

Заключение. Изучение микрофлоры ран культуральным методом показало, что комплексы хитозан-ß-циклодекстрин с левофлоксацином, примененные в лечении осетров, оказывают значительное антимикробное влияние на количество микроорганизмов по сравнению с контрольными группами, при этом к концу эксперимента наилучший эффект оказывали комплексы с 15 и 20% содержанием левофлоксацина.

Молекулярно-генетическое исследование методом ПЦР в режиме реального времени определило в составе нормофлоры наличие бактероидов, эубактерий, клостридий, пептострептокков, энтеробактерий, лактобацилл и

стафилококков. К концу наблюдений микрофлора толстого кишечника рыб характеризуется уверенным восстановлением числа молочнокислых бактерий, регулирующих иммунные процессы.

Ключевые слова: размножение; биотехнологии; аквакультура; воспалительный процесс; бактероиды; эубактерии; клостридии; пептострептококки; энтеробактерии

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Introduction

The research laboratory Progressive biotechnologies in aquaculture of the Saratov State University of Genetics, Biotechnology and Engineering named after N.I. Vavilov studied the effect of complexes of ß-cyclodextrin derivatives with levofloxacin on the healing of skin wounds in hybrid sturgeon fish. The total microbial count of sturgeon cut wounds was determined using the culture method and the composition of the microflora of the fish colon using the qPCR method under the influence of the ß-cyclodextrin complex. This complex was ß-cyclodextrin with levofloxacin included in a chitosan shell. The complex was adsorbed on the surface of the feed that the sturgeons received daily. Changes in the total microbial count demonstrate the nature of the inflammatory process and the effectiveness of the use of therapeutic drugs. The study of the microbiota of the colon also demonstrates the result of using these complexes in fish. It was found that the use of antibacterial complexes of ß-cyclodextrins with chitosan on the example of sturgeons leads to a significant decrease in the total microbial count of the wound surface. The greatest efficiency was demonstrated by chitosan-ß-cyclodextrin complexes with 20 and 15% levofloxacin content. The presence of bacteroids, eubacteria, clostridia, peptostreptocci, enterobacteria, lactobacilli and staphylococci were determined in the composition of the normal intestinal flora. At the same time, by the end of the experiment, the microbiome of the large intestine of fish is characterized by the restoration of the number of lactic acid bacteria.

Reproduction and cultivation of fish in aquaculture is inevitably associated with trauma to the skin of fish, infection with saprophytic, opportunistic and pathogenic microorganisms during transportation, sorting, dense planting, and transition to new feed. All these factors reduce the immune status of the fish organism and lead to the occurrence of various diseases that affect all metabolic processes. Currently, antibiotics of various groups with a wide spectrum of action are used to combat infectious diseases, as well as for prevention purposes. Due to the specific lifestyle of aquatic organisms, antibiotics are introduced into the fish organism in aquaculture using medicinal baths, injections, or orally with feed [1].

Recently, with the development of nanotechnology, various nanoparticles have been used to deliver drugs to animals. One of these developments is complexes of β-cyclodextrin (CD) derivatives for the delivery of drugs and prophylactic drugs to fish. Due to their tiny size and porous nature, β- cyclodextrin derivatives can bind poorly soluble drugs within their matrix and improve their bioavailability [2; 3].

Cyclodextrins and their derivatives have found application in pharmaceuticals as complexing agents that mask unpleasant odors and tastes, increasing the solubility, stability, and bioavailability of included molecules [4; 5]. They can be used to deliver drugs to specific sites, which prevents the degradation of drugs and proteins and prolongs the elimination of drugs [6-11]. The combination of cyclodextrin carriers with various polymers with a large number of covalent intramolecular bonds can cause a change in the properties of the drug compared to a simple drug-CD complex [8; 12].

A possible component of such a complex is a heteropolysaccharide. chitosan, which is characterized by good water solubility, biocompatibility and biodegradability, mucoadhesion, antimicrobial activity [13-16]. All these properties of chitosan make it attractive for use in agriculture and veterinary medicine. In this regard, scientific research on the creation and improvement of the effectiveness of such cyclodextrin drug complexes with antibiotics in the therapy of commercial fish is relevant.

One of the groups of antibiotics that fit into the porous structure of β-cyclodextrin derivative complexes are fluoroquinolones II generation, aimed at suppressing and destroying infections of various etiologies [8; 17], including pathogens of infectious lesions of cuts, burns and other types of wounds and damage to the outer skin.

Currently, ciprofloxacin is widely used in Russian aquaculture, while levofloxacin, also a fluoroquinolone, is a new agent for treating fish that has not been sufficiently studied, but is promising, since resistance to antibiotics used in aquaculture in fish is a fairly common phenomenon [18-20].

Purpose. The aim of the work was to study the effect of chitosan-ß-cyclodextrin complexes containing 10, 15 or 20% levofloxacin on the microflora of cut wounds and the composition of the microflora of the large intestine of fish using the qPCR method of juvenile hybrid Russian and Siberian sturgeon (*Acipenser queldenstadtii*, Brandt et Ratzeburg, 1833, and *Acipenser baeri stenorrhea Nikolsky*). In accordance with the principles of rational antibiotic therapy and to find the lowest effective concentration, complexes with different antibiotic contents were used in the work.

Materials and methods

The experiment was conducted in the research laboratory Advanced biotechnologies in aquacultureof the department “Genetics, breeding, feeding of animals and aquaculture” of the Federal State Budgetary Educational Institution of Higher Education Vavilov University in Saratov in the conditions of an aquarium installation. During the study, the effect of the chitosan-ß-cyclodextrin complex was studied. The studied chitosan-ß-cyclodextrin complex was synthesized and provided by the department “Chemical Enzymology” of the Lomonosov Moscow State University and and was a light yellow powder consisting of amphiphilic polymer particles have been developed that dissolve extremely slowly in water, since they contain chitosan and cyclodextrin, and they can be added to fish feed. Encapsulated fluoroquinolone will be released in a prolonged manner in the intestines of fish.

Chitosan and cyclodextrin are biocompatible, safe, and have mucoadhesive effects in the gastrointestinal tract. Cyclodectrin forms inclusion complexes with antibiotics and is used as a molecular container. The particles release the drug into the water extremely slowly (namely, 85% of levofloxacin is stored on the carrier in an hour), and therefore the entire antibiotic can be eaten by fish in the form of particles with food. At the same time, the bioavailability and effectiveness of antibacterial and healing effects increased.

The complex was created in the following way: A solution of carbonyldiimidazole (CDI) in DMSO of 50 mg/ml in a five-fold molar excess was added to a solution of hydroxypropyl cyclodextrin (HPC) in water of 5 mg/ml slowly dropwise with intensive stirring. The mixture is heated to 60 ° C for 2 hours. Then, activated HPCD was added to a 5 kDa chitosan solution in a sodium acetate buffer (0.02 M, pH 5) with intensive stirring. The solution was incubated for 12 hours at 50 °C. Purification from unreacted impurities was carried out using dialysis against water (3.5 kDa cut-off weight) for 24 hours. Then LF in 0.01 M HCl (30% by weight of polymer) was added to the solution. The system was incubated for 12 hours at 40°C. Purification from unreacted impurities was carried out using dialysis against water (3.5 kDa cut-off weight) for 24 hours. The samples were freeze-dried.

The degree of modification was calculated according to spectrophotometric titration of amino groups (before and after modification) with 2,4,6-trinitrobenzenesulfonic acid (TNBS) using 1 M TNBS solution in 1 M sodium borate buffer (pH 9.2). The content of amino groups in modified chitosan is assumed to be 100%.

Fourier infrared spectroscopy (FTIR). The IR spectra of the sample suspension were recorded using a Bruker Tensor 27 spectrometer equipped with a liquid nitrogencooled MCT (mercury-cadmium telluride) detector. The samples were placed in a BioATRII thermostatic cell with a ZnSe ATR element (Bruker, Bremen, Germany).

The FTIR spectra were obtained in the range from 850 to 4000 cm−1 with a spectral resolution of 1 cm−1. 50 scans were accumulated and averaged for each spectrum. Spectral data was processed using the Bruker Opus 8.2.28 software system (Bruker, Bremen, Germany).

The synthesis of nanospanges particles with LF includes: 1) obtaining chitosan particles grafted with CD 2) loading of LF. Chitosan-CD conjugates were obtained by the modification reaction of 5 kDa chitosan amino groups with activated OH CD groups to form the chitosan product:CD = 1:4 (according to the analysis of IR spectra).

The average particle size is 120±30 nm according to the analysis of the trajectory of nanoparticles.

In the process of conducting the research, before the experiment, 5 groups of sturgeons (n=10) were formed using the pair-analogue method and placed in aquariums. The experimental scheme is presented in Table 1.

Table 1.

Scheme experience

Group	Fish condition	Feeding type
1 control (K1)	Damaged	Basic diet of quality feed (BD_{QF})
2 control (K2)	Damaged	Basic diet of low-quality feed (BD_{LQF})
1 experienced	Damaged and receiving treatment	BD_{QF} + complex with 20% levofloxacin
2 experienced	Damaged and receiving treatment	BD_{QF} + complex with 15% levofloxacin
3 experienced	Damaged and receiving treatment	BD_{QF} + complex with 10% levofloxacin

To obtain a pronounced effect from the introduction of the chitosan-ß-cyclodextrin complex, the fish were fed with expired compound feed with a peroxide value of 24.68±2.22 (ORN) for 10 days before the experiment, which suggested a model digestive disorder and intestinal dysbiosis. The fish received feed with the preparation daily (3 times a day). Individuals of the 1st and 2nd control groups did not receive the studied complex; in addition, individuals of the 2nd control group continued to receive low-quality feed during the experiment. The experimental groups received high-quality feed with the chitosan -ß- cyclodextrin complex in different dosages of levofloxacin (the first - a complex with 20% levofloxacin, the second - with 15% levofloxacin and the third - with 10% levofloxacin) for 7 days. The composition of the combined feed for sturgeons (OR) is balanced in terms of nutrients.

The simulated wounds were dorsal skin incisions 2 cm long and 0.5 cm deep.

The total microbial count (TMC) was determined in fish wound swabs using the culture method (the method of serial dilutions followed by sowing on meat-peptone agar (MPA)) and the composition of the microflora of the large intestine of fish by the method qPCR (real-time PCR).

Results

The study of sturgeon wound microflora revealed a significant effect of the chitosan-ß-cyclodextrin complex with levofloxacin on the MFC of cut wounds. As can be seen from the results presented in Table 2, in the control groups (K1 and K2), the inflammatory process in the wounds continued until the end of the experiment (day 8).

In group K1, the MFC significantly decreased by day 8. At the same time, in group K2, the MFC value increased by day 8 and was 10 times higher compared to group K1, which indicates the effect of feed quality on the growth and development of fish wound microflora.

Table 2.

Cyclodextrin complexes with antibiotic and chitosan on the microflora of sturgeon cut wounds

Groups	Day	
	1	8
	OMCH, CFU/ml	
K1	$5.0 \cdot 10^{5} \pm 0.2$	$1.0 \cdot 10^{5} \pm 0.4^{*}$
K2	$5.0 \cdot 10^{5} \pm 0.2$	$1.0 \cdot 10^{6} \pm 0.4^{*\bullet}$
1 experimental - 20% levofloxacin	$5.0 \cdot 10^{5} \pm 0.2$	$1.0 \cdot 10^{2} \pm 0.2^{*\bullet\circ}$
2 experimental - 15% levofloxacin	$1.0 \cdot 10^{5} \pm 0.1$	$1.0 \cdot 10^{2} \pm 0.2^{*\bullet\circ}$
3 experimental - 10% levofloxacin	$5.0 \cdot 10^{5} \pm 0.4$	$2.0 \cdot 10^{3} \pm 0.8^{*\bullet\circ}$

Note: $p \leq 0.05$ relative to *the value of 1 day in its group; $^{\bullet}$ relative to the value in group K1; $^{\circ}$ relative to the value in group K2.

In the 1st group of fish, which received a 20% dose of antibiotic, a significant decrease in the TMC relative to the 1st day was established by the 8th day - by 1000 times. In the fish of the 2nd experimental group, which received 15% levofloxacin, the results of the TMC count on the 8th day were comparable with the results in the 1st experimental group and also lower than K1 by 1000 times, and K2 - by 10,000 times. In the 3rd experimental group, which received a therapeutic complex with a minimum dose of 10% levofloxacin with food, the wound contamination decreased by the end of the observations by 100 times compared to the 1st day, by 100 and 1000 times compared to K1 and K2, respectively.

As can be seen from Table 2, on the 8th day, the greatest suppressive effect on the microflora of fish wounds was exerted by complexes with 15 and 20% antibiotic content.

The results of the assessment of the diversity of representatives of the microflora of the large intestine of sturgeons under the influence of the chitosan -ß- cyclodextrin complex with 20% levofloxacin content, presented in Table 3, indicate a greater diversity of representatives of the bacterial community in the control group compared to the experimental ones.

Table 3.

Microflora of the large intestine of sturgeon fish under the influence of a complex of cyclodextrin with chitosan and levofloxacin

Identifiable groups of microorganisms	Microorganism content, genomes/g			
	Groups of fish participating in the experiment			
	K1	1 experimental - 20% levofloxacin		
	Day			
	1	1	8	14
Bacteroides (p. *Prevotella* And *Porphyromonas*)	$2.4\times10^{3}\pm0.7$	$2.1\times10^{3}\pm0.7$	$1.2\times10^{3}\pm0.4$	$2.0\times10^{3}\pm0.4$
Eubacteria (genus *Eubacterium*)	$5.0\times10^{5}\pm0.9$	$1.8\times10^{5}\pm0.7$	$4.9\times10^{4}\pm0.9$*	$2.7\times10^{3}\pm0.4$* •
Clostridia (p. *Lachnobacterium* And *Clostridium*)	$7.0\times10^{5}\pm0.9$	$1.8\times10^{5}\pm0.9$*	$8.0\times10^{4}\pm0.9$*	$4.8\times10^{3}\pm0.9$* •
Lactobacilli (genus *Lactobacillus*)	$8.4\times10^{2}\pm0.9$	< p.d.o.	< p.d.o.	$5.3\times10^{2}\pm0.7$
Lactate - utilizing bacteria (p. *Megasphaera* spp., *Veillonella* spp., Dialister *spp.*)	< p.d.o.	< p.d.o.	< p.d.o.	< p.d.o.
Peptostreptococci (genus *Peptostreptococcus*)	$7.5\times10^{5}\pm0.9$	$4.3\times10^{2}\pm0.5$	$4.2\times10^{2}\pm0.5$	$7.3\times10^{3}\pm0.4$* •
Enterobacteriaceae (family *Enterobacteriaceae*)	$3.4\times10^{4}\pm0.8$	$5.4\times10^{4}\pm0.9$	$4.2\times10^{3}\pm0.9$*	$1.4\times10^{6}\pm0.9$* •

Actinomycetes (*Mobiluncus*, *Corynebacterium*, *Atopobium*)	< p.d.o.	< p.d.o.	< p.d.o.	$4.3\times10^{2}\pm0.5$
Fusobacteria (genus *Fusobacterium*, *Sneathia*, *Leptotrichia*)	$2.6\times10^{4}\pm0.9$	< p.d.o.	< p.d.o.	$4.3\times10^{5}\pm0.8$*
Mycoplasmas (genus *Mycoplasma*, *Ureaplasma*)	< p.d.o.	< p.d.o.	< p.d.o.	< p.d.o.
Streptococci (p. *Streptococcus*)	< p.d.o.	< p.d.o.	< p.d.o.	< p.d.o.
Staphylococci (genus *Staphylococcus*)	$8.4\times10^{2}\pm0.9$	< p.d.o.	$5.4\times10^{2}\pm0.7$	$1.7\times10^{3}\pm0.9$*•
Fungi of the genus *Candida*	< p.d.o.	< p.d.o.	$8.7\times10^{2}\pm0.5$	< p.d.o.

Note: $p \leq 0.05$ relative to *value in group K1; • relative to the value on day 8 in the experimental group.

The data obtained in the control group describe the normal microflora of sturgeons grown in aquarium installations. Thus, in the control group of fish fed with quality food, the following genera were found: bacteroides, eubacteria, clostridia, peptostreptocci, enterobacteria , lactobacilli and staphylococci. At the same time, in the experimental group, where cyclodextrin preparations with an antibiotic were used after modeling a cut wound, on the 1st day differences in the diversity of microflora were observed in relation to lactobacilli, enterobacteria and fusobacteria , the number of genomes of which was below the limit of reliable detection.

Throughout the entire observation period, these representatives of the microflora were present in low quantities, which may indicate a natural imbalance (dysbacteriosis) caused by taking the antibiotic. Lactate -utilizing bacteria were not detected.

During the experiment, a decrease in the number of eubacteria and clostridia was observed, which is explained by the antimicrobial effect of levofloxacin and chitosan. At the same time, an increase in peptostreptococci , enterobacteria , fusobacteria and staphylococci was detected compared to normal microflora. This can be explained by the restoration of microflora after the use of the complex, including the detection of representatives of those genera, the number of genomes of which did not allow us to confirm their presence, at the same time, this may indicate a weakening of the immune system of fish after a long inflammatory process, which is injury, which requires additional attention during further sturgeon cultivation. Gradual recovery of the fish organism is confirmed by the presence of lactobacilli on the 14th day in the same amount as before injury and the use of the complex, as well as the absence of mycoplasmas, streptococci and Candida fungi.

Conclusions

A study of the wound microflora using the culture method showed that complexes with levofloxacin, used in the treatment of sturgeons, have a significant antimicrobial effect on the number of microorganisms compared to the control groups, with the best effect by the end of the experiment being provided by complexes with 15 and 20% levofloxacin content.

Molecular genetic research using the PCR method in real time determined the presence of bacteroids, eubacteria, clostridia, peptostreptocci, enterobacteria, lactobacilli and staphylococci in the composition of the normal flora. In 14 days the microflora of the large intestine of fish is characterized by a confident restoration of the number of lactic acid bacteria that regulate immune processes.

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Original article

COMPREHENSIVE MONITORING AND PREDICTION OF PRENATAL DISORDERS IN CALVES BORN FROM COWS WITH COMPLICATED PREGNACY

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Abstract

Background. In recent years, there has been a growing interest in modern methods for diagnosing feto- and uteroplacental insufficiency in cattle, which is due to the need to improve the reproductive health of animals and the quality of newborn offspring. The use of echographic and electrocardiographic methods makes it possible not only to assess in detail the condition of the fetus and uterus, but also to predict the course of pregnancy, which is crucial for preventing adverse outcomes. Particular attention is paid to hypoxic myocardial damage in cows, which is identified as one of the leading causes of adverse reproductive outcomes. This condition is associated with metabolic disorders, which in turn leads to the development of pathological metabolic acidosis. Acidosis has a depressing effect on enzymatic processes in the fetus, which can cause serious disturbances in its development and, as a result, negatively affect the health of newborn calves. The introduction of comprehensive monitoring, including regular ultrasound examinations and electrocardiographic monitoring, allows for timely detection of predisposition to feto- and uteroplacental insufficiency. This, in turn, creates the opportunity for early intervention and correction of identified disorders, which contributes to improving pregnancy outcomes and reducing the risk of prenatal pathologies.

Purpose. The objective of the present study is to develop methods for comprehensive monitoring in order to predict prenatal disorders in calves born from cows with complicated pregnancy.

Materials and methods. At the SPK Plemzavod Vtoraya Pyatiletka, from 2023 to 2024, the main studies on monitoring and predicting prenatal disorders in calves born to cows with feto- and uteroplacental insufficiency were carried out.

As an object of research, 200 heads of dry first-calf cows aged 24 to 48 months were selected by the blind sampling method. Thus, the first group (A) consisted of 100 animals with uncomplicated pregnancy and childbirth, while the second group (B) included 100 animals with complicated pregnancy due to feto- and uteroplacental insufficiency.

The selection of the livestock was carried out on the basis of anamnesis and physiological examination. To monitor and predict prenatal lesions in calves born to cows with feto- and uteroplacental insufficiency, a comprehensive clinical and laboratory study was conducted, namely: detection of signs of acute intrauterine fetal hypoxia during cardiographic monitoring using a Schiller AG Cardiovit AT-1 VET electrocardiograph, while assessing the heart rate (HR), morphology of the P wave, QRS complex and T wave, amplitude and duration of the P wave, QRS complex and T wave, duration of PR and QT intervals.

Determination of fetal growth deviations, echogenicity of the coruncle structure was carried out based on the results of an ultrasound examination using the EasyScan:Go device for cattle.

Evaluation of the decrease in blood flow and the state of the vessels in the fetal-uterine interface were determined by Dopplerography using a veterinary echograph Doppler FDC8100V from the manufacturer Shenzhen Well.D Medical Electronics.

Results. According to the obtained results of Dopplerography, 76% of cows with complicated pregnancy from group B have a decrease in blood flow through the fetal-uterine interface, which indicates a state of stress of the fetus and its underdevelopment. In addition, 54% of animals from group B have changes in blood flow pulsation and blood oxygenation. In cows of group A, the results of Dopplerography are within the normal range, only 15% of animals have increased oxygenation rates, which do not have serious consequences for the further development of the fetus.

Conclusion. Early diagnosis and timely administration of preventive and therapeutic measures are necessary to prevent the risk of developing postnatally significant diseases and improve the reproductive health of cattle. The introduction of an integrated approach to monitoring and predicting prenatal disorders can significantly improve the effectiveness of veterinary practice and ensure the well-being of both mothers and newborns.

Keywords: prenatal disorders; cattle; complicated pregnancy; feto- and uteroplacental insufficiency

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Научная статья

КОМПЛЕКСНЫЙ МОНИТОРИНГ И ПРОГНОЗИРОВАНИЕ ПРЕНАТАЛЬНЫХ НАРУШЕНИЙ У ТЕЛЯТ, РОЖДЕННЫХ ОТ КОРОВ С ОСЛОЖНЕННОЙ БЕРЕМЕННОСТЬЮ

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Аннотация

Обоснование. В последние годы возрос интерес к современным методам диагностики фето- и маточно-плацентарной недостаточности у крупного рогатого скота, что обусловлено необходимостью улучшения репродуктивного здоровья животных и качества новорожденного потомства. Использование эхографических и электрокардиографических методов позволяет не только детально оценить состояние плода и матки, но и прогнозировать течение беременности, что крайне важно для предотвращения неблагоприятных исходов. Особое внимание уделяется гипоксическому повреждению миокарда у коров, которое считается одной из ведущих причин неблагоприятных репродуктивных исходов. Это состояние связано с метаболическими нарушениями, которые, в свою очередь, приводят к развитию патологического метаболического ацидоза. Ацидоз оказывает угнетающее воздействие на ферментативные процессы в организме плода, что может вызвать серьезные нарушения в его развитии и, как следствие, негативно отразиться на здоровье новорожденных телят. Внедрение комплексного мониторинга, включающего регулярные ультразвуковые исследования и электрокардиографический контроль, позволяет своевременно выявить предрасположенность к фето- и маточно-плацентарной недостаточности. Это, в свою очередь, создает возможность для раннего вмешательства и коррекции выявленных нарушений, что способствует улучшению исходов беременности и снижению риска развития пренатальных патологий.

Цель. Цель настоящего исследования – разработать методы комплексного мониторинга для прогнозирования пренатальных нарушений у телят, рожденных от коров с осложненной беременностью.

Материалы и методы. В СПК «Племзавод „Вторая Пятилетка“ в 2023-2024 гг. были проведены основные исследования по мониторингу и прогно-

зированию пренатальных нарушений у телят, рожденных от коров с фето- и маточно-плацентарной недостаточностью.

В качестве объекта исследований методом слепой выборки было отобрано 200 голов сухостойных коров-первотелок в возрасте от 24 до 48 месяцев. Таким образом, в первую группу (А) вошли 100 животных с неосложненной беременностью и родами, во вторую группу (Б) – 100 животных с осложненной беременностью, обусловленной фето- и маточно-плацентарной недостаточностью.

Отбор поголовья проводился на основании анамнеза и физиологического обследования. Для мониторинга и прогнозирования пренатальных поражений у телят, рожденных от коров с фето- и маточно-плацентарной недостаточностью, было проведено комплексное клинико-лабораторное исследование, а именно: выявление признаков острой внутриутробной гипоксии плода при кардиографическом мониторинге с использованием электрокардиографа Schiller AG Cardiovit AT-1 VET с оценкой частоты сердечных сокращений (ЧСС), морфологии P-волны, комплекса QRS и T-волны, амплитуды и продолжительности P-волны, комплекса QRS и T-волны, продолжительности интервалов PR и QT.

Определение отклонений роста плода, эхогенности структуры венчика проводили по результатам ультразвукового исследования с использованием аппарата Easy-Scan:Go для крупного рогатого скота.

Оценку снижения кровотока и состояния сосудов в плодово-маточном промежутке определяли методом допплерографии с помощью ветеринарного эхографа Doppler FDC8100V от производителя Shenzhen Well.D Medical Electronics.

Результаты. Согласно полученным результатам допплерографии, у 76% коров с осложненной беременностью из группы Б отмечается снижение кровотока через плодово-маточный интерфейс, что свидетельствует о состоянии стресса плода и его недоразвитии. Кроме того, у 54% животных из группы В отмечаются изменения пульсации кровотока и оксигенации крови. У коров группы А результаты допплерографии находятся в пределах нормы, только у 15% животных повышены показатели оксигенации, что не имеет серьезных последствий для дальнейшего развития плода.

Заключение. Ранняя диагностика и своевременное проведение профилактических и лечебных мероприятий необходимы для предотвращения риска развития постнатально значимых заболеваний и улучшения репродуктивного здоровья крупного рогатого скота. Внедрение комплексного подхода к мониторингу и прогнозированию пренатальных нарушений может значительно

повысить эффективность ветеринарной практики и обеспечить благополучие как матерей, так и новорожденных.

Ключевые слова: пренатальные нарушения; крупный рогатый скот; осложненная беременность; фето- и маточно-плацентарная недостаточность

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Introduction

Comprehensive monitoring and prediction of prenatal disorders in calves born to cows with complicated pregnancy is an important and urgent task in veterinary medicine and animal husbandry. Prenatal disorders can have a significant impact on the health of both the mother and the newborn offspring, which emphasizes the need to implement effective diagnostic and preventive measures. In the conditions of modern animal husbandry, where high economic costs and product quality requirements are becoming increasingly important, early diagnosis and correction of pregnancy pathologies are becoming critically important.

Modern methods of ultrasound diagnostics and electrocardiography provide veterinary specialists with the opportunity to obtain objective information about the condition of the fetus and the cow, which is key to the timely detection and correction of pathologies.

Ultrasound diagnostics allows not only to visualize the fetus, but also to assess its viability, size, position and heartbeat, as well as to examine the condition of the uterus and placenta [1]. This method enables to detect signs of uteroplacental circulation disorders, such as increased placental thickness, edema, and impaired blood flow in large uterine vessels, which may indicate the development of fetoplacental insufficiency.

Ultrasound diagnostics is an important tool for fetal visualization, assessment of its viability, size, position, and heartbeat, as well as the condition of the uterus and placenta. Using this method, it is possible to detect signs of uteroplacental circulation disorders, such as increased placental thickness and edema [11]. In addition, fetal electrocardiography allows to assess cardiac activity and detect rhythm and conduction disorders, which may indicate fetal oxygen starvation [12].

The combined use of ultrasound and electrocardiography in pregnant cows significantly increases the accuracy of diagnostics and allows timely veterinary measures to preserve the fetus [15]. Thus, the integration of these modern diagnostic methods into veterinary medical practice represents an important step towards improving the reproductive health of cattle and reducing the risks associated with prenatal disorders.

Purpose. The objective of the present study is to develop methods for comprehensive monitoring in order to predict prenatal disorders in calves born from cows with complicated pregnancy.

Materials and methods

At the SPK Plemzavod Vtoraya Pyatiletka, from 2023 to 2024, the main studies on monitoring and predicting prenatal disorders in calves born to cows with feto- and uteroplacental insufficiency were carried out.

As an object of research, 200 heads of dry first-calf cows aged 24 to 48 months were selected by the blind sampling method. Thus, the first group (A) consisted of 100 animals with uncomplicated pregnancy and childbirth, while the second group (B) included 100 animals with complicated pregnancy due to feto- and uteroplacental insufficiency.

The selection of the livestock was carried out on the basis of anamnesis and physiological examination. To monitor and predict prenatal lesions in calves born to cows with feto- and uteroplacental insufficiency, a comprehensive clinical and laboratory study was conducted, namely: detection of signs of acute intrauterine fetal hypoxia during cardiographic monitoring using a Schiller AG Cardiovit AT-1 VET electrocardiograph, while assessing the heart rate (HR), morphology of the P wave, QRS complex and T wave, amplitude and duration of the P wave, QRS complex and T wave, duration of PR and QT intervals.

Determination of fetal growth deviations, echogenicity of the coruncle structure was carried out based on the results of an ultrasound examination using the Easy-Scan:Go device for cattle.

Evaluation of the decrease in blood flow and the state of the vessels in the fetal-uterine interface were determined by Dopplerography using a veterinary echograph Doppler FDC8100V from the manufacturer Shenzhen Well.D Medical Electronics.

Results

Analysis of cardiographic studies in cows with complicated pregnancy

As a result of the electrocardiographic studies, 200 ECG records were obtained. The analysis of the records showed that pregnant cows from group B with feto- and uteroplacental insufficiency show characteristic changes in cardiac activity, which indicates possible compensatory reactions of the fetus's body to this pathological condition (Table 1).

Table 1.

Indicators of electrocardiographic studies of cows

ECG parameters	**Group A – pregnancy without complications Group**			**Group B – complicated (pathological) pregnancy**		
	Median	Min	Max	Median	Min	Max
Heart rate (bpm)	70	49	95	99	68	130
P wave duration (seconds)	0,12	0,07	0,12	0,13	0,09	0,16
P wave amplitude (mV)	0,19	0,09	0, 23	0,21	0,11	0,26
QRS complex duration (seconds)	0,08	0,07	0,13	0,14	0,12	0,19
R wave amplitude (mB)	0,09	0,04	0,41	0,28	0,21	0,56
Q-T interval duration (seconds)	0,38	0,30	0,44	0,42	0,33	0,49
S-wave amplitude (mV)	0,70	0,42	1,11	0,71	0,40	1,10
T wave duration (seconds)	0,08	0,06	0,13	0,14	0,12	0,18
T wave amplitude (mV)	0,30	0,21	0,60	0,53	0,38	0,84
P-R interval duration (seconds)	0,19	0,12	0,25	0,23	0,17	0,29

ECG – electrocardiographic; bpm – beats per minute; mV – millivolts.

Thus, from the data in Table 1 obtained during the electrocardiographic study, it was established that 74% of cows from group B with complicated pregnancy have signs of acute intrauterine fetal hypoxia, namely, the changes were characterized by an increased heart rate from 68 to 130 beats per minute with an average value of a set of indicators of 99 beats per minute and a reliable prolongation of the QRS interval with an average median of 0.13 seconds, compared to group A by 38%, where the average median was 0.08 seconds. In addition, 71% of animals with signs of intrauterine fetal hypoxia have changes in the shape and amplitude of the teeth and segments, particularly in the T wave (Fig. 1).

Thus, changes in the ECG graphs in cows with complicated pregnancy were characterized by an increase in the median duration of the P-R intervals by 21.1% and Q-T by 10.5%, are associated with a pathological state of the heart and blood circulation in the fetus and its acute hypoxia, which in turn leads to various growth disorders, oxygen starvation and contributes to a decrease in nutrients in the fetus in group B, all other ECG parameters in cows from group B did not differ ($p > 0.07$).

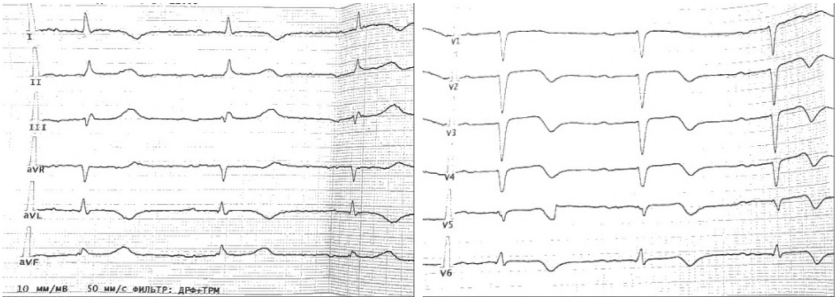

Fig. 1. Electrocardiogram of a cow from group B with uteroplacental insufficiency

Ultrasound examination assessment

At the same time, cows from group A did not have intrauterine fetal hypoxia, the duration of the P-R and Q-T intervals corresponded to the norm, the shape of the P, Q, R, S and T waves was of normal configuration, however, 32% of animals from this group had a slight increase in heart rate from 53 to 95 beats per minute with an average value of 74 beats per minute, which is typical for pregnant cows.

During the ultrasound examination conducted on cows from Group B with feto- and uteroplacental insufficiency, deviations were identified, namely, a decrease in the echogenicity of the caruncle structure was established, caused by insufficient communication between the caruncle and the placenta, which leads to insufficient supply of nutrients through the feto-uterine interface (Fig. 2).

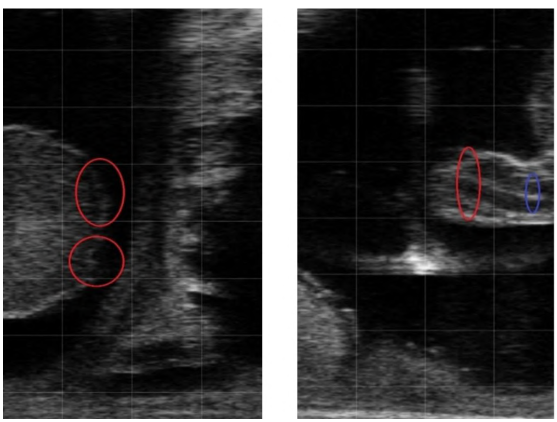

Fig. 2. Ultrasound results in complicated pregnancy.

Thus, from the data presented in Fig. 2, it is evident that cows from Group B were found to have stenosis of the vessel feeding the fetus, while 71% of animals from this group were found to have intrauterine growth retardation, 65% had underdevelopment of organs, in particular the lungs, spinal cord and heart, and 52% had oligohydramnios, in addition, 53% of pregnant cows had thickening of the placenta, abnormal localization and changes in the structure of the placenta.

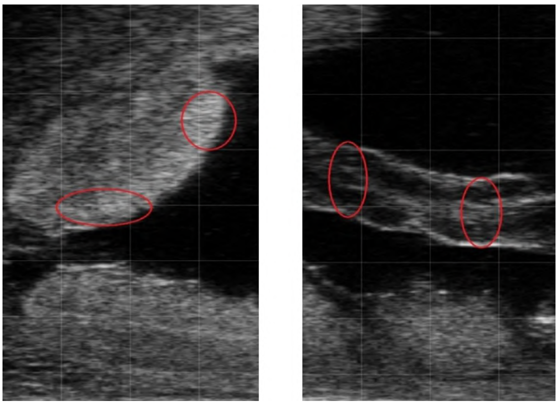

Fig. 3. Ultrasound results for physiological pregnancy.

In the same study, in cows from group A with uncomplicated pregnancy, the echogenicity of the caruncle was significantly higher, which indicates good contact with the placenta; no growth deviations in the fetus were recorded.

All pathological changes can disrupt the molecular structure of the placenta. Insufficient blood flow and reduced oxygen concentration lead to an imbalance in the processes of growth, differentiation, and secretion in placental cells (Table 2).

Table 2.

Oxygenation level according to the results of Dopplerography in cows from the experimental groups

Study groups	Oxygenation level
A group – pregnancy without complications	PaO2* – 25-35 mm Hg. SaO2** – 60-80%
Group B – complicated (pathological) pregnancy	PaO2* – 14-22 mm Hg. SaO2** – 45-59%

* – partial pressure of oxygen in fetal arterial blood.

** – fetal blood oxygen saturation.

According to the obtained results of Dopplerography, 76% of cows with complicated pregnancy from group B have a decrease in blood flow through the fetal-uterine interface, which indicates a state of stress of the fetus and its underdevelopment. In addition, 54% of animals from group B have changes in blood flow pulsation and blood oxygenation. In cows of group A, the results of Dopplerography are within the normal range, only 15% of animals have increased oxygenation rates, which do not have serious consequences for the further development of the fetus.

Conclusion

As a result of the electrocardiographic analysis, significant changes in the cardiovascular system were revealed in cows with complicated pregnancy from group B, including an increased heart rate, varying from 68 to 130 beats per minute, with an average value of 99 beats per minute. A significant prolongation of the QRS interval to 0.13 seconds, which is 38% higher than the indicators of group A, as well as an increase in the median duration of the P-R and Q-T intervals by 21.1% and 10.5%, respectively, indicate the presence of serious disturbances in the electrophysiological state of the heart. In addition, a similar situation was observed during ultrasound examination and was characterized by stenosis of the nutrient vessel, a decrease in the echogenicity of the caruncle structure, caused by insufficient communication between the caruncle and the placenta, which leads to a deterioration in the supply of nutrients through the fetal-uterine interface and, as a consequence, a decrease in the concentration of oxygen in the blood.

Comprehensive monitoring of prenatal disorders in calves born to cows with feto- and uteroplacental insufficiency is critical to predicting the viability and productivity of newborn calves. Feto- and uteroplacental insufficiency is a serious problem that can lead to irreversible consequences, including malnutrition, stress and intrauterine infections, which negatively affect fetal development and weaken the bond between the fetus and the mother.

The long-term consequences of uteroplacental insufficiency can manifest as metabolic and immunological disorders in calves at an adult age, which increases the risk of a reduced immune response and predisposition to various diseases. In cattle, fetoplacental insufficiency can manifest itself as premature birth, which also emphasizes the importance of early diagnosis and intervention.

Uteroplacental insufficiency, a multifactorial condition, can result from hormonal and genetic disorders and manifests in two forms: early and late. The early form affects the formation of the placenta and can lead to fetal growth retardation and embryonic death, while the late form, developing at 32-36 weeks of pregnancy, affects the functioning of the placenta and causes impaired fetal growth.

Thus, early diagnosis and timely administration of preventive and therapeutic measures are necessary to prevent the risk of developing postnatally significant diseases and improve the reproductive health of cattle. The introduction of an integrated approach to monitoring and predicting prenatal disorders can significantly improve the effectiveness of veterinary practice and ensure the well-being of both mothers and newborns.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

ZOOPATHOGENIC ROLE OF *MORAXELLACEAE* AND *CORYNEBACTERIACEAE* BACTERIA IN MASTITIS IN RUMINANTS

N.V. Pimenov, R.F. Ivannikova, S.V. Pozyabin

Abstract

Background. The article examines the incidence and pathogenic significance of Moraxella and Corynebacteria in mastitis of ruminants using the example of large and small cattle in various farms in the regions of the Russian Federation. As a result of the conducted studies, the sporadic presence of Moraxella microorganisms in the microbiota of mastitis milk among opportunistic pathogens in cows was established. No Moraxella was found in goats. Several cases were identified at once in which Acinetobacter spp., belonging to the Moraxellaceae family, was isolated in associations. The incidence of pathogenic corynebacteria as the leading representative of the clinical microbiota was noted at the level of 60% in the goats of LLC « Pikaev » in the Republic of Morodovia and 26.7% in cows from various farms in the Moscow region, the Republic of Morodovia and Bashkortostan.

Purpose. The purpose of this work is to study the incidence and pathogenic significance of bacteria Moraxella and Corynebacterium in mastitis in cattle and small cattle.

Materials and methods. The research was carried out at livestock enterprises in the Moscow region, the Republic of Mordovia, and the Republic of Bashkortostan. In the period from March to August 2024, clinical trials were conducted in the field and in production conditions for mastitis of large and small cattle with sampling of pathological material. The clinical (pathological) material was milk, which was collected in sterile containers. Screening bacteriological studies for indication of microorganisms (20 studies) and identification of bacteria were conducted. The samples were seeded onto Petri dishes with 10% blood and chocolate agar content. Petri dishes were incubated at 37 °C for 48 hours. Putative colonies of Moraxella, identified by their smooth, rounded and grayish-white appearance with a hemolysis zone, were subjected to Gram staining and biochemical tests, then positive colonies were further confirmed using MALDI–TOF, other bacterial pathogens were also identified using biochemical tests and mass spectrometry. For this purpose, after sampling, a well-isolated colony was removed using a sterile loop, then re-suspended in 300 µl of distilled water, then the suspension was centrifuged for 10 minutes at 10,000 rpm, after which 2 µl of a reactogenic solution was added to the precipitate, transferred to a MALDI plate and loaded into an ionization chamber.

Results. The following types of microorganisms have been detected and identified in cattle with a clinical picture of serous, catarrhal mastitis: Streptococcus uberis, Staphylococcus capitis, Trueperella pyogenes, Bacillus pumilus, Brevibacterium celere, Corynebacterium xerosis, Bacillus licheniformis, Acinetobacter junii, Escherichia coli, Paraclostridium bifermentans, Psychrobacter immobilis, Enterococcus faecium, Serratia liquefaciens, Citrobacter freundii, Pseudomonas spp., Corynebacterium spp., Enterococcus faecalis, Psychrobacter phenylpyruvicus, Raoultella ornithinolytica, Moraxella catarrhalis (1 isolate). The following types of microorganisms were found in goats with a clinical picture of serous catarrhal mastitis: Aerococcus viridians, Corynebacterium stationis, Staphylococcus haemolyticus, Staphylococcus chromogenes, Corynebacterium xerosis, Corynebacterium stationis, and Staphylococcus epidermidis. The results are presented in table 1. No growth was detected from samples of biological material from mastitis milk of sheep and goats, during screening bacteriological studies on blood agar. To determine the pathogenic properties of the isolated cultures, a coagulase test for staphylococci and a bioassay on white mongrel mice were used. The inoculum diluted to the desired concentration (10^8 CFU/ml), OD = 600 nm = 1, obtained from a pure culture of Moraxella bovis and Moraxella bovoculi, was administered subcutaneously to mice at a dose of 100 µl.

Conclusion. The nosological role of moraxella microorganisms in mastitis in cows and goats has not been confirmed at this stage of research. Cases of indication of Moraxella catarrhalis and Acinetobacter spp. have been noted among the clinical microbiota, which does not exclude the nosological role of microorganisms of the Moraxellaceae family in these pathologies, as early studies occasionally noted.

Keywords: Moraxella; Corynebacteria; mastitis; ruminants; cattle

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Научная статья

ЗООПАТОГЕННАЯ РОЛЬ БАКТЕРИЙ СЕМЕЙСТВА *MORAXELLACEAE* И *CORYNEBACTERIACEAE* ПРИ МАСТИТЕ У ЖВАЧНЫХ ЖИВОТНЫХ

Н.В. Пименов, Р.Ф. Иванникова, С.В. Позябин

Аннотация

Обоснование. В статье рассматривается частота встречаемости и патогенная значимость Moraxella и Corynebacteria при маститах жвачных животных на примере крупного и мелкого рогатого скота в различных хозяйствах регионов Российской Федерации. В результате проведенных исследований установлено спорадическое присутствие микроорганизмов Moraxella в микробиоте маститного молока среди условно-патогенных микроорганизмов у коров. У коз моракселла не обнаружена. Было выявлено сразу несколько случаев, когда в ассоциациях выделяли Acinetobacter spp., относящийся к семейству Moraxellaceae. Частота встречаемости патогенных коринебактерий как ведущего представителя клинической микробиоты отмечена на уровне 60% у коз ООО «Пикаев» в Республике Мородовия и 26,7% у коров из различных хозяйств Московской области, Республики Мородовия и Башкортостана.

Цель. Цель работы – изучить частоту встречаемости и патогенную значимость бактерий Moraxella и Corynebacterium при маститах крупного и мелкого рогатого скота.

Материалы и методы. Исследования проводились на животноводческих предприятиях Московской области, Республики Мордовия и Республики Башкортостан. В период с марта по август 2024 года проведены клинические испытания в полевых и производственных условиях при мастите крупного и мелкого рогатого скота с отбором проб патологического материала. Клиническим (патологическим) материалом служило молоко, которое собирали в стерильные емкости. Проводились скрининговые бактериологические исследования на индикацию микроорганизмов (20 исследований) и идентификацию бактерий. Образцы высевали на чашки Петри с 10% кровяным и шоколадным агаром. Чашки Петри инкубировали при 37°C в течение 48 часов. Предполагаемые колонии Moraxella, идентифицированные по гладкому, округлому и серовато-белому виду с зоной гемолиза, подвергались окрашиванию по Граму и биохимическим тестам, затем положительные колонии подтверждались методом MALDI-TOF, другие бактериальные патогены также идентифицировались с помощью биохимических тестов и масс-спектрометрии. Для этого после отбора проб хорошо изолированную колонию удаляли стерильной петлей, затем повторно суспендировали в 300 мкл дистиллированной воды, суспензию центрифугировали в течение 10 минут при 10000 об/мин, после чего к осадку добавляли 2 мкл реактогенного раствора, переносили на MALDI-пластину и загружали в ионизационную камеру.

Результаты. У крупного рогатого скота с клинической картиной серозного, катарального мастита были обнаружены и идентифицированы следующие виды микроорганизмов: Streptococcus uberis, Staphylococcus capitis, Trueperella pyogenes, Bacillus pumilus, Brevibacterium celere, Corynebacterium xerosis, Bacillus licheniformis, Acinetobacter junii, Escherichia coli, Paraclostridium bifermentans, Psychrobacter immobilis, Enterococcus faecium, Serratia liquefaciens, Citrobacter freundii, Pseudomonas spp.., Corynebacterium spp., Enterococcus faecalis, Psychrobacter phenylpyruvicus, Raoultella ornithinolytica, Moraxella catarrhalis (1 изолят). У коз с клинической картиной серозно-катарального мастита были обнаружены следующие виды микроорганизмов: Aerococcus viridians, Corynebacterium stationis, Staphylococcus haemolyticus, Staphylococcus chromogenes, Corynebacterium xerosis, Corynebacterium stationis и Staphylococcus epidermidis. Результаты представлены в таблице 1. При скрининговых бактериологических исследованиях на кровяном агаре в пробах биологического материала из маститного молока овец и коз роста не обнаружено. Для определения патогенных свойств выделенных культур использовали коагулазный тест на стафилококки и биопробу на белых беспородных мышах. Инокулят, разведенный до нужной концентрации (108 КОЕ/мл), OD = 600 нм = 1, полученный из чистой культуры Moraxella bovis и Moraxella bovoculi, вводили мышам подкожно в дозе 100 мкл.

Заключение. Нозологическая роль микроорганизмов моракселлы при мастите у коров и коз на данном этапе исследований не подтверждена. Среди клинической микробиоты отмечены случаи индикации Moraxella catarrhalis и Acinetobacter spp., что не исключает нозологической роли микроорганизмов семейства Moraxellaceae при данных патологиях, как это периодически отмечалось в ранних исследованиях.

Ключевые слова: Moraxella; Corynebacteria; мастит; жвачные животные; крупный рогатый скот

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Introduction

Dairy cattle breeding plays a leading role in productive animal husbandry and is a high-tech branch of agriculture. Mastitis is one of the most common and studied diseases, which leads to a decrease in milk productivity and significant economic losses associated with a shortage of milk and a decrease in its quality. Among productive dairy cattle in Russia, mastitis affects from 15 to 60% of the livestock, and milk losses reach up to 30% of the annual milk yield [1-5]. Even after successful treatment of mastitis, hypogalactia or agalactia most often develops, and treatment costs and losses from animal culling account for significant economic losses. At the same time, significant investments aimed at eliminating mastitis do not lead to the development of reliable preventive measures, and losses from the disease continue to be global. In addition, numerous studies indicate that milk from sick animals can be a source of infection of young animals, and if ingested by humans.

Mastitis occurs in animals at any age, while it is less common in the first three lactation periods. The proportion of mastitis increases with age. This disease occurs in all seasons of the year [6; 7].

Pathogenic and opportunistic microorganisms play a leading role in the occurrence of mastitis, and mechanical damage associated with impaired milking technology, cracks and udder wounds also provoke the development of the disease [8-10]. Taking into account the role of the microbial factor in the development of breast pathology, researchers constantly point out the sanitary and epidemiological significance of mastitis, especially in lactating cows. Currently, it is difficult to distinguish a boundary in determining the pathogenic properties of some microorganisms. They have a high prevalence, the ability to multiply extremely quickly, and most types of microorganisms become unpretentious in the use of food and energy sources [11-14]. Many previously considered conditionally pathogenic microorganisms have acquired new properties and ecological niches and today play an important role in the development of diseases, including mastitis in productive animals [15].

In this regard, the study of the issues of timely bacteriological diagnosis of mastitis with the determination of the etiological structure remains relevant today.

Purpose. The purpose of this work is to study the incidence and pathogenic significance of bacteria Moraxella and Corynebacterium in mastitis in cattle and small cattle.

Materials and methods

The research was carried out at livestock enterprises in the Moscow region, the Republic of Mordovia, and the Republic of Bashkortostan. In the period from March to August 2024, clinical trials were conducted in the field and in production conditions for mastitis of large and small cattle with sampling of pathological material. The clinical (pathological) material was milk, which was collected in sterile containers. Screening bacteriological studies for indication of microorganisms (20 studies) and identification of bacteria were conducted. The samples were seeded onto Petri dishes with 10% blood and chocolate agar content. Petri dishes were incubated at 37 °C for 48 hours. Putative colonies of Moraxella, identified by their smooth, rounded and grayish-white appearance with a hemolysis zone, were subjected to Gram staining and biochemical tests, then positive colonies were further confirmed using MALDI–TOF, other bacterial pathogens were also identified using biochemical tests and mass spectrometry. For this purpose, after sampling, a well-isolated colony was removed using a sterile loop, then re-suspended in 300 μl of distilled water, then the suspension was centrifuged for 10 minutes at 10,000 rpm, after which 2 μl of a reactogenic solution was added to the precipitate, transferred to a MALDI plate and loaded into an ionization chamber.

Results

The following types of microorganisms have been detected and identified in cattle with a clinical picture of serous, catarrhal mastitis: Streptococcus uberis, Staphylococcus capitis, Trueperella pyogenes, Bacillus pumilus, Brevibacterium celere, Corynebacterium xerosis, Bacillus licheniformis, Acinetobacter junii, Escherichia coli, Paraclostridium bifermentans, Psychrobacter immobilis, Enterococcus faecium, Serratia liquefaciens, Citrobacter freundii, Pseudomonas spp., Corynebacterium spp., Enterococcus faecalis, Psychrobacter phenylpyruvicus, Raoultella ornithinolytica, Moraxella catarrhalis (1 isolate). The following types of microorganisms were found in goats with a clinical picture of serous catarrhal mastitis: Aerococcus viridians, Corynebacterium stationis, Staphylococcus haemolyticus, Staphylococcus chromogenes, Corynebacterium xerosis, Corynebacterium stationis, and Staphylococcus epidermidis. The results are presented in table 1. No growth was detected from samples of biological material from mastitis milk of sheep and goats, during screening bacteriological studies on blood agar. To determine the pathogenic properties of the isolated cultures, a coagulase test for staphylococci and a bioassay on white mongrel mice were used. The inoculum diluted to the desired concentration (10^8 CFU/ml), OD = 600 nm = 1, obtained from a pure culture of Moraxella bovis and Moraxella bovoculi, was administered subcutaneously to mice at a dose of 100 μl.

Table 1.

Results of microbiological examination of biomaterial samples for mastitis in cows and goats.

№	Kind of animal	Age	Isolated mocrjjrganisms	Pathogenic microorganisms
1	Goat	2 years	Aerococcus viridians Corynebacterium stationis Staphylococcus haemolyticus	Corynebacterium stationis
2	Goat	1.5 years	Staphylococcus chromogenes Staphylococcus haemolyticus Corynebacterium xerosis	Corynebacterium xerosis
3	Goat	2.3 years	Staphylococcus chromogenes	-
4	Goat	2.4 years	Staphylococcus chromogenes Aerococcus viridians Staphylococcus haemolyticus Corynebacterium xerosis Corynebacterium stationis	Corynebacterium xerosis Corynebacterium stationis
5	Goat	2.1 years	Staphylococcus epidermidis	Staphylococcus epidermidis
6	Cow	2 years	Pseudomonas sp. Enterococcus faecalis Serratia liquefaciens Citrobacter freundii	Serratia liquefaciens
7	Cow	2.7 years	Serratia liquefaciens Psychrobacter phenylpyruvicus Raoultella ornithinolytica	-
8	Cow	3 years	Enterococcus faecalis Citrobacter freundii Trueperella pyogenes	-
9	Cow	2.1 years	Bacillus licheniformis Moraxella catarrhalis	Bacillus licheniformis Moraxella catarrhalis
10	Cow	3 years	Streptococcus uberis Staphylococcus capitis Trueperella pyogenes Bacillus pumilus	Bacillus pumilus
11	Cow	2.6 years	Bacillus licheniformis Acinetobacter junii Escherichia coli Corynebacterium xerosis	Corynebacterium xerosis
12	Cow	2,2 years	Paraclostridium bifermentans Psychrobacter immobilis Enterococcus faecium Escherichia coli	Paraclostridium bifermentans Psychrobacter immobilis
13	Cow	2 years	Serratia liquefaciens Citrobacter freundii	-
14	Cow	3.4 years	Escherichia coli Pseudomonas sp. Corynebacterium spp.	Corynebacterium sp.
15	Cow	3 years	Bacillus licheniformis Escherichia coli	Bacillus licheniformis
16	Cow	3 years	Streptococcus uberis Staphylococcus capitis Trueperella pyogenes Bacillus pumilus	Bacillus pumilus
17	Cow	2.5 years	Brevibacterium celere Corynebacterium xerosis	Corynebacterium xerosis
18	Cow	2.2 years	Bacillus licheniformis Escherichia coli	Bacillus licheniformis Escherichia coli
19	Cow	2.3 years	Staphylococcus spp.	Staphylococcus spp.
20	Cow	3 years	Brevibacterium celere Corynebacterium xerosis	Corynebacterium xerosis

Discussion

A study of the nosological role of the moraxella group of bacteria in mastitis in ruminant productive animals revealed, during screening of pathological material (n=20), the sporadic presence of moraxella microorganisms in the clinical microbiota of mastitis milk among other representatives, opportunistic pathogens: S. uberis, Staph. capitis, haemolyticus, chromogenes, epidermidis, T. pyogenes, Corynebacterium xerosis, stationis, E. coli. Thus, in 2 cases, Moraxella catarrhalis was identified (1 isolate was obtained). Aerococcus viridans was also detected in goats with a clinical picture of serous catarrhal mastitis, but no moraxella was detected. Several cases were identified at once in which Acinetobacter spp., belonging to the Moraxellaceae family, was isolated in associations, colonies of which formed hemolysis on blood agar. However, Acinetobacter spp. and representatives of the genus Moraxella – M. catarrhalis have been identified together with Staphylococcus and Pseudomonas aeruginosa. The detection of this combination in various samples may indicate a probable zoopathogenic role of Acinetobacter spp. and Moraxella spp., however, further research is required for more definitive conclusions. In addition, Psychrobacter bacteria, known as opportunists, which are important in the pathogenesis of a number of inflammatory diseases of humans and small domestic animals, were isolated from samples of clinical material in the associations. The role of psychrobacteria in zoonosology has not yet been disclosed. The data obtained with the isolation of pathogenic Psychrobacter immobilis in association may indicate its developing pathogenetic significance.

In contrast to Moraxellaceae, bacteria of the Corynebacteriaceae family played a more significant role in the primary screening of mastitis secretions in ruminants. The incidence of pathogenic corynebacteria as the leading representative of the clinical microbiota was noted at the level of 60% in the goats of LLC «Pikaev» in the Republic of Morodovia and 26.7% in cows from various farms in the Moscow region, the Republic of Morodovia and Bashkortostan. This indicates the leading role of corynebacteria in the nosology of mastitis in cattle and small cattle, with Corynebacterium xerosis showing the dominant etiotropic value. Of course, the problem of mastitis is not limited to the range of microorganisms involved in etiopathogenesis, broader screening and monitoring studies by various authors identify Streptococcus uberis, Trueperella pyogenes, Staphylococcus epidermidis and a number of other pathogens – staphylococcus, streptococcus, E. coli. However, the results obtained develop an idea of the participants of the microbiome in serous mastitis of productive livestock and require biological control and medicinal application, at least against corynebacteria.

Conclusion

The nosological role of moraxella microorganisms in mastitis in cows and goats has not been confirmed at this stage of research. Cases of indication of Moraxella catarrhalis and Acinetobacter spp. have been noted among the clinical microbiota, which does not exclude the nosological role of microorganisms of the Moraxellaceae family in these pathologies, as early studies occasionally noted.

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Original article

THE IMPACT OF AGRICULTURAL ACTIVITY ON SOIL PHYTOTOXICITY: THE CHOICE OF BIOINDICATORS

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Abstract

Background. The study is devoted to the assessment of phytotoxicity of soils affected by agricultural activities by the method of bioindication. The main objective is to select the most sensitive bioindicator for the determination of phytotoxicity in agricultural soils. It was found that cruciferous crops, *Brassica napus* (rapeseed), *Lepidium sativum* (watercress), are the most sensitive to contamination, demonstrating a decrease in germination to 24% and phytomass to 0.13-0.62 g, while barley showed a germination resistance of 70-100%. Cases of latent phytotoxicity have been identified with preserved germination, but inhibition of root growth. The results confirm the effectiveness of the method and the need for an integrated approach using several bioindicators.

Purpose. The purpose of this study is to select the most sensitive bioindicator for determining the phytotoxicity of agricultural soils.

Materials and methods. To assess the phytotoxicity of soils, samples were taken from the DSTU training ground. The main series included 4 arable samples (n=4), selected by the envelope method from a depth of 0-20 cm according to GOST 17.4.4.02-2017. The control sample was taken from the adjacent forest belt (n=1). Each combined sample weighing 1 kg was formed from 5-point samples. Four test crops were used: radish (*Raphanus sativus L.*), barley (*Hordeum vulgare L.*), rapeseed (*Brassica napus L.*) and watercress (*Lepidium sativum L.*). 3 analytical replications in Petri dishes were prepared for each sample and culture. Incubation was carried out for 10 days. The following parameters were evaluated: germination (%), germination energy (%), length of shoots and roots (mm), crude phytomass (g). Statistical data processing was performed with the calculation of average values and standard deviation for each sample and test culture.

Results. The results have shown a significant inhibition of the test plant growth in contaminated samples, which resulted in a decrease in key indicators by 24-92% compared with the control. Cruciferous crops (rapeseed and watercress) showed the greatest sensitivity, with a sharp decrease in germination to 24%, germination energy to 1.0, and phytomass to 0.13-0.62 g. At the same time, barley has demonstrated relative stability, maintaining germination at the level of 70-100%, which confirms the need to use several bioindicators for a comprehensive assessment.

Conclusion. During the study, it was found that agricultural activity in the field under study led to the formation of phytotoxicity of the soil, manifested in the suppression of sensitive cruciferous crops (rapeseed, watercress) and the radish root system. Rapeseed and watercress are highly sensitive bioindicators for monitoring. The revealed heterogeneity of phytotoxicity requires a differentiated approach to assessing soil conditions. The conducted studies have demonstrated the effectiveness of the phytoindication method for assessing the phytotoxicity of soils exposed to agrogenic effects.

Keywords: soil phytotoxicity; bioindication; phytotesting; cruciferous crops; environmental monitoring

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Научная статья

ВЛИЯНИЕ СЕЛЬСКОХОЗЯЙСТВЕННОЙ ДЕЯТЕЛЬНОСТИ НА ФИТОТОКСИЧНОСТЬ ПОЧВ: ВЫБОР БИОИНДИКАТОРОВ

П.А. Дубницкая, В.С. Лигачева, Е.А. Мун, А.Г. Поляков, М.Ю. Одабашян

Аннотация

Обоснование. Исследование посвящено оценке фитотоксичности почв подверенной влиянию сельскохозяйственной деятельности методом биоиндикации. Установлено, что крестоцветные культуры, Brassica *napus* (рапс), *Lepidium sativum* (кресс-салат), наиболее чувствительны к загрязнению, демонстрируя снижение всхожести до 24% и фитомассы до 0,13-0,62 г, тогда как ячмень показал устойчивость всхожесть 70-100%. Выявлены случаи скрытой фитотоксичности при сохранной всхожести, но угнетении роста корней. Результаты подтверждают эффективность метода и необходимость комплексного подхода с использованием нескольких биоиндикаторов.

Цель. Целью исследования – подбор наиболее чувствительного биоиндикатора для определения фитотоксичности почв сельскохозяйственного назначения.

Материалы и методы. Для оценки фитотоксичности почв были отобраны пробы с учебно-опытного полигона ДГТУ. Основная серия включала 4 пахотные пробы (n=4), отобранные методом конверта с глубины 0-20 см согласно ГОСТ 17.4.4.02-2017. Контрольный образец взят из прилегающей лесополосы (n=1). Каждая объединенная проба массой 1 кг формировалась из 5 точечных проб. Использовали четыре тест-культуры: редис *(Raphanus sativus L.),* ячмень *(Hordeum vulgare L.),* рапс *(Brassica napus L.)* и кресс-салат *(Lepidium sativum L.).* Для каждого образца и культуры подготовили по 3 аналитические повторности в чашках Петри. Инкубацию проводили 10 суток. Оценивали следующие параметры: всхожесть (%), энергию прорастания (%), длину побегов и корней (мм), сырую фитомассу (г). Статистическую обработку данных выполняли с расчетом средних значений и стандартного отклонения для каждой пробы, и тест-культуры.

Результаты. Результаты показали значительное угнетение роста тест-растений в загрязненных образцах, что выражалось в снижении ключевых показателей на 24–92% по сравнению с контролем. Наибольшую чувствительность проявили крестоцветные культуры (рапс и кресс-салат), у которых зафиксировано резкое снижение всхожести до 24%, энергии прорастания до 1,0 и фитомассы до 0,13–0,62 г. В то же время ячмень продемонстрировал относительную устойчивость, сохраняя всхожесть на уровне 70–100%, что подтверждает необходимость использования нескольких биоиндикаторов для комплексной оценки.

Заключение. В ходе исследования было установлено, что сельскохозяйственная деятельность на исследуемом поле привела к формированию фитотоксичности почвы, проявляющейся в угнетении чувствительных крестоцветных культур (рапс, кресс-салат) и корневой системы редиса. Рапс и кресс-салат являются высокочувствительными биоиндикаторами для мониторинга. Выявленная неоднородность фитотоксичности требует дифференцированного подхода к оценке состояния почв. Проведенные исследования продемонстрировали эффективность метода фитоиндикации для оценки фитотоксичности почв, подверженных агрогенному воздействию.

Ключевые слова: фитотоксичность почв; биоиндикация; фитотестирование; крестоцветные культуры; экологический мониторинг

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Introduction

Modern agriculture, being the basis of food security, has an intense and multifactorial impact on soil ecosystems. The use of mineral fertilizers, pesticides, ameliorants, the use of heavy machinery, intensive tillage and monoculture agriculture lead to complex changes in the physico-chemical and biological properties of soil. In order to control the influence level of the above listed anthropogenic factors on agroecosystems, environmental monitoring is used. Currently, it is based on physical and chemical methods that make it possible to quantify the content of pollutants and compare them with established standards, such as maximum permissible concentrations (MPC) [1]. However, this approach has significant limitations, since MPCs do not take into account the complex effects on ecosystems, their ability to accumulate in food chains and cause long-term consequences [1]. As a result, the data obtained exclusively by physical and chemical methods are insufficient to predict environmental risks [1]. In this regard, biomonitoring, based on the assessment of the reaction of living organisms to anthropogenic impact, is becoming increasingly important. Biological methods are highly sensitive, allowing them to detect negative changes even at low concentrations of pollutants, and provide a more integrated assessment of the state of ecosystems compared to instrumental analyses [2].

A special place in environmental monitoring is occupied by the assessment of soils, which play a key role in the functioning of ecosystems. For agricultural lands, fertility is a key criterion – the ability of the soil to provide plants with nutrients, moisture, and optimal physical and chemical conditions. Fertility determines crop yields and biological productivity of natural vegetation, while natural and artificial fertility created by agrotechnical techniques are distinguished. Depending on productivity, arable land is classified into highly productive more than 5 tn/ha, medium-productive 3-4 tn/ha, unproductive 1-2 tn/ha and unsuitable for agriculture less than 1 tn/ha.

One of the most effective methods of assessing the ecological state of soils is biotesting, based on the use of standardized test organisms to detect toxic, mutagenic or other harmful effects [1]. Unlike chemical analysis, biotesting makes it possible to assess the integral toxicity of the soil, taking into account the combined effect of all pollutants, including those whose concentrations are below the detection threshold of the devices. An important advantage of this method is its ability to detect negative changes at an early stage, before the appearance of visible disturbances in the ecosystem [1].

Seeds of higher plants such as cress (*Lepidium sativum*), yellow mustard (*Sinapis alba*) and sorghum (*Sorghum saccharatum*) are widely used as test objects. Criteria of phytotoxicity are indicators of germination (germinating capacity, germination energy) and development of germinating seedlings (length and weight of roots, aboveground part). Small-seeded crops with a limited supply of nutrients are more sensitive to contamination, which makes them convenient bioindicators.

At the same time, the soil is a complex object for biotesting due to its heterogeneity and high content of organic and mineral components. The reliability of the results is influenced by sampling methods, test conditions, and the choice of test organisms. Therefore, for a comprehensive assessment of soil conditions, it is recommended to combine biological methods with physical and chemical analysis, which allows obtaining the most complete information about their ecological condition and potential risks to the environment.

Based on this, the relevance of this work lies in the fact that agrochemical analyses cannot predict changes in agroecosystems, and cannot show the effect of a particular compound on a plant, which underlines the need for biomonitoring to identify deviations in ecosystems. Timely identification of problems will help prevent critical situations and maintain high yields.

Phytotoxicity of the soil is its property to have a sparing effect on higher plants, which causes the presence of pollutants and toxins in the soil. Phytotoxicity leads to disruption of physiological processes, suppression of plant growth and development, resulting from increased accumulation of physiologically active substances, including phenolic compounds, organic acids, aldehydes, alcohols, etc. [3]. The source of toxic substances in the soil is the root secretions of plants, post-harvest plant residues, products of microbial metabolism, as well as residual products from fertilizers and plant protection products. Phytotoxic substances accumulate most actively during the development of anaerobic conditions in the soil and during the cultivation of homogeneous or biologically similar crops in one place. Root secretions secreted by plants or pathogens are highly toxic. They contain 15 groups of water-soluble organic substances, including alkaloids, coumarins, cinnamic acid, quinones, terpenoids, flavonoids, tannins, and many other compounds [4]. The following factors influence the formation of general phytotoxicity of soils: the content of heavy metals in the soil by 39%, soil factors by 34%, the content of pesticides by 22%, and saturation of crop rotation with grain crops by 5% [4].

Heavy metals (HMs) are one of the most dangerous pollutants, the main sources of entry into uncontaminated soils of which are quarries and mines for the extraction of polymetallic ores, metallurgical enterprises; vehicles, chemical means of protecting crops from diseases and pests. Also, the impact of gas and dust emissions from industrial enterprises extends over a distance of 50 km or more from the city limits. It is important to take into account that HMs can be absorbed by plants not only from the soil, but also directly from the atmosphere (cadmium, lead), which poses a great danger of accumulation of toxic substances in plants that are grown in fields located in the zone of influence of the city. HMS also play the role of an ecotoxicological factor that determines the direction and nature of the development of soil cenosis, which can be observed both when soils are contaminated with heavy metals in high concentrations once, and with systematic contamination with small doses, which is much more common. The consequences of this pollution can be toxicosis of plants, animals and humans [3].

Another of the most dangerous and frequently encountered pollutants are pesticides. Their use leads to a restructuring of the ecological situation in the soil, changing its microbiocenosis inhibiting some groups of microorganisms and stimulating the reproduction of others, whose representatives are able to produce phytotoxic substances and thereby exacerbate the negative effects of the drugs used. Even the complex use of pesticides in recommended doses provokes a decrease in the number of ammonifying bacteria, a shift in the microcenosis of cellulose-destroying microorganisms in the soil occurs. Pesticides not only cause soil toxicity, but also accumulate in the root system and final products, which leads to environmentally inferior products [4].

To assess the phytotoxicity of soils resulting from agricultural activities, various biotesting methods are used to determine the reaction of test plants to the presence of toxicants.

The seedling method is based on the analysis of the reaction of plant seeds to polluted soil. The seeds are sown in Petri dishes with soil selected from various sites, and the germination rate, germination energy, length of the root and aboveground parts, as well as the weight of the dry matter of the seedlings are monitored [5].

The contact method is the placement of test crop seeds directly on moistened soil plates, without prior preparation of an aqueous extract. It allows us to assess the cumulative effect on plants of both water-soluble compounds and substances adsorbed on soil particles.

This approach is one of the most informative for rapid assessment of the general toxic background of the soil [8].

The initiated microbial community (IMC) method is a modified version of the contact method. The method is based on the artificial creation of a microbial community on the surface of sterilized soil plates. To do this, starch, agar-agar, or any other substrate that is nutritious for microorganisms is applied to the soil, after which the samples are incubated under optimal humidity and temperature conditions. During this time, an active microbial community has formed on the soil surface. Next, seeds of test plants are placed on the grown colonies of microorganisms and their germination and seedling development are analyzed. Comparing the results with ordinary soil plates (without IMS), the role of the biogenic factor can be assessed. If the difference between the variants is significant, it means that the phytotoxicity is more due to the activity of microorganisms. If the differences are minimal, then the main negative impact is associated with accumulated chemical pollutants in the soil [2].

The eluant phytotesting method consists in analyzing the toxicity of aqueous extract (eluate) of soils. Its essence is the assessment of the impact of water-soluble pollutants on indicator plants. The seeds were germinated in Petri dishes on filter paper soaked in an aqueous extract of the sample, and the control group in distilled water. After 3-7 days, the length of the roots of the seedlings and the germination of the seeds are measured [9, 10].

Criteria for selecting test objects for assessing phytotoxicity include germination rate, sensitivity to pollutants, representativeness for the studied region, and diversity of functional groups. The international standard ISO 11269-2 regulates the selection of at least two plant species, one monocotyledonous and the other dicotyledonous.

Examples of bioindicators. In the course of the development of science, as knowledge about changes in the biochemical state of plants and the ecological and geochemical state of soils increased, the term "biological monitoring" was formed, the essence of which is to study the state of air, water and soil environments based on the results of the analysis of the reaction of living organisms [13]. In direct proportion to the increase in the impact of anthropogenic impact, the importance of environmental monitoring, of which biological monitoring is a part, is growing.

Bioindicators are living organisms or a community of organisms whose presence, condition, and behavior determine bioecotopic changes in the environment. Various macro-organisms and microorganisms, including plants, can act as bioindicators. Based on the type of reaction to the content of elements in the environment, accumulators are isolated – plants that accumulate pollutants, indicators that reflect the current state and plants that exclude the transfer of metal from the environment. When diagnosing pollution of environmental components by various pollutants, plants with a reliably known reaction to their effects are used, lettuce, shoot-forming vole, common pine, hanging birch, and dioecious nettle are widely used [13; 14; 16].

Together with the harvest, a certain amount of nutrients is removed from the soil, to replenish which fertilizers are applied. For reasons of economy, crude or insufficiently purified fertilizers can be used, which contain heavy metals as trace substances that are inactive in the soil environment [13].

The introduction of excessive amounts of fertilizers leads to the fact that most of them, being absorbed by plants, at the same time cannot be included in the metabolic processes. For example, when an excess amount of saltpeter is added to the soil, nitrates accumulate in the upper parts of plants, most of them turn into nitrites, which are toxic salts for living organisms [13].

These examples of negative impacts threaten not only human health, but also the stability of agroecosystems, as the circulation of organic substances is disrupted, the soil structure and demoecological indicators of populations in cultivated areas are changing. This determines the relevance of biological monitoring [13; 15; 17].

Bioindicator plants have a number of advantages: they are widespread, relatively easy to cultivate, and have clear and measurable responses to pollutants (for example, changes in biomass, physiological parameters, and accumulation of pollutants in tissues).

Radish is often used as a bioindicator, due to its sensitivity to various factors of the soil environment and the precocity of the crop. The rapid growth and short growing season of radishes make it possible to get results quickly. Radishes accumulate heavy metals, which leads to visible changes in morphology: contamination can lead to changes in the size of root crops, their shape, the formation of necrotic spots on the leaves, etc., which is an advantage of this plant as a bioindicator. Its disadvantages include sensitivity to abiotic factors (temperature, humidity) and relatively low biomass.

Rapeseed is an oilseed crop with high adaptability to various types of soils. The advantages of rapeseed as a bioindicator include: high biomass, which makes it possible to obtain a sufficient amount of material for analysis, the ability to accumulate heavy metals in seeds and other organs, and some varieties can be used for phytoremediation [17]. However, rapeseed has a longer growing season compared to radishes and microgreens, which slows down the results.

Microgreens are sprouts of various vegetable and grain crops harvested at the stage of the first true leaves. It has a high nutritional value, which simplifies the analysis of heavy metal content, high growth, which allows obtaining results within a few days, and the ability to grow under controlled conditions, which minimizes the influence of external factors [18; 19]. These properties make microgreens a promising object for biological monitoring. The disadvantages of microgreens as a bioindicator include low biomass.

Materials and Methods

The soil samples for the study were obtained from the educational and experimental landfill of the Don State Technical University. The main series is represented by 4 samples (n=4) selected by the envelope method from an arable field subjected to regular agricultural processing. Each combined sample is formed from 5-point samples taken from a depth of up to 20 cm in accordance with the requirements of GOST 17.4.4.02-2017 "Nature Protection. Soils. Methods of sampling and preparation of samples for chemical, bacteriological, helminthological analysis" (GOST – Russian National Standard). The control sample (n=1) was selected by a similar method from the adjacent forest belt, considered as a zone with minimal anthropogenic impact. The total weight of each sample was approximately 1 kg.

The samples were transported to the laboratory in an inert polyethylene container. Preparation was carried out in the laboratory: foreign inclusions, roots, stones, and macrofauna were removed. For biotesting, analytical samples weighing 25.0±0.1 g were selected from each sample of arable soil and control.

Phytotoxicity assessment was carried out by direct germination of seeds on a soil substrate in accordance with the principles of GOST R ISO 22030-2009 "Soil quality. Biological methods. Chronic phytotoxicity in relation to higher plants". A 25.0 g soil sample was placed in sterile Petri dishes. The soil is evenly moistened with 25 ml of tap water soil:water ratio = 1:1, which provided optimal moisture for seed germination without flooding.

The following types of bioindicators were used:

1. Radish Raphanus sativus L., a precocious variety.
2. Spring barley *Hordeum vulgare* L.
3. Spring rapeseed *Brassica napus* L.
4. Watercress salad *Lepidium sativum* L.

3 analytical replications of Petri dishes were prepared for each test crop and each soil sample (4 arable + 1 control). The optimal number of seeds of the selected crop was sown in each cup, based on their size, which had not previously been etched. The number of radish seeds is 25, barley-30, rapeseed-55, lettuce - 50. Petri dishes are labeled, covered with lids to maintain moisture and placed in the laboratory under an ultraviolet lamp.

Incubation lasted 10 days under strictly controlled conditions: temperature: 22±1°C; relative humidity: 70±5%.

1. Seed germination (%): The number of germinated seeds was recorded daily; the germination criterion was the appearance of a root ≥ 2 mm long. The final germination was calculated on the 10th day relative to the total number of sown seeds according to GOST 12038-84 “Seeds of agricultural crops. Methods for determining germination”.

2. Germination energy (%). It was calculated as the percentage of seeds germinated in the first 3 days for radishes and watercress, and 4 days for barley and rapeseed, taking into account the specific features of the germination rate.

3. Morphometric parameters of seedlings (mm): On the 10th day, the length of the hypocotyl/coleoptile and the length of the primary root of each seedling in the Petri dish were measured. No measurements were performed for the root system of barley, where root accretion was observed.

4. Crude phytomass (g): On the 10th day, all seedlings in each cup, analytical repeat, were cut off with a scalpel at the substrate level. The aboveground part, the phytomass, was immediately weighed on an analytical balance with an accuracy of 0.001 g to determine the crude mass.

Statistical data processing. For each measured parameter (Germination, Germination energy, Average shoot length, Average Root length, Crude phytomass) The arithmetic mean and standard deviation were calculated for each soil sample and test culture based on three analytical repetitions. A graphical visualization of the results is presented in Table 1.

Table 1.

Results of germination of test objects

	Radish	Barley	Rapeseed	Watercress salad
Germination%	84	90	60	63
	80	70	60	45
	72	100	48	56
	76	100	24	42
	76	100	60	45
Control	84	83	24	67
The average value	79.3	90.5	46.0	53.0
Standard deviation, %	4.8	11.2	16.4	9.5
Seedling vigor	2.1	2.3	2.5	2.9
	2.0	1.75	2.1	2.1
	1.8	2.5	2.0	2.6
	1.9	2.5	1.0	1.9
	1.9	2.5	2.5	2.1

Control	2.1	2.1	1.0	3.1
The average value	1.9	2.3	1.9	2.5
Standard deviation, %	0.1	0.3	0.7	0.5
Phytomass, g	2.5	3.2	0.1	0.2
	2.7	2.9	0.4	0.1
	1.5	2.5	0.6	0.1
	2.2	2.3	1.2	0.4
	2.3	3.4	0.4	0.3
The average value	2.2	2.9	0.5	0.2
Standard deviation, %	0.5	0.4	0.4	0.1
Length of the green part, mm	Max= 60 Min= 25	Max= 150 Min= 10	Max= 22 Min= 5	Max= 30 Min= 5
	Max= 80 Min= 21	Max= 190 Min= 45	Max= 80 Min= 12	Max= 35 Min= 20
	Max= 70 Min= 25	Max= 170 Min= 20	Max= 32 Min= 10	Max= 40 Min= 15
	Max= 70 Min= 29	Max= 170 Min= 23	Max= 35 Min= 4	Max= 35 Min= 15
Control	Max= 87 Min= 35	Max= 195 Min= 31	Max= 65 Min= 30	Max= 30 Min= 17
The average value	Max= 73,4 Min= 27,0	Max= 175,0 Min= 25,8	Max= 46,8 Min= 12,2	Max= 34,0 Min= 14,4
The length of the roots, mm	Max= 115 Min= 10	The roots fused into one eco-system, measure-ment was not possi-ble.	Max= 40 Min= 15	Max= 35 Min= 15
	Max= 40 Min= 25		Max= 100 Min= 5	Max= 50 Min= 25
	Max= 90 Min= 73		Max= 30 Min= 40	Max= 40 Min= 5
	Max= 45 Min= 15		Max= 30 Min= 30	Max= 50 Min= 6
	Max= 120 Min= 51		Max= 40 Min= 1	Max= 30 Min= 5
Control	Max= 115 Min= 1		Max= 15 Min= 10	Max= 50 Min= 40
The average value	Max= 87.5 Min= 29.2		Max= 42.5 Min= 16.8	Max= 42.5 Min= 16.00

The presented methodology, based on the principles of GOST R ISO 22030-2009 and GOST 32640-2014, provided a comprehensive assessment of the phytotoxicity of soils in the arable field of DSTU landfill in comparison with the background control of the forest belt. The use of a standardized phytotest with four test cultures (*Raphanus sativus L., Hordeum vulgare L., Brassica napus L., Lepidium sativum*) and three analytical replicates per sample allowed us to obtain representative data on key biometric indicators. The analysis of the results confirms the logic of the chosen approach:

1. The data show marked differences in the response of test objects to agrogenic effects. For example, the indicators of barley: germination 70-100%, germination energy 1.7-2.5, phytomass 2.4-3.4 g in arable samples are often comparable or slightly different from the control: germination 83-100%, energy 2.08-2.5, phytomass 2.0-3.0 g, indicating its relative tolerance. At the same time, rapeseed and watercress showed high sensitivity: rapeseed in arable samples showed a sharp decrease in germination to 24%, germination energy to 1.0 and phytomass to 0.13 g relative to the control: germination 60%, energy 2.5, phytomass 1.20 g.

2. The results on the length of roots and shoots revealed inhibition of growth, which does not always correlate with a decrease in germination. Thus, watercress in individual arable samples with a relatively high germination rate of 45-67% showed a critical suppression of root length (Mp=5 mm versus Mp=40 mm in the control) and phytomass of 0.09-0.19 g versus 0.35 g in the control, which emphasizes the importance of evaluating these parameters to identify latent phytotoxicity.

3. Standardized incubation conditions and consideration of parameters, germination, germination energy, length of shoots / roots, phytomass, in accordance with GOST 12038-84 ensured reproducibility of the results.

Thus, the integrated phytotesting approach used has proven effective in identifying and quantifying the phytotoxicity of agrogenically disturbed soils, providing reliable data for subsequent analysis of the causes of the observed suppression of test crops. The results obtained substantiate the applicability of the selected bioindicators and accounting parameters for monitoring the state of agricultural soils. Agricultural activity in the studied field of DSTU landfill led to the formation of soil phytotoxicity, manifested in significant suppression of sensitive cruciferous crops (rapeseed, watercress) and the radish root system. Rapeseed and watercress, especially in terms of root length and phytomass, are highly sensitive bioindicators for monitoring. The revealed spatial heterogeneity of phytotoxicity requires a differentiated approach to assessing soil conditions and developing remediation measures.

Results and discussion

There are differences in the reaction of test objects to agrogenic effects, which confirms the need to use several different bioindicators for a comprehensive assessment of soil phytotoxicity. Indicators of rapeseed and microgreens indicate the manifestation of high sensitivity

There is an inhibition of the growth of shoots and roots, which does not always correlate with a decrease in germination. In microgreens in individual arable samples with relatively high germination (45-67%), a critical suppression of root length (Min=5 mm, Max=40 mm in arable samples versus Min=40 mm, Max=50 mm in control) and phytomass (0.09-0.19 g versus 0.3 g in control) was observed. These parameters are important for detecting latent phytotoxicity. Radishes also show a significant reduction in root length in arable samples (Min=10 mm, Max=120 mm) compared with the control (Min=1 mm, Max=115 mm). Obtaining such results may be due to the content of phytotoxicants in the soil, which affect the processes of plant growth and development, but do not affect seed germination.

The results obtained substantiate the applicability of the selected bioindicators for monitoring the state of agricultural soils. Agricultural activity in the field under study led to the formation of phytotoxicity of the soil, manifested in the suppression of sensitive cruciferous crops (rapeseed, watercress) and the radish root system. Rapeseed and watercress are highly sensitive bioindicators for monitoring. The revealed heterogeneity of phytotoxicity requires a differentiated approach to assessing soil conditions.

A similar study conducted by Altai State Agrarian University also demonstrates the high effectiveness of the phytoindication method for assessing soil toxicity, which is confirmed by a significant inhibition of the growth of test plants in contaminated samples. The results showed that in the most polluted areas – the Industrial District, school No. 120 – phytotoxicity reached 83% and 64%, respectively, compared with the control. These data are consistent with Marfenina's research, which noted a decrease in the biological activity of soils with heavy metal content above the MPC.

Of particular interest are the revealed differences in the reaction of test cultures. Cruciferous plants (rapeseed, watercress) showed the greatest sensitivity – a decrease in germination to 24% and phytomass to 0.13-0.62 g against control values of 60% and 0.38 g, respectively. At the same time, barley demonstrated relative stability (germination rate 70-100%, phytomass 2.45-3.24 g with control 83% and 3.42 g). This 2-3-fold difference in key indicators confirms the need to use several bioindicators for a comprehensive assessment.

It is important to note that in 45-67% of samples with relatively preserved microgreenage germination, a critical decrease in root length (5-40 mm versus 40-50 mm in the control) and phytomass (0.09-0.19 g versus 0.3 g) was observed. These data, obtained by repeating the experiments 4 times, indicate the presence of latent phytotoxicity, which is not detected by standard methods.

The comparison with the radish data is particularly significant, where the root length in the contaminated samples ranged from 10 to 120 mm versus 1-115 mm in the control. The identified spatial heterogeneity of contamination (the spread of phytotoxicity indicators from 40 to 92% at different sampling points) requires a differentiated monitoring approach. Studies have shown that the use of highly sensitive indicators (rapeseed, watercress) makes it possible to detect contamination at an early stage, when the content of toxicants still does not exceed 1.5-2 MPC.

A comparative analysis of the results of two studies on the assessment of soil phytotoxicity by phytoindication revealed a number of important patterns. Both studies confirmed the high efficiency of this method, demonstrating a significant inhibition of the growth of test plants in contaminated samples - a decrease in indicators by 24-92% relative to the control. At the same time, a pronounced species-specific reaction of plants to pollution was established: cruciferous crops (rapeseed, watercress) showed maximum sensitivity with a decrease in germination to 24% and phytomass to 0.13-0.62 g, while barley showed relative stability while maintaining germination at the level of 70-100%. Of particular value are the identified cases of latent phytotoxicity, when, with relatively high germination (45-67%), a critical suppression of root length (5-40 mm versus 40-50 mm in the control) and phytomass (0.09-0.19 g versus 0.3 g) was observed. The data obtained convincingly prove the need for an integrated approach using several bioindicators and taking into account both germination parameters and morphometric parameters. The revealed spatial heterogeneity of pollution (the range of phytotoxicity indicators from 40 to 92%) underlines the importance of differentiated monitoring of the soil condition. The research results are consistent with each other and confirm the expediency of using highly sensitive indicators (rapeseed, watercress) for early detection of pollution, which is of great practical importance for developing remediation measures for contaminated areas.

Conclusion

The conducted studies have demonstrated the effectiveness of the phytoindication method for assessing the phytotoxicity of soils exposed to agrogenic effects. The results showed a significant inhibition of the growth of test plants in contaminated samples, which resulted in a decrease in key indicators by 24-92% compared with the control. Cruciferous crops (rapeseed and watercress) showed the greatest sensitivity, with a sharp decrease in germination to 24%, germination energy to 1.0, and phytomass to 0.13-0.62 g. At the same time, barley has demonstrated relative stability, maintaining germination at the level of 70-100%, which confirms the need to use several bioindicators for a comprehensive assessment.

Of particular importance are the identified cases of latent phytotoxicity, when, with preserved germination (45-67%), a critical suppression of root length (5-40 mm versus 40-50 mm in the control) and phytomass (0.09–0.19 g versus 0.3 g) was observed. This underlines the importance of taking into account not only germination parameters, but also morphometric indicators to identify the negative effects of pollutants. The spatial heterogeneity of phytotoxicity (the range of indicators from 40 to 92%) indicates the local nature of pollution and the need for a differentiated approach to monitoring and remediation of soils. The data obtained are consistent with the results of other studies, confirming the expediency of using highly sensitive bioindicators such as rapeseed and watercress for early detection of phytotoxicity.

Thus, the phytoindication method combined with a comprehensive analysis of biometric indicators provides a reliable assessment of soil condition and can be recommended for monitoring agricultural areas. It is advisable to focus further research on the identification of specific pollutants and the development of measures to restore soil fertility.

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Original article

INTELLIGENT MODELS AND SUSTAINABILITY ASSESSMENT OF THE SECURITY SYSTEM OF AGRO-INDUSTRIAL ENTERPRISES

A.I. Dubrovina

Abstract

Background. In the era of digitalization, maintaining resilient security systems in agro-industrial enterprises is crucial. This paper examines approaches to developing intelligent models aimed at assessing and predicting the resilience of organizational and technical systems based on the analysis of interrelated risk factors. Cognitive and fuzzy modeling approaches are applied as methodological tools to formalize expert knowledge and support managerial decision-making. A methodology for constructing an integrated resilience indicator that takes into account both external and internal dynamics is proposed. Scenario analysis demonstrates the potential of intelligent algorithms to model critical situations and to select optimal response measures. The developed models can be applied to strengthen infrastructure protection strategies, enhance information and physical security, and ensure the sustainable operation of enterprises in uncertain environments.

The aim of the study is to develop and verify a model based on fuzzy cognitive maps (FCMs) for the mathematical assessment of the resilience of agricultural enterprise security systems. The work aims to integrate expert knowledge, scenario modeling, and dynamic visualization of system behavior under changing external and internal factors.

Materials and methods. The methodological framework of the study is based on cognitive and fuzzy modeling, simulation, and machine learning. FCMs are used as tools, accounting for uncertainty, the subjectivity of expert assessments, and nonlinear relationships between factors. Logistic Regression, Random Forest, and XGBoost algorithms, implemented in Python, were used for computational experiments. The analysis was conducted using the IGLA package for constructing cognitive models and assessing impact scenarios.

Results. An intelligent security system resilience model was developed, incorporating five key concepts: financial resilience, human resources, technological reliability, information security, and organizational processes. Scenario modeling was conducted to identify the impact of various management strategies on the integrated resilience indicator. Scenario simulations revealed that an integrated approach can increase overall system resilience by 15–20% compared to isolated security improvements.

Machine learning experiments achieved a high classification accuracy (up to 0.98) across all models, with logistic regression providing the best balance between precision and recall.

Conclusion. Intelligent models based on fuzzy cognitive maps and machine learning methods provide effective assessments of the resilience of security systems in agricultural enterprises. The proposed approach allows for the consideration of uncertainty, modeling threat scenarios, and improving the adaptability of security systems. The practical significance of this work lies in the potential application of the developed models to improve infrastructure protection strategies, enhance information and physical security, and ensure the stable operation of enterprises in uncertain environments.

Keywords: intelligent models; organizational systems; sustainability assessment; fuzzy cognitive maps; decision support; artificial intelligence

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Научная статья

ИНТЕЛЛЕКТУАЛЬНЫЕ МОДЕЛИ И ОЦЕНКА УСТОЙЧИВОСТИ СИСТЕМЫ БЕЗОПАСНОСТИ АГРОПРОМЫШЛЕННЫХ ПРЕДПРИЯТИЙ

А.И. Дубровина

Аннотация

Обоснование. В условиях цифровизации обеспечение устойчивости систем безопасности предприятий агропромышленного комплекса приобретает особое значение. В данной работе рассматриваются подходы к разработке интеллектуальных моделей, направленных на оценку и прогнозирование устойчивости организационно-технических систем на основе анализа взаимосвязанных факторов риска. Когнитивные и нечеткие модели используются в качестве методического инструмента для формализации экспертных знаний и поддержки принятия управленческих решений. Предложена методика построения интегрального показателя устойчивости, учитывающего как внешнюю, так и внутреннюю динамику. Сценарный анализ демонстрирует потенциал интеллектуальных алгоритмов при моделировании критических ситуаций и выборе оптимальных мер реагирования. Практическая значимость исследования заключается в возможности использования разработанных моделей для совершенствования стратегий защиты инфраструктуры, повышения информационной и физической безопасности, обеспечения устойчивой работы предприятий в условиях неопределенности.

Цель исследования заключается в разработке и верификации модели на основе нечетких когнитивных карт (НКК) для математической оценки устойчивости системы безопасности аграрных предприятий. Работа направлена на интеграцию экспертных знаний, сценарное моделирование и динамическую визуализацию поведения системы при изменении внешних и внутренних факторов.

Материалы и методы. Методологическую основу исследования составляют методы когнитивного и нечеткого моделирования, имитационное моделирование и машинное обучение. В качестве инструментария применены НКК, позволяющие учитывать неопределенность, субъективность экспертных оценок и нелинейные взаимосвязи факторов. Для вычислительных экспериментов использованы алгоритмы Logistic Regression, Random Forest и XGBoost, реализованные на Python. Анализ проводился с использованием пакета ИГЛА для построения когнитивных моделей и оценки сценариев воздействия.

Результаты. Разработана интеллектуальная модель устойчивости системы безопасности, включающая пять ключевых концептов: финансовая устойчивость, кадровый потенциал, технологическая надежность, информационная безопасность и организационные процессы. Проведено сценарное моделирование, выявившее влияние различных стратегий управления на интегральный показатель устойчивости. Установлено, что при комплексном подходе устойчивость повышается на 15–20 % по сравнению с частичными мерами усиления безопасности.

Результаты машинного обучения показали высокую точность классификации (до 0,98) для всех моделей, при этом логистическая регрессия продемонстрировала наилучший баланс точности и полноты.

Заключение. Интеллектуальные модели на основе нечетких когнитивных карт и методов машинного обучения обеспечивают эффективную оценку устойчивости систем безопасности агропромышленных предприятий. Предложенный подход позволяет учитывать неопределенность, моделировать сценарии угроз и повышать адаптивность систем защиты. Практическая значимость работы заключается в возможности применения разработанных моделей для совершенствования стратегий защиты инфраструктуры, повышения уровня информационной и физической безопасности и обеспечения стабильного функционирования предприятий в условиях неопределенности.

Ключевые слова: интеллектуальные модели; организационные системы; оценка устойчивости; нечеткие когнитивные карты; поддержка принятия решений; искусственный интеллект

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Introduction

In the current era of digital transformation, maintaining stable and resilient organizational security systems has become a crucial research focus. Agricultural enterprises, in particular, rely on complex information and communication infrastructures to manage production, logistics, and financial flows. The vulnerability of such infrastructures to cyber threats, technological failures, and organizational risks directly affects the resilience of enterprises and, consequently, national food security.

Traditional approaches to assessing the resilience of security systems often rely on static risk assessment methods or formalized checklists that fail to capture the dynamics and interdependencies of security-related processes. These methods frequently overlook the impact of latent factors, the ambiguity of expert judgments, and the nonlinear nature of cause-and-effect relationships in complex organizational systems. As a result, decision-makers may receive incomplete or distorted information, thereby reducing the effectiveness of management strategies.

Purpose. The aim of this study is to develop and validate a fuzzy cognitive map (FCM)-based model for a quantitative evaluation of the resilience of security systems in agricultural enterprises. The study places particular emphasis on the integration of expert knowledge, scenario modeling, and dynamic visualization of system behavior.

The main objectives of the research are as follows:

- Identification and formalization of the most significant concepts determining the security of agricultural enterprises
- Construction of a fuzzy cognitive map reflecting causal relationships among the selected concepts

- Assessment of security system resilience under various scenarios and identification of critical risk factors

To address these objectives, modern mathematical and computational models were employed, including fuzzy logic, cognitive modeling, and simulation techniques. Among them, fuzzy cognitive maps represent a powerful tool for analyzing the structural and dynamic properties of security systems. FCMs enable the integration of quantitative indicators with qualitative expert judgments, thereby capturing uncertainty and modeling causal dependencies.

Characteristics of the automated facility

The scientific novelty of this work lies in the development of a methodological framework that combines cognitive modeling with fuzzy inference methods for assessing the resilience of organizational security systems. Unlike traditional static models, the proposed approach enables scenario analysis, incorporates uncertainty in expert assessments, and provides dynamic visualization of security system behavior in the agro-industrial sector.

The expected scientific results of the research include the development and expansion of the methodological framework for risk analysis and management in the fields of information security and organizational management. The main practical result of this work is the creation of an adaptive model applicable in subject areas characterized by a high degree of uncertainty and the presence of complex systemic relationships between elements.

Literature review

Assessing the stability of systems is a key problem in modern management theory and applied computer science. The management systems of agro-industrial enterprises are very complex and are characterized by a high degree of uncertainty and a multitude of interrelated factors.

In studies [1-3], methods for constructing cognitive maps to model complex systems explored, with particular attention given to the interaction between organizational and technological factors. Fuzzy cognitive maps (FCMs), originally proposed by B. Kosko, have found broad application in describing systems characterized by weakly structured relationships and subjective expert evaluations.

In works [4-5], FCMs were applied to model risk management and information security processes. Such models allow for the incorporation of uncertainty in source data, which is particularly relevant under dynamic external influences on agro-industrial enterprises (e.g., changes in economic conditions, resource price fluctuations, and climate risks).

Recent studies [6-8] also highlight the role of intelligent data analysis methods, including machine learning, expert systems, and hybrid models. However, specialized methods for the agro-industrial sector remain underdeveloped, where system resilience depends not only on technological but also on organizational and economic factors.

Therefore, the use of FCMs in combination with scenario modeling tools represents a promising direction for assessing the resilience of security systems in agro-industrial enterprises.

Research methods

In the framework of assessing the resilience of security systems in agro-industrial enterprises, an intelligent methodology was developed based on the application of fuzzy cognitive maps (FCMs) and dynamic simulation algorithms. This approach makes it possible to account for environmental uncertainty, the human factor, and nonlinear interactions among system components.

Statement of the problem

The primary task was to formalize a model of the enterprise's security system by identifying key concepts and establishing causal relationships between them. The following basic concepts were considered:

- Organizational resilience (availability of policies and security regulations)
- Technical protection (level of information infrastructure security)
- Personnel security (staff training and qualification levels)
- Financial resilience (resource support for protective measures)
- External threats (cyberattacks, economic sanctions, environmental risks)

Dynamic simulation algorithm

The system dynamics were described using an iterative equation.

$$C^{(t+1)} = f(C^{(t)}W) \tag{1}$$

where:

- C(t) – vector of concept values at step t
- W – weight matrix
- f(x) – activation function (sigmoid normalization was applied)

This allowed the modeling of various scenarios such as intensification of external threats, reduction in financial support, and improvement of personnel training.

Software implementation

In the experimental part, Python scripts were developed to verify the correctness of calculations and to visualize the dynamics of concepts. The algorithm consisted of seven stages:

- Data loading and preprocessing – the built-in Breast Cancer Wisconsin dataset from scikit-learn was used; features included morphological characteristics, with balanced and structured data
- Correlation analysis – a correlation matrix of features was generated (Fig. 1)
- Data splitting – 70% of the data were used for training and 30% for testing
- Model training – Logistic Regression (linear model), Random Forest (ensemble of trees), and XGBoost (gradient boosting) were employed
- ROC analysis (Fig. 2) – ROC curves for all models were plotted and AUC (area under the curve) was computed
- Feature importance analysis – the top 10 features were extracted for Random Forest and XGBoost
- Performance evaluation – precision, recall, and F1-score were calculated for each model

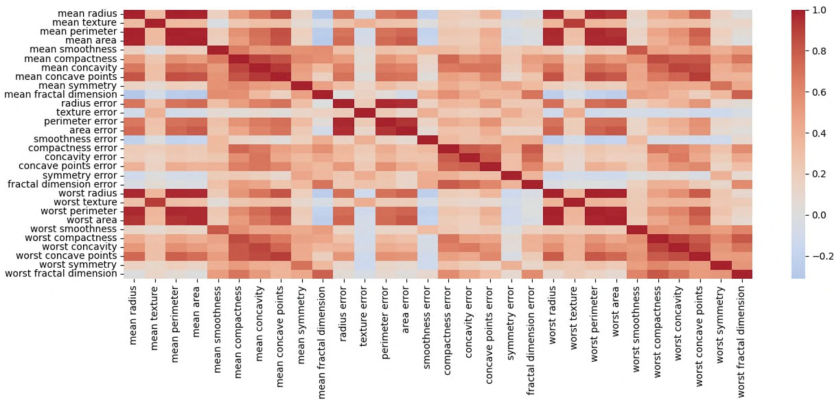

Fig. 1. Feature correlation analysis

The heatmap illustrates the correlation analysis of features in the Breast Cancer Dataset (sklearn). Strong correlations were observed among feature groups:

- mean radius, mean perimeter, and mean area (coefficients > 0.9)
- worst radius, worst perimeter, and worst area
- Features related to concavity and concave points (mean, worst).

Many features exhibit redundancy (e.g., mean radius and worst radius), which is critical since excessive correlation may hinder interpretability and affect the stability of linear algorithms (e.g., logistic regression).

Conversely, parameters such as texture error, smoothness error, and fractal dimension error demonstrated weak correlations with other features, indicating their unique contribution.

For models sensitive to multicollinearity (e.g., logistic regression), feature selection methods such as PCA or regularization are beneficial. For tree-based models (Random Forest, XGBoost), multicollinearity is less critical, though strong feature groups still influence feature importance distributions.

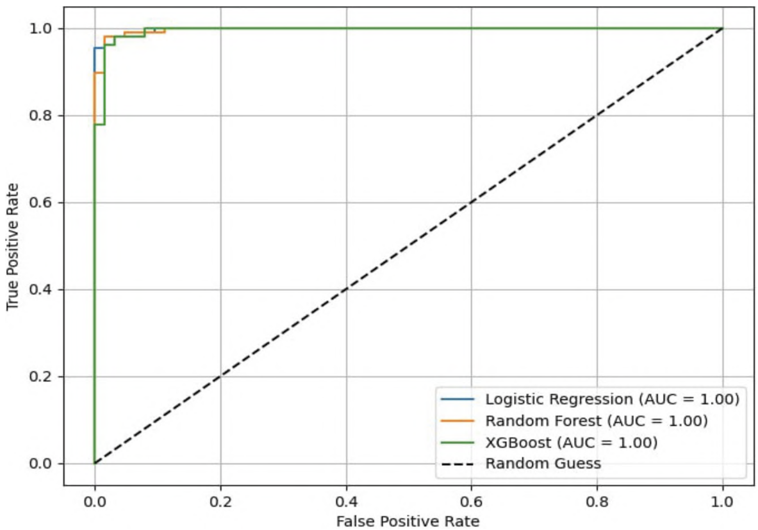

Fig. 2. ROC curves for intelligent models

Figure 2 presents ROC curves for the three models (Logistic Regression, Random Forest, and XGBoost) in the breast cancer classification task. All three models achieved AUC = 1.00, corresponding to maximum classification performance. The black dashed line ("Random Guess") represents the baseline (AUC = 0.5).

The models significantly outperformed random guessing, confirming the informativeness of the features and the adequacy of the chosen models. With an AUC of 1.0, the models exhibited no classification errors: the True Positive Rate reached 1 at nearly zero False Positive Rate.

This outcome, while rare, may indicate either an exceptionally clean dataset with well-separated classes or potential overfitting (especially if the test set is small or feature correlations are high) (Fig. 3).

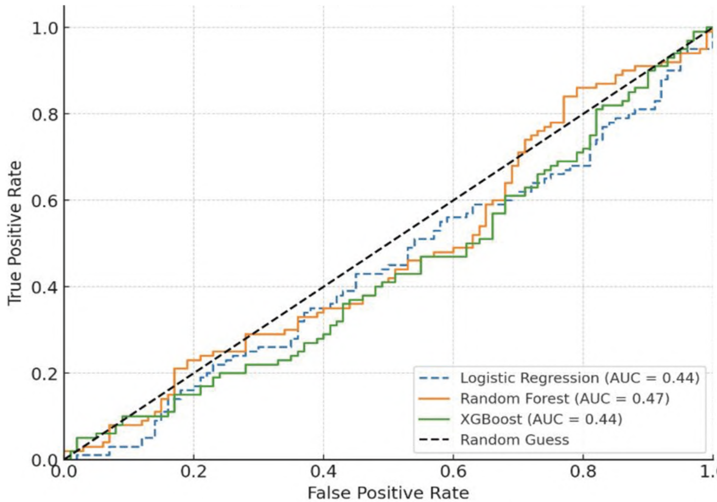

Fig. 3. ROC curves for intelligent models on the dataset

The high performance indicators of classification models, visualized through ROC curves (Figure 3), are interpreted ambiguously. While this result is desirable and may indicate a representative dataset with well-separated classes, it also raises a red flag indicating potential overfitting. This phenomenon is especially likely when using a small amount of test data or when there are signs of multicollinearity. Thus, to verify the result, it is necessary to use additional diagnostic methods in order to eliminate modeling artifacts and confirm result validity.

Experimental results

To evaluate the effectiveness of the developed intelligent model of security system resilience for agro-industrial enterprises, a series of simulation experiments was conducted for a representative enterprise characterized by a branched management structure and a high number of critical processes. The initial data included expert assessments of risk probabilities as well as monitoring data of production and management processes.

The experimental methodology comprised the following steps:

- Construction of a FCM including the key concepts: financial stability, human resource potential, technological reliability, information security, and environmental safety

- Development of scenario-based simulations incorporating three management strategies were tested: Scenario 1 – maintaining of the current level of security, Scenario 2 – strengthening of information security through the introduction of additional monitoring technologies, Scenario 3 – integration of a comprehensive model considering the interaction of all critical factors
- The results demonstrated the following patterns: under Scenario 1 (baseline), the system exhibited a gradual decline in resilience caused by the accumulation of technological and personnel-related risks, in Scenario 2, a temporary increase in resilience was observed due to enhanced information security; however, the absence of a systemic approach led to a rapid rise in vulnerabilities in other areas, under Scenario 3 (integrated model), the highest level of resilience was achieved owing to the balanced distribution of protective measures, ensuring adaptability and effective crisis prevention
- The dynamics illustrated in Figures 4–5 indicated that the integration of the intelligent model increased system resilience by 15–20% compared to partial reinforcement strategies.

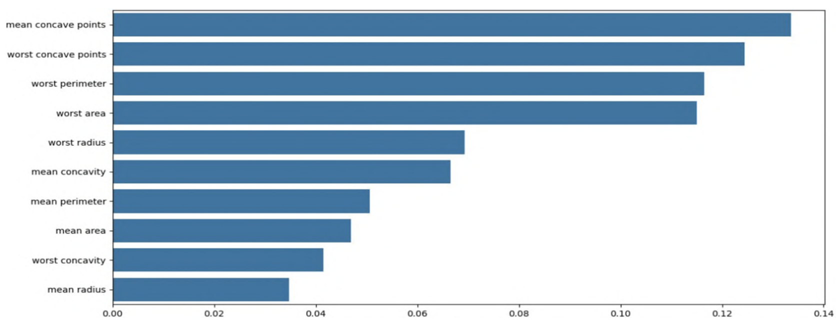

Fig. 4. Feature importance by Random Forest

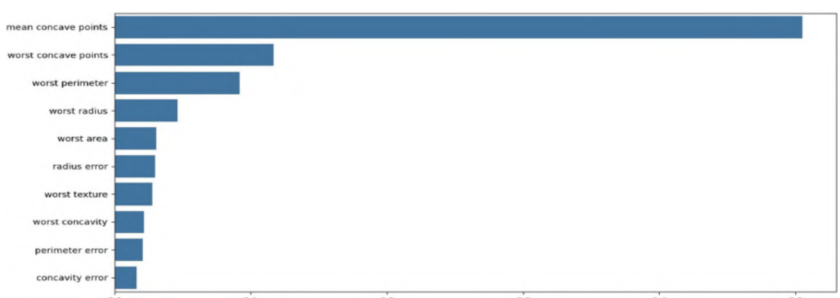

Fig. 5. Feature importance by XGBoost

Random Forest analysis (Fig. 4) emphasized the relevance of geometrical characteristics such as mean concave points, worst concave points, worst perimeter, worst area, worst radius, distributing feature importance relatively evenly across several attributes. Conversely, XGBoost (Fig. 5) demonstrated a high dependency on mean concave points (over 50% contribution), indicating a more focused but potentially less generalizable classification. Both models consistently confirmed the critical importance of contour concavity parameters, although Random Forest demonstrated higher robustness to noise, while XGBoost achieved greater precision with a risk of overfitting.

A series of scenario simulations was carried out using the IGLA software package, where the following key concepts were modeled: Information Security (IS), Financial Stability (FS), Human Resources (HR), Technical Protection (TP), and Organizational Processes (OP). Disturbance factors (external threats, internal risks) were varied within the interval [−1,+1].

Table 1.

Dynamics of the integral security system resilience index

Scenario	Initial state	Iteration 3	Iteration 5	Final state	Resilience rating
Baseline (no threats)	0.72	0.74	0.75	0.76	High
Moderate threats	0.72	0.65	0.61	0.59	Medium
Strong threats	0.72	0.52	0.45	0.41	Low
Security reinforcement	0.72	0.70	0.73	0.78	High
Workforce deficit	0.72	0.60	0.55	0.51	Low

The results highlight the following:

- Under strong threats, system resilience declines sharply
- Reinforced security compensates for negative impacts, even exceeding baseline levels
- Workforce shortages result in gradual degradation, underscoring the critical role of the human factor

Model classification performance was assessed using standard metrics (precision, recall, F1-score, accuracy). XGBoost achieved Accuracy = 0.96 and F1-score = 0.96–0.97 (Table 2), though it showed signs of overfitting and reduced balance between precision and recall.

Random Forest achieved an accuracy of 0.97 and F1-score = 0.97–0.98 (Table 3), performing slightly worse in recall for class «0», but excelling in detecting class “0” / “1”.

Table 2.

XGBoost

	Precision	**Recall**	**F1-score**	**Support**
0	0.94	0.97	0.95	63
1	0.98	0.96	0.97	108
Accuracy			0.96	171
Macro avg	0.96	0.97	0.96	171
Weighted avg	0.97	0.96	0.97	171

Table 3.

Random Forest

	Precision	**Recall**	**F1-score**	**Support**
0	0.98	0.94	0.96	63
1	0.96	0.99	0.98	108
Accuracy			0.97	171
Macro avg	0.97	0.96	0.97	171
Weighted avg	0.97	0.97	0.97	171

Logistic Regression demonstrated the most balanced results, with Accuracy = 0.98 and an F1-score of 0.97–0.98 (Table 4), confirming its reliability and stability.

Table 4.

Logistic Regression

	Precision	**Recall**	**F1-score**	**Support**
0	0.97	0.97	0.97	63
1	0.98	0.98	0.98	108
Accuracy			0.98	171
Macro avg	0.97	0.97	0.97	171
Weighted avg	0.98	0.98	0.98	171

All three models demonstrated high levels of accuracy and robustness, with only minor differences in performance. Logistic Regression proved to be the most balanced and reliable model for resilience assessment under the studied conditions.

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Original article

INFLUENCE OF POLISHING DEGREE ON TECHNOLOGICAL TRAITS OF GRAIN OF DIFFERENT RICE VARIETIES

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Abstract

Background. The quality of rice products, their physical properties and nutritional value depend on the degree of grain processing, including its polishing, which removes the surface shells and the germ. The task of the work is to assess the effect of the degree of grain polishing of Russian-bred rice varieties with different grain sizes and shapes on the physical (technological) traits of the grain.

Purpose. The goal of the study was to assess the influence of the grain polishing degree of Russian-bred rice varieties with different grain sizes and shapes on the physical (technological) traits of the grain.

Materials and methods. The research material included the following varieties: Favorit, Veles, Trio, Regul 2, Forsazh, Strombus, Prestige, Vector, most of which are approved for use. The set of parameters for assessing grain quality included the following indicators: grain size, vitreousity, grain fracturing, total milling yield, head rice content, and bran yield during polishing. The duration of polishing was 50, 90, and 120 seconds.

Results. The mass of 1000 absolutely dry grains was in the range of 25.6–26.6 g in the group of medium-weight varieties and 28.4–33.1 g in the group of large-grain rice varieties. In the group of large-grain varieties, the varieties Forsazh and Strombus were the most resistant to intensive polishing, the varieties Prestige and Regul 2 were the least resistant; in the group of medium-weight varieties, the corresponding indicators of the head rice content were significantly lower.

Conclusion. Significant dynamics of the indicators was noted already at the initial stage of grain polishing (90 s) in the rice varieties Favorit and Strombus for the indicator “head rice content”, Favorit and Utes - for the bran yield; at the stage of 120 s - in the vari-eties Regul 2 and Vector, Prestige for all traits, the varieties Trio and Forsazh for the indicators “total milling yield” and “bran yield”. Equivalent changes in the indicator of traits with different degrees of polishing were typical for the varieties Strombus and Utes for the indicator of total milling yield; Trio, Utes and Forsazh- for the head rice content and the variety Strombus - for the bran yield.

Keywords: rice; technological traits; rice quality; polishing degree

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Научная статья

ВЛИЯНИЕ СТЕПЕНИ ШЛИФОВАНИЯ НА ТЕХНОЛОГИЧЕСКИЕ ПРИЗНАКИ ЗЕРНА РАЗЛИЧНЫХ СОРТОВ РИСА

Э.Ю. Папулова, Н.Г. Туманьян, С.С. Чижикова, Р.Н. Троян, Т.Б. Кумейко

Аннотация

Обоснование. Качество рисопродуктов, их физические свойства и пищевая ценность зависят от степени обработки зерна, в том числе его шлифования, при котором удаляются поверхностные оболочки и зародыш. В работе поставлена задача провести оценку влияния степени шлифования зерна сортов риса российской селекции с различной крупностью и формой зерновки на физические (технологические) признаки зерна.

Цель. Целью исследования являлась оценка влияния степени шлифования зерна сортов риса российской селекции с различной крупностью и формой зерновки на физические (технологические) признаки зерна.

Материалы и методы. Материалом исследования служили сорта Фаворит, Велес, Трио, Регул 2, Форсаж, Стромбус, Престиж, Вектор, большинство из которых допущено к использованию. В комплекс параметров оценки качества зерна входили показатели признаков: крупности, стекловидности, трещиноватости зерна, общего выхода крупы, содержания целого ядра и выхода мучки при шлифовании. Длительность шлифования: 50, 90, 120 секунд.

Результаты. Масса 1000 а. с. зерен находилась в диапазоне 25,6-26,6 г в группе средних по массе сортов и 28,4–33,1 г в группе крупнозерных сортов риса. В группе крупнозерных сорта Форсаж и Стромбус были наиболее устойчивы к интенсивному шлифованию, сорта Престиж и Регул 2 - наименее; в группе средних по массе сортов соответствующие показатели содержания целого ядра в крупе были значительно ниже.

Заключение. Была отмечена значительная динамика показателей уже на начальном этапе шлифования зерна (90 с) у сортов риса Фаворит и Стромбус для показателя «содержание целого ядра», Фаворит и Утес – для выхода мучки; на этапе 120 с – у сортов Регул 2 и Вектор, Престиж для всех признаков, сортов Трио и Фор-саж для показателей «общий выход крупы» и «выход мучки». Равнозначным изменением показателей признаков при различной степени шлифования характеризовались сорта Стромбус и Утес для показателя общего выхода крупы; Трио, Утес и Форсаж – для выхода целого ядра и сорт Стромбус – для показателя выхода мучки.

Ключевые слова: рис; технологические признаки; качество риса; степень шлифования

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Introduction

Rice (Oryza sativa L.) is considered the main source of energy and nutrients for more than half of the world's population [1]. Consumer preferences for rice depend on the cultural traditions of the population and are associated with various grain quality parameters, including the amylose content of the reserve starch.

The rice caryopsis is a grain, in which the seed is covered with an outer coat (pericarp), developing from the walls of the ovary. Behind the pericarp are two layers of cells, which are the seed coat. The outer layer of the endosperm, adjacent to the coat, is filled with aleurone grains, rich in protein. The inner, central part of the endosperm consists of starch grains. In the lower part of the grain is the embryo, the length of which does not exceed 1/3 of the grain length. The embryo contains a significant amount of fat [2].

Rice is consumed mainly in the form of milled rice, the production of which involves a range of technological operations aimed at improving its consumer properties, the most important of which are the processes of hulling and polishing. During the hulling process, the flower films are removed, and during polishing, the peripheral layers of the grain (outer and seed coats), the germ, and partially or completely the aleurone layer are removed, which form a by-product - rice bran. Husked rice is relatively rich in vitamins and contains thiamine (B_1), riboflavin (B_2), nicotinic acid (PP) and some others. Industrial enterprises usually polish rice to improve the physical and taste qualities of rice grains and stability during storage [1; 3].

The nutritional value of rice is one of the most important indicators of its quality. The main purpose of polishing is to separate the germ, outer and seed coats from the grain endosperm. The degree of removal of the grain layers is determined by the polishing degree, which determines the whiteness of the rice [4]. Kernels that have undergone different degrees of polishing have different functional and taste properties [5; 6].

Polished rice consists mainly of carbohydrates (80%) and a small amount of proteins (6-7%), minerals, fats, etc. The proteins contained in rice are particularly nutritious, rich in the essential amino acid lysine and hypoallergenic. It has been shown that 61% of mineral elements and about 84.2% of kernel proteins are concentrated in the outer endosperm, and with further polishing their concentration decreases [7]. The central part of the endosperm is mainly composed of starch (84.6%). The ratio of magnesium and potassium has a great influence on the viscosity of rice [8].

Wang et al. (2014) suggested that the degree of polishing has little effect on cooking and taste of rice, but has a significant effect on nutrient content.

Chagam Koteswara Reddy from Pondicherry University, India (2017) in his research claimed that 9% polishing resulted in decrease in moisture, ash, protein and fat content in pigmented rice while carbohydrate content (including amylose) increased in pigmented rice. Monks J.L.F. et al. from Federal University of Pelotas, Brazil (2013), Roy R. et al. from National Food Research Institute, Japan (2008) also reported that fat content in brown rice decreased with 12% polishing.

Differences in the amount and composition of the bran formed during grain polishing may arise depending on the characteristics of genotypes, environmental conditions and agronomic cultivation practices [1]. Research by Belgian scientists has shown that the loss of protein content is lower in pigmented rice (from 3.08% to 5.02%) due to polishing (9%), which was possible due to the fact that the absolute protein content in the endosperm of rice grains is higher than in the bran layers [11].

The amylose content plays a decisive role in determining the taste of rice grains [12] and in the cooking process, it affects the viscosity of the starch dispersion and the consistency of cooked rice [4]. With an increase in the degree of polishing, the amylose content increases. With an increase in the duration of grain polishing of eleven varieties, an increase in the concentration of amylose, nitrogen, minerals towards the center of the grain was found, and the outer parts of the grain were rich in phosphorus, magnesium, potassium and manganese [7]. These results indicated that the outer part contains various compounds other than starch, while the inner part contains relatively pure starch. Rice flavor and other characteristics can be improved by controlling the polishing degree.

Analysis of the relationship between protein content and the polishing degree showed that protein is unevenly distributed in the kernel of husked rice [13]. Increasing the degree of polishing rice grains leads to the loss of essential amino acids such as glutamic acid, lysine and tartaric acid, which are mainly responsible for the aroma and taste qualities when cooking rice [5]. Varietal response to polishing was found, with iron content loss ranging from 25 to 84% for different varieties. Like other nutrients, selenium was also lost during polishing [14]. Important functions of selenium include its antioxidant properties and its ability to perform enzymatic functions, making it an essential element of food products [15].

Evaluation of the physicochemical and biochemical quality traits of rice varieties with different degrees of polishing is necessary for developing optimal modes of processing grain of different varieties in order to preserve the necessary nutrients in rice.

Purpose. The goal of the study was to assess the influence of the grain polishing degree of Russian-bred rice varieties with different grain sizes and shapes on the physical (technological) traits of the grain.

Materials and methods

The material for the study was the grain of medium-weight and large and medium-grain rice varieties grown at the experimental production site of the Federal Scientific Rice Centre and in rice-growing farms of Krasnodar region in 2024 (Table 1). The variety Favorit was used as a standard. The studied rice varieties Favorit st, Veles, Trio, Regul 2, Forsazh, Strombus, Prestige, Vector are included in the State Register of Breeding Achievements approved for use in the North Caucasus region. When the seeds reached full ripening, rice grain samples were collected (full ripening phase). The panicles were cut, dried to a standard grain moisture content of 14% and stored. The grain size was determined by the trait of "mass of 1000 absolutely dry grains" in accordance with GOST 10842-89 "Grain of cereal and legume crops and oilseeds" using the ELVIZ-2 moisture analyzer, the ASESh-8-2 air-thermal measuring unit and the SLY-C automatic seed counter. Vitreousity was determined according to GOST 10987-76 "Grain. Methods for determining vitreousity". Fracturing and vitreousity were assessed in transmitted light using the DZZ-3 device. The morphological grain traits (grain shape) were determined by its linear dimensions on the scanner (image analysis system LA 2400, WinFOLIA using the Seedling computer program, Canada). The quality traits of the milled rice were assessed under certain parameters: moisture 10–14%, shaft rotation speed 600–900 rpm. The rice grains were hulled and polished on a Yasar Makina CRM 125 2T unit (Turkey) for 50 (46), 90 (87), and 120 (117) seconds. Technological quality traits were determined by standardized methods: grain size by the mass of 1000 absolutely dry grains (mass of 1000 a.d. grains) - according to GOST 10842-89. The yield of polished rice was determined according to GOST R 50438-92. Total milling yield, head rice content, the percentage of crushed rice (kernels that were less than two-thirds of the grain length were considered crushed) were determined. The duration of grain polishing was 50, 90, 120 seconds.

Statistical processing was performed in Excel (M), standard error of the mean (±SEM), LSD at 5% significance level.

Table 1.

Research material – Russian-bred rice varieties

Variety	Patent	Group of varieties according to grain shape
Favorit, st	№ 7226	medium-grain
Utes	-	medium-grain
Veles	№ 10934	medium-grain
Trio	№ 13458	medium-grain
Regul 2	-	medium-grain
Forsazh	№ 13457	medium-grain
Strombus	-	medium-grain
Prestige	№ 12435	medium-grain
Vector	№ 86788	medium-grain

Results and discussion

The research included differentiation of varieties by grain size and shape (Table 2). The group of medium-grain varieties with medium grain weight included the varieties Utes, Veles, Trio; the group of medium-grain large-grain varieties included Favorit, Regul 2, Forsazh, Strombus, Prestige, Vector.

With different grain polishing intensities, the kernels differed in color (Fig. 1).

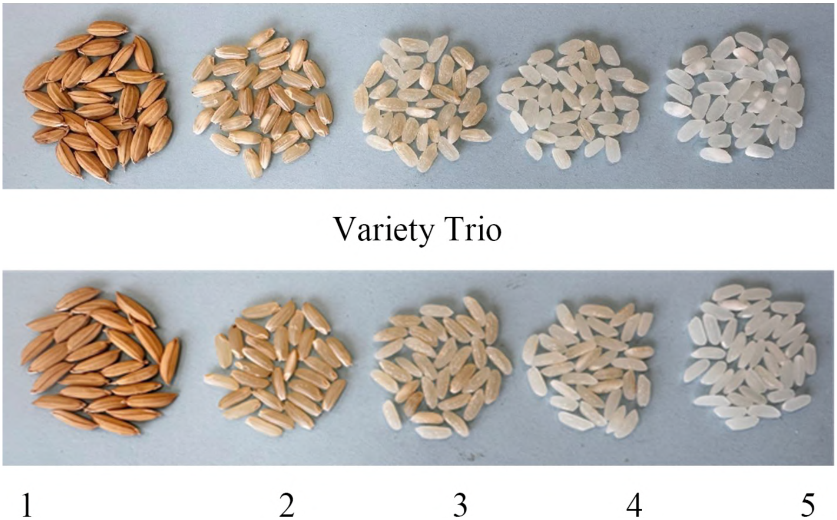

Fig. 1. Rice grain, husked rice, polished rice.
1 - rice grain, 2 - husked rice, 3 - rice polished for 50 s, rice polished for 90 s, rice polished for 120 s.

When rice is husked, the seed coat and outer coat of the grain are preserved. When polished for 50 s, the germ and seed coat are partially preserved, as evidenced by the cream color of the kernel. When polished for 90 s, traces of the seed coat are visible on the surface of the kernel, the germ is absent. When polished for 120 s, all kernels are typically white, while the germ, seed coat and outer coat are completely removed, the kernel is the endosperm.

The assessment of physical (technological) quality traits was carried out based on the characteristics of grain size, shape, filminess, vitreousity, and fracturing (Table 2).

The weight of 1000 a.d. grains was in the range of 25.6-26.6 g in the group of medium-weight varieties and 28.4-33.1 g in the group of large-grain rice varieties. The highest value of the trait was noted in the medium-weight variety Utes (26.6 g) and in the large-grain variety Strombus (33.1 g), which was 3.5 g lower and 3.0 g higher than the values of the standard variety Favorit, respectively.

The filminess of the studied rice varieties was within 16.8–22.8% in the group of medium-weight varieties and 16.2–19.2% in the group of large-grain varieties. The highest value of the trait was noted in the varieties Utes (22.8%)

and Regul 2 (19.2%), which exceeded the filminess of the standard variety Favorit by 4.2 and 0.6%, respectively.

Table 2.

Characteristic of rice varieties by technological grain quality traits

№	Variety	Mass of 1000 a.d. grains, g	Gran length-to-width ratio (l/b)	Filminess, %	Vitreousity, %	Fracturing, %
medium-weight rice varieties						
1	Utes	26,6±0,10	2,5±0,06	22,8±0,21	99±1,15	38±0,58
2	Veles	25,9±0,06	2,4±0,10	16,8±0,10	98±1,53	22±1,00
3	Trio	25,6±0,20	2,8±0,10	20,0±0,25	90±1,25	27±1,73
large-grain rice varieties						
1	Favorit st	30,1±0,08	2,4±0,10	18,6±0,15	75±1,75	19±1,10
2	Regul 2	29,4±0,20	2,4±0,08	19,2±0,22	90±1,10	88±1,15
3	Forsazh	31,9±0,10	2,3±0,20	16,6±0,17	80±1,60	21±1,73
4	Strombus	33,1±0,15	2,5±0,17	16,2±0,18	89±1,32	17±1,00
5	Prestige	29,1±0,22	2,3±0,15	18,6±0,21	87±1,45	45±1,73
6	Vector	30,6±0,17	2,3±0,10	19,0±0,23	85±1,10	71±1,52
	LSD_{05}					

Vitreousity in the group of large-grain varieties was average and varied within the range from 80 to 90%. The highest value of the trait was noted in the variety Regul 2 (90%), which exceeded the trait value in the standard variety Favorit by 15%. In the group of medium-weight varieties, vitreousity was highest in the variety Utes (99%), and lowest in the variety Trio (90%).

Grain fracturing ranged from 22 (Veles) to 38% (Utes) in the group of medium-weight rice varieties and from 17 (Strombus) to 88% (Regul 2) in the group of large-grain varieties. The variety Regul 2, with high vitreousity, exhibits high cracking.

Analyzing the values of the traits by groups, we concluded that the filminess and vitreousity were higher in medium-weight varieties. The medium-weight variety Utes and the large-grain variety Strombus were recognized as the best quality varieties.

The results of the influence of the polishing degree on the total yield of polished rice and the head rice content for medium-weight and large-grain varieties are presented in Tables 3, 4 and in Figures 2, 3. The total yield of polished rice was the highest for all medium-weight varieties in the experiment when polished for 50 seconds (73.3% for Utes, 74.6% for Veles and 73.2% for Trio) (Table 3).

Table 3.

Characteristics of medium-weight medium-grain rice varieties by polishing intensity

Variety	Indicator	Polishing time, s		
		50	90	120
Utes	total yield of polished rice, %	73,3	68,2	65,3
	head rice content,%	82,3	81,6	81,0
	bran, % from grain	3,9	9,0	12,0
Велес	total yield of polished rice, %	74,6	73,2	65,5
	head rice content,%	82,0	81,8	80,8
	bran, % from grain	8,6	10,0	17,7
Трио	total yield of polished rice, %	73,2	68,7	60,9
	head rice content,%	70,0	69,2	67,4
	bran, % from grain	7,7	12,0	19,7

With increasing polishing time, the values of the trait decreased: when polishing for 90 seconds - by 5.1% for Utes, 1.4% for Veles, 4.5% for Trio; at 120 seconds - by 8.0% for Utes, 9.1% for Veles and 12.3% for Trio. The total yield of polished rice was higher for the variety Veles.

Head rice content was the highest when polished for 50 seconds (82.3% for Utes, 82.0% for Veles, and 70.0% for Trio). With an increase in the polishing time, the values of the trait increase: with a polishing time of 90 seconds by 0.7% for Utes, 0.2% for Veles, and 0.8% for Trio; with a polishing time of 120 seconds by 1.3% for Utes, 1.2% for Veles, and 2.6% for Trio. Head rice content of the varieties Utes and Veles differed insignificantly, and in the variety Trio it was significantly lower.

The bran yield was studied under conditions of different polishing degrees of medium-weight varieties. The bran content was determined in the experiment in relation to the initial mass of grain and to the mass of husked rice. With the shortest polishing time (50 seconds), the bran content in relation to the initial grain mass is minimal: 3.9% for Utes, 8.6% for Veles, 7.7% for Trio. The values of the trait increase with increasing polishing time: by 5.1 and 8.1% for Utes, 1.4 and 9.1% for Veles, 4.3 and 12.0 for Trio with a polishing time of 90 and 120 seconds, respectively.

The large-grain varieties showed the same tendency as the medium-weight varieties. The total milling yield decreased with increasing polishing time. The values of the trait were the highest for all varieties in the experiment when polishing for 50 seconds (72.3% for Favorit, 75.1% for Regul 2, 74.8% for Forsazh, 75.0% for Strombus, 74.0% for Prestige, and 73.2% for Vector) (Table 4).

Table 4.

Characteristics of large-grain medium-grain rice varieties by polishing intensity

Variety	Indicator	Polishing time, s 50	90	120
Favorit	total yield of polished rice, %	72,3	69,5	67,4
	head rice content,%;	88,1	84,7	84,1
	bran, % from grain;	9,1	11,9	14,0
Regul 2	total yield of polished rice, %;	75,1	68,9	60,6
	head rice content,%;	30,9	28,0	19,2
	bran, % from grain;	5,7	11,9	20,2
Forsazh	total yield of polished rice, %;	74,8	74,0	67,6
	head rice content,%;	82,6	81,8	78,8
	bran, % from grain;	8,6	9,3	15,8
Strombus	total yield of polished rice, %;	75,0	71,6	67,1
	head rice content,%;	83,0	80,4	80,3
	bran, % from grain;	8,8	12,2	16,7
Prestige	total yield of polished rice, %;	74,0	69,7	62,4
	head rice content,%;	30,8	27,5	21,4
	bran, % from grain;	7,4	11,7	19,0
Vector	total yield of polished rice, %;	73,2	68,1	55,7
	head rice content,%;	25,2	26,6	43,5
	bran, % from grain	7,8	12,9	25,3

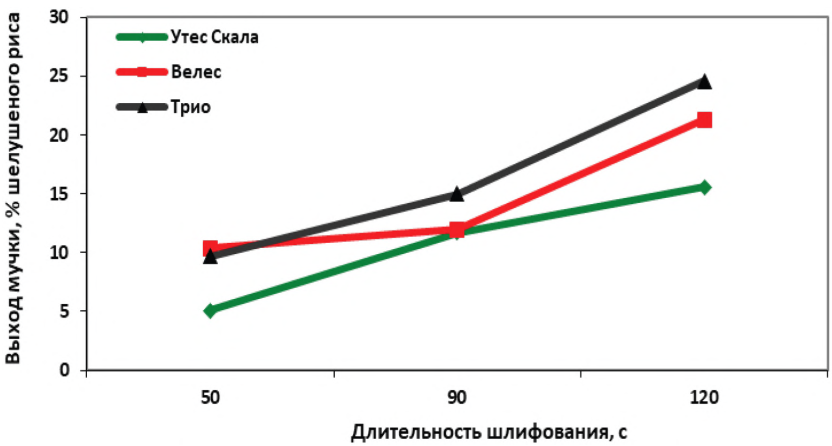

Fig. 2. Bran yield under conditions of varying grain polishing degrees of medium-weight medium-grain rice varieties.

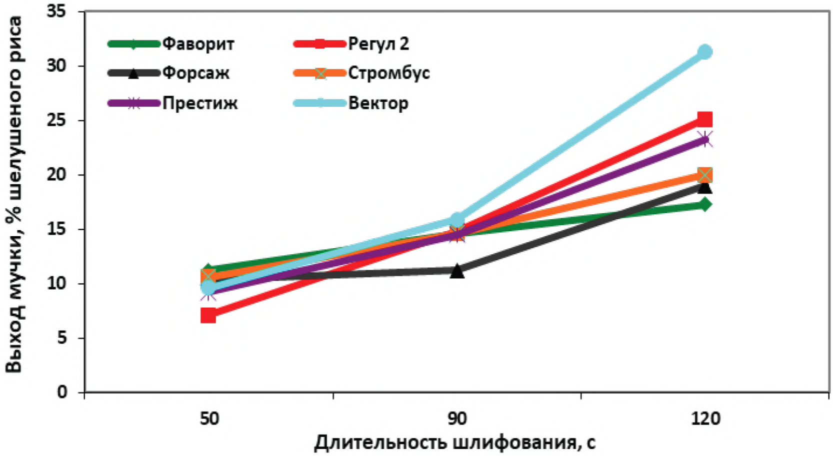

Fig. 3. Bran yield under conditions of varying grain polishing degrees of large-grain medium-grain rice varieties.

With the increase of polishing time, the values of the total milling yield decreased: with a polishing time of 90 seconds by 2.8% for Favorit, 6.2% for Regul 2, 0.8% for Forsazh, 3.4% for Strombus, 4.3% for Prestige, 5.1% for Vector; with a polishing time of 120 seconds by 4.9% for Favorit; 14.5% for Regul 2; 7.2% for Forsazh; 7.9% for Strombus; 11.6% (7.3%) for Prestige; 17.5% for Vector. The total yield of polished rice was higher for variety Forsazh.

Head rice content was the highest at a polishing time of 50 seconds: 88.1% for Favorit, 30.9% for Regul 2, 82.6% for Forsazh, 83.0% for Strombus, 30.8% for Prestige, 26.6%. The trait values decreased with an increase in the polishing time to 90 and 120 s: by 3.4 and 4.0% for Favorit, 2.9 and 11.7% for Regul 2, 0.8 and 3.8% for Forsazh, 2.6 and 2.7% for Strombus, 3.3 and 9.4% for Prestige, 1.4% and 18.3% for Vector, respectively, at 90 and 120 s.

The bran content in relation to the initial grain weight is minimal with the shortest polishing time (50 seconds): 9.1% for Favorit, 5.7% for Regul 2, 8.6% for Forsazh, 8.8% for Strombus, 7.4% for Prestige, 7.8% for Vector. The trait values increase with increasing polishing time: by 2.8 and 4.9% for Favorit, 6.2 and 14.5% for Regul 2, 0.7 and 7.2% for Forsazh, 3.4 and 4.5% for Strombus, 4.3 and 11.6% for Prestige, 5.1 and 17.5% for Vector, with a polishing time of 90 and 120 seconds respectively.

The bran content during grain polishing was estimated in order to eliminate the effect of rice filminess on the indicator (Fig. 2, 3). The bran content relative to the weight of husked rice increased with increasing polishing time for all varieties in the experiment. For varieties with a medium grain weight, the value of the trait at 50 seconds was 5.1% for Utes, 10.4% for Veles, and 9.7% for Trio. With a polishing time of 90 seconds, the bran yield increased by 6.6% for Utes, 1.6% for Veles, and 5.3% for Trio (Fig. 2). With a further increase in the polishing time to 120 seconds, the values of the trait increased by 10.5% for Utes, 10.9% for Veles, and 14.9% for Trio.

The bran content relative to the mass of husked rice increased with increasing polishing time for all varieties in the experiment: at 50 seconds, the value of the trait was 11.2% for Favorit, 7.1% for Regul 2, 10.3% for Forsazh, 10.6% for Strombus, 9.2% for Prestige, and 9.6% for Vector. At a polishing time of 90 seconds, the bran yield increased by 3.4% for Favorit, 7.7% for Regul 2, 0.9% for Forsazh, 4.0% for Strombus, 5.3% for Prestige, and 6.3% for Vector (Fig. 3). With a further increase in the polishing time to 120 seconds, the trait values increased by 6.1% for Favorit, 18.0% for Regul 2, 8.7% for Forsazh, 9.4% for Strombus, 14.1% for Prestige, and 21.7% for Vector.

Thus, increasing the polishing time to 120 seconds reduces the total yield of polished rice to a lesser extent in the varieties Utes and Favorit, the head rice content in the varieties Veles and Strombus, the bran content relative to the initial grain weight in the varities Utes and Strombus, and the bran content relative to the mass of husked rice in the varieties Utes, Veles and Favorit. The varieties with medium-weight grains were characterized by resistance of rice grain to polishing due to crushing.

For the varieties, unequal dynamics of quality traits were noted under conditions of intensified polishing: in some varieties, significant changes occurred already with an increase in the polishing duration to 50 s, while in others they occurred at 120 s, as in the varieties Vector and Veles (total yield).

Conclusion

Rice varieties were grouped according to grain size. When polished for 50 s, the germ and seed coat were partially preserved; when polished for 90 s, traces of the seed coat were visible on the surface of the kernel, the germ was absent; when polished for 120 s, all kernels were white, while the germ, seed coat and outer coat were completely removed. The mass of 1000 a.d. grains was in the range of 25.6-26.6 g in the group of medium-weight varieties and 28.4-33.1 g in the group of large-grain rice varieties. The grain fracturing was in the range from 22 for the variety Veles to 38% for the variety Utes in the group of medium-weight rice varieties and from 17 for the variety Strombus to 88% for variety Regul 2 in the group of large-grain varieties. Filminess and vitreousity were higher in medium-weight varieties.

The total yield of polished rice was the highest for all medium-weight varieties in the experiment when polished for 50 seconds. With an increase in the polishing duration to 120 s, total milling yield decreased by 55.7% for the large-grain variety Vector to 67.6% for the variety Forsazh. Among large-grain varieties, the maximum decrease in the total milling yield was typical for varieties Trio (12.3%) and Regul 2 (14.5%). Among medium-weight varieties, the decrease in the total milling yield was significantly less: up to 65.3-67.4%.

With increasing polishing duration, kernel crushing increased, which led to a decrease in the head rice content. In the group of large-grain varieties, Forsazh and Strombus were the most resistant to intensive polishing: the head rice content decreased by 3.8 and 3.7% at 120 s; the varieties Prestige and Favorit were the least resistant (11.7 and 18.3%). In the group of medium-weight varieties, the corresponding indicators of the head rice content were significantly lower: 1.2-2.6%.

Thus, significant dynamics of the indicators was noted already at the initial stage of grain polishing (90 s) in the rice varieties Favorit and Strombus for the indicator “head rice content”, Favorit and Utes - for the bran yield; at the stage of 120 s - in the varieties Regul 2 and Vector, Prestige for all traits, the varieties Trio and Forsazh for the indicators “total milling yield” and “bran yield”. Equivalent changes in the indicator of traits with different degrees of polishing were typical for the varieties Strombus and Utes for the indicator of total milling yield; Trio, Utes and Forsazh- for the head rice content and the variety Strombus - for the bran yield.

Differences in the nature of the influence of the polishing degree on the rice quality traits may be due to the physical properties of the grain: the endosperm structure, grain shape and size. The relationship between the polishing degree and the rice quality parameters must be taken into account in the breeding process in accordance with the task of developing new genotypes with certain technological traits and nutritional values and in the production processes of cereals (polished rice).

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Original article

EVALUATION OF QUALITY OF EXPERIMENTAL WHITE-GRAN RICE POPULATIONS IN ACCELERATED BREEDING BY GRAIN SIZE AND VITREOUSITY

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Abstract

Background. In marker-assisted rice breeding, the accelerated development of varieties with superior grain quality traits through advanced biotechnological approaches requires the generation of segregating rice populations followed by phenotyping of genotypes for traits of interest. These segregating populations are used to identify genetic loci (QTLs) associated with complex traits, including rice grain quality, based on phenotypic data.

Purpose. The goal of the work was to evaluate experimental BC_3 populations of rice based on physical characteristics of grain: size, vitreousity, fracturing, in order to carry out work on targeted selection based on phenotyping and genotyping data of promising plants - prototypes of varieties with specified traits in marker-assisted rice breeding.

Materials and methods. The study involved hybrids of 15 combinations of parental forms. The seeds were sown in vessels on the vegetation site of FSBSI Federal Scientific Rice Centre, Pryanishnikov's mixture was used as the main fertilizer; as they ripened, the seeds were harvested manually. High-tech methods of phenotyping the breeding material were used to conduct the research. The grain size was estimated by the mass of 1000 absolutely dry grains using a moisture analyzer, an air-heat unit, and an automatic seed counter; the vitreousity and grain fracturing were estimated in transmitted light using a diaphanoscope.

Results. Genotypes were differentiated and distributed into groups for each trait. As a result of the quality study of the obtained BC_3 samples, lines combining high technological grain quality traits were identified using phenotyping data. The mass of 1000 absolutely dry grains was in the range of 23.2-30.2 g in the group of medium-weight samples, the indices of vitreousity and fracturing were 62-93% and 1-9%, respectively.

Conclusion. As a result of the comparative analysis of hybrids and parental forms, combinations were noted for which the heterosis effect was typical for grain quality traits.

Keywords: rice; physical traits of grain; rice quality; vitreousity; fracturing; grain size

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Научная статья

ОЦЕНКА КАЧЕСТВА ЭКСПЕРИМЕНТАЛЬНЫХ БЕЛОЗЕРНЫХ ПОПУЛЯЦИЙ РИСА В УСКОРЕННОЙ СЕЛЕКЦИИ ПО КРУПНОСТИ И СТЕКЛОВИДНОСТИ ЗЕРНА

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Аннотация

Обоснование. В маркер-обоснованной селекционной практике риса в ускоренном процессе создания сортов с высокими показателями признаков качества зерна на основе новых биотехнологических приемов актуально создание сегрегирующих популяций риса с последующим фенотипированием генотипов по признакам интереса. Сегрегирующие популяции используются для выявления генетических локусов (QTL), связанных со сложными признаками, в том числе качества зерна риса на основе данных фенотипирования.

Цель. В работе была поставлена цель провести оценку экспериментальных популяций риса BC_3 по физическим признакам зерна: крупности, стекловидности, трещиноватости, в целях осуществления работ по прицельному отбору по данным фенотипирования и генотипирования перспективных растений – прототипов сортов с заданными признаками в маркер-опосредованной селекции риса.

Материалы и методы. В исследование были вовлечены гибриды 15-ти комбинаций скрещиваний родительских форм. Семена высевали на вегетационной площадке ФГБНУ ФНЦ риса в сосуды, в качестве основного удобрения использовали смесь Прянишникова; по мере созревания семена убирали вручную. Для проведения исследований были использованы высокотехнологичные методы фенотипирования селекционного материала. Крупность зерна оценивали по массе 1000 абсолютно сухих зерен с использованием анализатора влажности, установки воздушно-тепловой, автоматического счетчика семян; оценку стекловидности и трещиноватости зерна - в проходящем свете с помощью диафаноскопа.

Результаты. Генотипы дифференцировали и распределяли в группы по каждому признаку. В результате проведения исследования качества полученных образцов BC_3 по данным фенотипирования были выделены линии, сочетающие высокие технологические признаки качества зерна. Масса 1000 абсолютно сухих зерен находилась в диапазоне 23,2-30,2 г в группе средних по массе образцов, показатели стекловидности и трещиноватости соответственно: 62-93 % и 1-9 %.

Заключение. В результате сравнительного анализа гибридов и родительских форм были отмечены комбинации, для которых был характерен эффект гетерозиса по признакам качества зерна.

Ключевые слова: рис; физические признаки зерна; качество риса; стекловидность; трещиноватость; крупность зерна

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Introduction

In Russia, rice is a valuable cereal crop and is widely used in traditional, baby and dietary nutrition. For most Asian countries, rice is the main source of energy, protein and microelements [1]. The economic value of rice is determined by the profitability of its production, nutritional and culinary advantages (ECQ). The directions of the rice breeding process, as a result of which new varieties are created, are formed by the consumer advantages of genotypes, the tasks of functional and healthy nutrition [10].

The concept of rice quality includes many indicators that form an assessment system. As a result of assessing the quality of rice grains at the stages of breeding and production processes, the indicators meet the requirements of consumers and production.

The main traits of grain that determine consumer merits are morphological, physicochemical and biochemical. Morphological characteristics include shape, color, dimensions, weight, grain size, length, width, thickness, length to width ratio, etc.

In rice production at rice processing plants, grain mass assessment is mandatory when accepting grain, forming and receiving grain shipments for processing according to the parameters of pest infestation and contamination, the content of red, yellow, puny, chalky grains of vitreous and fractured, etc. [1; 10].

In rice breeding, the world's research centers use the latest modern science-intensive technologies to develop varieties with high grain quality. Enrichment of rice germplasm occurs with the involvement of genotypes with different pericarp colors in breeding schemes based on highly effective approaches using post-genomic and cellular technologies [9; 14]. The breeding of rice varieties with high grain quality begins with the selection of parental pairs and the crossing of valuable genotypes. Subsequently, samples with the best agrobiological characteristics and grain quality parameters are selected using phenotyping and biotechnological methods [11]. Much attention is paid to genome-wide association studies of grain appearance (size, shape, flour content, chalky rice content in the total mass) of the world collection of rice germplasm, historical breeding populations [15].

For more than two decades, large-scale genotyping by sequencing (GBS) has been carried out in research centers around the world, the results of which are used in the rice breeding process.

Russian rice varieties are mostly the result of a breeding process based on classical routine techniques [2]. A segregating F_2 rice population obtained by crossing Nipponbare (Oryza sativa ssp. japonica cv.) and wild African (O. Longistaminata). 8,154 informative SNP markers were identified in the analysis of 1,081 F_2 plants. Work has been carried out on the localization of quantitative loci (QTL) that determine the "number of panicles" trait on chromosomes 1, 3, 4 and 8.

The efficiency of GBS for the analysis of a highly heterozygous population was demonstrated [2; 3]. The introduction of genes of interest into the rice genome is used in breeding programs [5].

A number of genes/QTLs have been identified for ECQ properties such as protein content and aromatic properties [5; 8]. Grain filling is accompanied by starch accumulation with the help of enzymes: ADP-glucose pyrophosphorylase (AGPase), starch synthase (SSs), starch branching enzymes (SBEs), and starch splitting enzymes (DBEs) [13].

Functional markers are used for fragrant rice. Marker-assisted breeding has identified high nutritional value alleles in rice varieties. Association mapping using 18,824 high-quality markers yielded 38 QTLs for 10 traits, five of which corresponded to known genes or precisely mapped QTLs. Much attention is paid to genome-wide association studies of grain appearance (size, shape, flour content, chalky rice content in the total mass) of the world collection of rice germplasm, historical selection populations.

Several genes for grain mealyness have been mapped, including Chalk5, which is expressed in the endosperm on chromosome 5 (encodes vacuolar pyrophosphatase), qPGWC-7, qPGWC-8, and qACE-9 [13; 16]. (PCG), qPCG1, was localized in a 139 kb region on the long arm of chromosome 1 [4]. Hundreds of QTLs for flour content trait have been identified. Scientists at Hunan Agricultural University (HUNAU) conducted DAP-seq of multiple rice accessions and showed that overexpression of OsFIF3 inhibited the expression of FLO2 and SUT1, thereby increasing flour content and reducing grain size. In the qPCG1 study, the QTL for mealyness was mapped in an interval with a physical distance of about 139 kb on chromosome 1 [18].

Grain sizes, for which a large number of quantitative trait loci (QTL) have been recorded, are of great interest in connection with the effect on rice yield. Thus, the basic grain size QTL (qTGW3) encodes SHAGGY-like kinase 41; (OsSK41)/OsGSK5, BIG GRAIN1 (BG) encodes a positive regulator of auxin reaction and transport [7].

The high nutritional value of rice products is determined by the breeding process based on the involvement of the widest range of genotypes and the use of the latest breeding methods, with an integrated approach, the use of modern postgenomic and cellular technologies, and the genomic approach. Various traditional approaches in breeding require effective phenotypic screening for the presence of traits of interest in terms of rice grain quality in breeding selection. Scientists attribute the breakthrough in rice breeding to the development of genomic approach mechanisms [12; 15]. However, the genomic approach to rice breeding also requires phenotyping of organisms when developing marking systems for target traits.

Thus, rice breeding based on the use of modern postgenomic and cellular technologies, as well as the genomic approach, is a tool for achieving success in expanding its assortment with valuable grain quality characteristics [12; 15]. The effectiveness of the methodology for assessing traits based on rice genotypes ensures an accelerated breeding process and high information content of the characteristics that are signs of interest.

The aim of the study was the phenotyping of samples of experimental BC_3 populations, the selection of sources of valuable signs of grain quality with further involvement in marker-mediated breeding work.

Purpose. To evaluate experimental populations of BC_3 rice based on physical characteristics of grains: size, vitreousness, and cracking, in order to carry out targeted selection based on phenotyping and genotyping data of promising plants – prototypes of varieties with specified characteristics in marker-assisted rice breeding.

Materials and methods

The material for the study (grain) was grown on the vegetation site of FSBSI "Federal Scientific Rice Centre", Krasnodar. The soil was taken from the experimental plot of Federal Scientific Rice Centre. The material of the study was the grain of the 3-rd generation hybrids, BC_3 backcrosses from crossing white-grained and colored rice varieties with different grain shapes (round, round-oval, oval, elongated-oval, elongated, long). The parental forms were obtained from the Unique Scientific Installation (USI) "Collection of Genetic Resources of Rice, Vegetable and Melon Crops" of Federal Scientific Rice Centre (Russia, Krasnodar) (Table 1).

Table 1.

Rice varieties – parental forms, distribution by grain shape and color of the grain pericarp

Variety	Group of varieties by the grain form	Color of pericarp
Rubin	oval	red
Veles	oval	white
Alliance	oval	white
Mavr	prolonged	purple
Svetlana	long	white
Kurazh	prolonged	white
Gagat	long	purple
Red Blastonik	oval	red
Dihaploid Heibar	oval	red
Dig. lo-2327-10	prolonged	red
VNIIR 10163	oval	red
Khaw-sri-nin	long	red purple

The study involved hybrids from 15 combinations of crosses between parental forms.

Phenotyping of BC_3 samples for grain quality traits was performed on certified equipment in accordance with GOSTs and instructions for scientific instruments. Grain size was estimated by the mass of 1000 absolutely dry grains according to GOST 10842-89 “Grain of cereal and legume crops and oilseeds” using an ELVIZ-2 moisture analyzer, an ASESh-8-2 air-heat unit, an SLY-C automatic seed counter, and a Cas CUW-420H electronic laboratory scale. Grain vitreousity was estimated according to GOST 10987-76 “Grain. Methods for Determining Vitreousity”; grain fracturing in transmitted light using a DSZ-3 and DSZ-2M diaphragm.

The seeds of the previously isolated white-grained BC_3 samples were sown in vessels with 6 kg of soil. The main fertilizer was Pryanishnikov’s mixture: complex and mineral fertilizers: urea (46% active ingredient), nitroammophoska, double superphosphate (46% active ingredient). The harvesting was performed manually. When the grains reached full maturity, they were threshed from the panicles, the grain moisture content was brought to 14% and they were stored.

The heterosis index of hybrids was calculated using the formula of K.P. Svechin. Mathematical and statistical processing of data was carried out using calculations in Microsoft Excel.

Results

On a broad genetic basis, when crossing contrasting forms, new source material was obtained - experimental hybrid populations of BC_3 back-crosses. A significant range of variation in quality indicators allowed for successful selection to improve these traits. Rice grain was obtained by growing plants to full maturity of experimental populations obtained from crossing contrasting forms of BC_2 on a vegetation site. The total number of samples studied was 52 pcs.

The set of grain quality traits is the subject of study in fundamental, theoretical, and applied research in breeding programs. Crossbreeding programs aim to select valuable samples at the stages of the breeding process of varieties with high consumer merits. Traditional and genomic approaches to breeding require effective phenotypic screening with high information content for the presence of traits (genes) of interest in terms of rice grain quality in accelerated breeding selection.

The rice grain quality traits “size”, “vitreosity”, “fracturing” characterize both the consumer qualities of rice and the physical properties of the grain. In order to accelerate the breeding process using marker-mediated backcrossing for further molecular marking in experimental populations, an assessment of the samples was carried out according to grain quality traits (vitreosity, fracturing, size).

Previously, the authors proposed an algorithm for assessing experimental populations, including sequential determination of moisture, size, shape, vitreousity, fracturing with differentiation of samples into groups depending on the indicators of the traits. The work was carried out in accordance with the recommendations [10].

Due to the selection of parent forms with different quality traits, the BC_3 combination samples also differed in grain quality parameters. The results of the study of the grain size of the BC_3 samples are presented in Table 2.

Table 2.

Quality of BC_3 rice samples by the grain size

BC_3	Mass of 1000 a. d. grains, g			
	high ≥30,1		medium 20,3-30,0	
	min-max	number, pcs.	min-max	number, pcs.
1. Rubin/Veles//Veles/// Veles	-	-	22,4	1
2. Rubin /Alliance//Alliance///Alliance	-	-	22,6-25,1	13
3. Mavr/Svetlana//Svetlana///Svetlana	-	-	25,0-25,6	2
4. Mavr/Kurazh//Kurazh///Kurazh	-	-	24,8	1
5. Gagat/Svetlana//Svetlana///Svetlana	-	-	23,4	1
6. Red Blastonik/Veles//Veles///Veles	-	-	26,9-28,1	2
7. Red Blastonik/Alliance //Alliance///Alliance	-	-	24,4-27,1	2
8. Dihaploid Heibar/Veles//Veles///Veles	-	-	24,6-25,7	3
9. Dihaploid Heibar/Alliance//Alliance/// Alliance	-	-	25,6-25,8	2
10. Dihaploid k.2327/Veles// Veles///Veles	-	-	26,2	1
11. Dihaploid k.2327/Alliance//Alliance	30,3	1	23,8-30,0	12
12. VNIIR10163/Veles//Veles///Veles	-	-	24,8-27,3	4
13.VNIIR10163/Alliance//Alliance/// Alliance	-	-	25,6	2
14.Khaw-sri-nsn/Svetlana//Svetlana/// Svetlana	-	-	22,4-27,3	4
15. Khaw-sri-nsn/Kurazh//Kurazh///Kurazh	-	-	22,7-27,5	2

The grain size was low (medium) for all combinations. The variation range of the trait was insignificant in the combinations Mavr/Svetlana//Svetlana/// Svetlana (0.6 g), Dihaploid Heibar/Veles//Veles///Veles (1.1 g), Dihaploid Heibar/Alliance//Alliance///Alliance (0.2 g). For the remaining combinations, the variation of the values of the trait "mass of 1000 a.d. grains" was 2.2-4.9 g. In this group, the upper limit of grain size was represented by the samples of the following combinations: Red Blastonik/Veles//Veles///Veles (26.9-28.1 g), Dihaploid k.2327/Alliance//Alliance///Alliance (23.8-30.0 g). The last combination had one plant with a high mass of 1000 a.d. grains (30.3 g). Such samples are considered promising and are used for reseeding.

Based on the results of the evaluation of BC_3 samples, the best samples in terms of grain size were identified (Table 3). The range of variation of the trait was insignificant in the combinations Dihaploid Heibar/Veles//Veles///Veles (0.4 g), Dihaploid Heibar/Alliance//Alliance///Alliance (0.2 g), Rubin /Alliance//Alliance///Alliance (1.3 g) (Table 3); significant in combinatioms: Mavr/Svetlana//Svetlana///Svetlana (2.8 g), Red Blastonik/Veles//Veles///Veles (4.1 g), Dihaploid k.2327/Alliance//Alliance///Alliance (6.1 g), VNIIR10163/Veles//Veles///Veles (1.5 g).

Table 3.

Distribution of best BC_3 rice samples by grain size

BC_3	**Mass of 1000 a. d. grains, g**	
	medium 20,3-30,0	
	min-max	**number, pcs.**
2. Rubin /Alliance//Alliance///Alliance	23,2-24,5	3
3. Mavr/Svetlana//Svetlana///Svetlana	25,0-27,8	3
4. Mavr/Kurazh//Kurazh///Kurazh	24,8	1
5. Gagat/Svetlana//Svetlana///Svetlana	23,7	1
6. Red Blastonik/Veles//Veles///Veles	24,1-28,2	3
7. Red Blastonik/Alliance//Alliance///Alliance	27,3	1
8. Dihaploid Heibar/Veles//Veles/// Veles	25,5-25,9	2
9.Dihaploid Heibar/Alliance//Alliance///Alliance	25,7-25,9	2
10. Dihaploid k.2327/Veles// Veles///Veles	23,7	1
11. Dihaploid k.2327/Alliance//Alliance	23,9-30,0	9
12. VNIIR10163/Veles//Veles///Veles	24,7-26,2	2
13. VNIIR10163/Alliance//Alliance ///Alliance	25,9	1

According to the upper limit of grain vitreousity, promising samples were identified in the combinations Mavr/Svetlana//Svetlana///Svetlana with a mass of 1000 a.d. grains of 25.0, 25.8 and 27.8 g; Red Blastonik/Veles//Veles///Veles - 24.1, 24.3 and 28.2 g; Red Blastonik/Alliance//Alliance///Alliance - 27.3 g; Dihaploid k.2327 /Alliance//Alliance///Alliance - 23.9, 24.6, 25.0, 25.8, 27.0 and 30.0 g; VNIIR10163/Veles//Veles///Veles – 24.7, 26.2 g.

Vitreousity in samples of most combinations in the experiment was low (≤85%). In this group, at the upper limit of grain vitreousity, samples of combinations were distinguished: Khaw-sri-nsn/Svetlana//Svetlana///Svetlana (78-86%) and Khaw-sri-nsn/Kurazh //Kurazh///Kurazh (82-84%). In the remaining combinations, the values of the trait were average (85-93%). The range of variation of the trait was insignificant in the combinations Dihaploid Heibar/Alliance//Alliance///Alliance (2%), Dihaploid k.2327/Alliance//Alliance///Alliance (5%), VNIIR10163/Veles//Veles///Veles (3%), Khaw-srinsn/Kurazh //Kurazh///Kurazh (2%). In the remaining combinations, the variation of the values of the trait “vitreousity” was 7.0-19%.

Grain fracturing in most of the studied samples of combinations was noted as low (0.0-10.0%). Average values of the trait were typical for the samples of combinations

Rubin/Alliance//Alliance///Alliance (11-17%), Dihaploid Heibar/Veles//Veles///Veles (12%), Dihaploid k.2327/Alliance//Alliance///Alliance (14-15%), VNIIR10163/Veles//Veles///Veles (12-20%) (Table 4).

Table 4.

Quality of BC_3 rice samples by the traits of grain vitreousity and fracturing

BC_3	Vitreousity				Fracturing, %			
	medium 85-93		low ≤85		medium 10,1-30,0		low 0,0-10,0	
	min-max	number, pcs.	min-max	number, pcs.	min-max	number, pcs.	min-max	number, pcs.
1. Rubin/Veles//Veles///Veles	-	-	70	1	-	-	4	1
2.Rubin /Alliance//Alliance///Alliance	-	-	63-81	13	11-17	5	6-9	8
3. Mavr/Svetlana//Svetlana///Svetlana	86	2	-	-	-	-	5-8	2
4. Mavr/Kurazh//Kurazh///Kurazh	-	-	62	1	-	-	5	1
5. Gagat/Svetlana//Svetlana///Svetlana	91	1	-	-	-	-	5	1
6. Red Blastonik/Veles//Veles///Veles	87	1	77	1	-	-	3-8	2
7.Red Blastonik/Alliance//Alliance///Alliance	-	-	74-81	2	-	-	6-8	2
8. Dihaploid Heibar/Veles//Veles///Veles	-	-	64-83	3	12	1	7-9	2
9. Dihaploid Heibar/Alliance//Alliance///Alliance	91-93	2	-	-	-	-	5-9	2
10. Dihaploid k.2327/Veles// Veles///Veles	-	-	73	1	-	-	5	1
11. Dihaploid k.2327/Alliance//Alliance	87-92	11	71-82	2	14-15	3	4-8	10
12. VNIIR10163/Veles//Veles///Veles	89-92	2	77-80	2	12-20	2	5-9	2
13.VNIIR10163/Alliance//Alliance///Alliance	-	-	77	2	-	-	4-7	2

14.Khaw-sri-nsn/ Svetlana//Svetlana/// Svetlana	-	-	78-86	4	-	-	8-10	4
15. Khaw-sri-nsn/Kurazh//Kurazh///Kurazh	-	-	82-84	2	-	-	7-8	2

The best samples by the traits of vitreousity and fracturing were selected (Table 5). The variation range of the “vitreousity” was 1-5%, “fracturing” - 1-6%, which was insignificant. According to the upper limit of grain vitreousity, promising samples were selected in the combinations Dihaploid Heibar/Alliance//Alliance///Alliance with vitreousity of 91, 93%; Dihaploid k.2327/Alliance//Alliance///Alliance - 88, 90, 93%; Gagat/Svetlana//Svetlana///Svetlana - 92%. According to the upper limit of grain fracturing, promising samples were identified in the combinations Rubin/Alliance//Alliance///Alliance, where fracturing was 4 and 5%, VNIIR10163/Alliance//Alliance ///Alliance – 5%; Mavr/Kurazh//Kurazh///Kurazh, Gagat/Svetlana//Svetlana///Svetlana; Dihaploid k.2327/Veles//Veles///Veles, where the value of the trait was 3%.

Table 5.

Distribution of best BC_3 rice samples by the traits of grain vitreousity and fracturing

BC_3	Vitreousity, %				Fracturing	
	medium, 85-93		low, ≤85		low, 0,0-10,0	
	min-max.	number, pcs.	min-max	number, pcs.	min-max	number, pcs.
1. Rubin/Veles//Veles///Veles	-	-	-	-	-	-
2. Rubin /Alliance//Alliance///Alliance	-	-	79-81	3	4-5	3
3. Mavr/Svetlana//Svetlana///Svetlana	86	2	82	1	3-7	3
4. Mavr/Kurazh//Kurazh///Kurazh	-	-	62	1	3	1
5. Gagat /Svetlana//Svetlana///Svetlana	92	1	-	-	3	1
6. Red Blastonik/Veles//Veles///Veles	88-89	2	77	1	3-9	3
7. Red Blastonik/Alliance//Alliance///Alliance	-	-	77	1	9	1
8. Dihaploid Heibar/Veles//Veles///Veles	-	-	83-85	2	9	2
9. Dihaploid Heibar/ Alliance//Alliance///Alliance			-	-	3-7	2
10. Dihaploid k.2327/Veles// Veles///Veles	-	-	85	1	3	1
11. Dihaploid k.2327/Alliance//Alliance	88-93	9	-	-	2-8	8
12. VNIIR10163/Veles//Veles///Veles	87	1	82	1	4-9	2
13. VNIIR10163/Alliance//Alliance///Alliance	-	-	77	1	5	1

The best (large grain size, vitreousity and low grain fracturing) were samples from the combinations Mavr/Svetlana//Svetlana///Svetlana and Dihaploid k.2327/Alliance//Alliance///Alliance.

The study examined the effect of the hybrid trait exceeding the trait value of the parental forms (Fig. 1-3). Heterotic effects in grain size were noted for the samples of the combinations Dihaploid k.2327/Alliance//Alliance – 114.0%, Red Blastonik/Veles//Veles///Veles - 104.5%, Mavr/Svetlana//Svetlana///Svetlana – 106.7%.

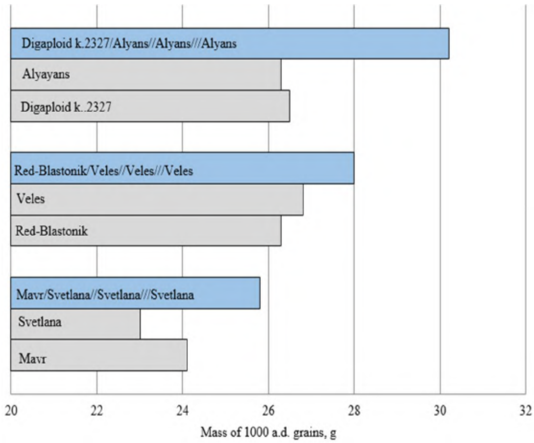

Fig. 1. Size of parental forms and BC_3 with heterotic effect to both parents (3.2.2, 6.1.4, 11.4.1).

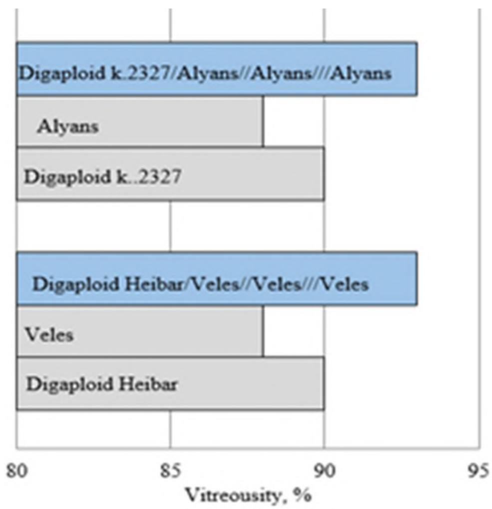

Fig. 2. Vitreousity of parental forms and BC_3 with heterotic effect to both parents (9.1.2, 11.8.3)

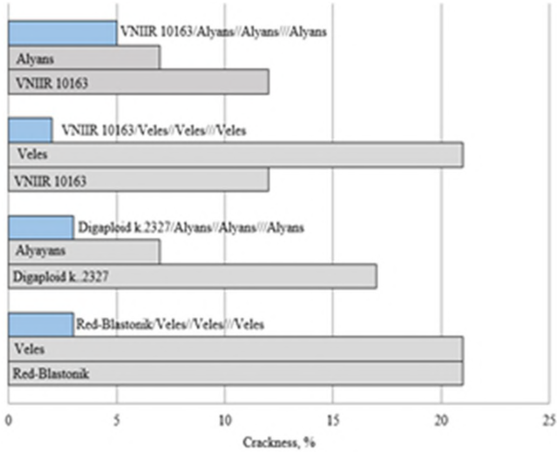

Fig. 3. Fracturing of parental forms and BC_3 with heterotic effect to both parents (6.1.4, 11.1.3, 12.3.2, 13.6.1)

In terms of grain vitreousity and fracturing, the following combinations showed excess values: Vitreousity: Dihaploid Heibar/Veles//Veles///Veles 105.7%; Dihaploid k.2327/Alliance//Alliance///Alliance % 105.7%; fracturing: Red Blastonik/Veles//Veles///Veles 700.0%; Dihaploid k.2327/Alliance//Alliance///Alliance 567.0%; VNIIR10163/Veles//Veles///Veles 1000%; VNIIR10163/Alliance//Alliance ///Alliance 2400%.

Identification of heterotic forms of rice hybrids with significant improvement in quality traits compared to parental forms allows optimizing breeding work.

Conclusions

In the study under conditions of phenotyping for grain quality traits within the framework of rice marker-assisted breeding, the differentiation of samples of experimental populations by grain size, vitreousity and fracturing was carried out. Promising samples of segregating BC_3 populations of 15 combinations with parental forms contrasting by quality traits, selected in a short period of highly effective phenotyping, were identified. The samples were divided into groups by mass of 1000 a.d. grains with a mass of ≥30.1 g (high), 20.3-30.0 g (medium); by vitreousity - 85-93% (medium), ≤85 (low); by fracturing - 10.1-30.0% (medium), 0.0-10.0% (low). The best samples were identified for 12 out of 15 combinations, the mass of 1000 absolutely dry grains was in the range of 23.2-30.2 g in the group of medium-weight samples, vitreousity and fracturing indices were 62-93% and 1-9%, respectively. The most promising samples were recognized as samples of BC_3 segregating populations: Mavr/Svetlana//Svetlana///Svetlana, Red Blastonik/Veles//Veles///Veles, Red Blastonik/Alliance//Alliance///Alliance, Dihaploid k.2327/Alliance//Alliance///Alliance, VNIIR10163/Veles//Veles///Veles. The samples were characterized by high indicators of grain size, vitreousity and fracturing.

The heterotic effect in terms of grain quality traits was noted in terms of grain size, vitreousity and fracturing in the following combinations: Dihaploid k.2327/Alliance//Alliance, Red Blastonik/Veles//Veles///Veles, Mavr/Svetlana//Svetlana///Svetlana in terms of grain size (IG=106-114%).

The results of the study will be used in accelerated breeding work to develop rice varieties with high indicators of grain size on new biotechnological methods in marker-assisted breeding practice of rice.

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Original article

CORRELATION BETWEEN CARDIC RHYTHM PARAMETERS AND CYTOKINE PROFILE LEVELS IN YOUNG CATTLE DURING EARLY NEONATAL ONTOGENESIS

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Abstract

Background. During the growth and development of young cattle, there is a significant association between functional changes in the body and housing conditions, influencing the regulation of immune responses and metabolic processes. In calves kept in natural conditions, the activity of natural immunity regulators prevails, contributing to the optimisation of growth and development processes. At the same time, in young animals exposed to stressful conditions associated with intensive housing methods, a decrease in the activity of these regulators is recorded, which can negatively affect their health and adaptability. Activation of neurohumoral mechanisms, including the influence of the hypothalamic-pituitary system, plays a key role in the regulation of metabolic processes and the immune response in young animals. In calves under stress, an increase in the level of proinflammatory cytokines is noted, which indicates a violation of the physiological balance in the cytokine network. Conversely, in calves kept in more favorable (natural) conditions, a more balanced ratio between pro- and anti-inflammatory cytokines is observed, contributing to the maintenance of homeostasis and improved adaptive responses.

Purpose. The main objective of the present research is to find out the correlation between cardiac rhythm parameters and cytokine profile levels in young cattle during early neonatal ontogenesis.

Materials and methods. To study the nature of the correlation between the parameters of the heart rate and the levels of cytokines in young cattle in early neonatal ontogenesis, 50 one-day-old calves aged 5 days were randomly selected at the premises of Chapaevskoye SP LLC.

In the first experimental group, after calving, the newborn calf underwent a primary veterinary examination, after which it was left in a group with its mother, simulating natural conditions for the entire duration of the experiment.

In the second experimental group, calves were managed according to industrial livestock farming practices. Newborn calves were separated from their mothers immediately after birth and fed with colostrum: two liters within 1-2 hours after birth, followed by an additional two liters by the 12th hour of life. This approach subjected the animals to higher adaptive and domestication stress. Statistical significance was determined in relation to the second experimental group.

The calves of all groups underwent heart rate analysis at 5 days of age; the animals were examined in a standing position, in a stall, and in a lateral lying position on an isolated surface using a diagnostic device, a single-channel electrocardiograph EK1T-07 "Axion".

Blood samples were collected aseptically from the tail vein of each experimental group using S-Monovette 1.2 ml (66x8 mm) KZ-EDTA tubes. In stabilized samples, cytokine levels in blood plasma were measured using flow cytometry on a Bio-Plex Protein Assay System (Bio-Rad, USA). The Human 8-Plex Cytokine Panel reagent kit was used for the analysis according to the manufacturer's instructions. As a result of the study, four types of cytokines were quantitatively measured: interleukin-2 (IL-2), interleukin-4 (IL-4), interleukin-8 (IL-8), and interleukin-10 (IL-10).

To ensure data reliability, cytokine concentrations were determined in three independent experimental series, both for calibration solutions and for the analyzed samples. Quantification was determined in pg/ml using Bio-Plex Manager 6.1 software (Bio-Rad) based on standard calibration curves. The obtained data were processed using descriptive and structural statistics.

To analyze the relationships between various heart rate parameters and cytokine levels in young cattle, the statistical method of Pearson correlation (r) was used, determining the degree and direction of the relationship between variables, which is critical for understanding physiological processes and their impact on animal health.

Results. Increased activity of the autonomic mechanisms regulating heart rate in newborn calves was associated with reduced function of innate immunity regulators (IL-8), specific immune responses (IL-2 and IL-4), and cytokines involved in inflammatory processes (IL-10). A weak relationship was also found between the activity of the autonomic nervous system, reflected in the very low frequency component (VLF) of heart rate variability, and the level of IL-4. The increased influence of the central nervous system on cardiac activity, including activation of the hypothalamic-pituitary axis, is accompanied by an increase in the concentration of

IL-4, which plays an important role in the differentiation of lymphocytes and the development of the immune response, including inflammatory reactions.

Conclusion. Analysis of the heart rate dynamics confirmed that under stress conditions, an activation of the autonomous regulatory circuit is observed, which can negatively affect the health of calves. An increase in the activity of low-frequency waves is associated with increased sympathetic activity and stress, while high-frequency waves correlate with the activity of the parasympathetic nervous system and improved adaptive mechanisms.

Thus, the study highlights the critical importance of optimizing housing conditions for newborn calves. Correction of environmental factors and minimization of stress are essential to ensure harmonious interaction between central and autonomic regulation. This, in turn, can contribute to improved health, strengthening of the immune response and increased survival of newborn offspring, as well as the effectiveness of adaptation of young cattle in early neonatal ontogenesis.

Keywords: cardiac rhythm; cytokine profile levels; cattle; neonatal ontogenesis

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Научная статья

КОРРЕЛЯЦИЯ МЕЖДУ ПАРАМЕТРАМИ КАРДИАЛЬНОГО РИТМА И УРОВНЕМ ЦИТОКИНОВОГО ПРОФИЛЯ У МОЛОДНЯКА КРУПНОГО РОГАТОГО СКОТА В РАННЕМ НЕОНАТАЛЬНОМ ОНТОГЕНЕЗЕ

В.С. Самойленко, А.А. Лапина, С.В. Пушкин, А.Р. Онищенко, О.Н. Онищенко

Аннотация

Обоснование. В период роста и развития молодняка крупного рогатого скота существует значительная связь между функциональными изменениями в организме и условиями содержания, влияющими на регуляцию иммунных реакций и метаболических процессов. У телят, содержащихся в естествен-

ных условиях, преобладает активность естественных регуляторов иммунитета, способствующая оптимизации процессов роста и развития. В то же время у молодняка, подверженного стрессовым условиям, связанным с интенсивными методами содержания, отмечается снижение активности этих регуляторов, что может негативно сказаться на их здоровье и адаптивности. Активация нейрогуморальных механизмов, включая влияние гипоталамо-гипофизарной системы, играет ключевую роль в регуляции метаболических процессов и иммунного ответа у молодняка. У телят, подвергнутых стрессу, отмечается повышение уровня провоспалительных цитокинов, что свидетельствует о нарушении физиологического баланса в цитокиновой сети. И наоборот, у телят, содержащихся в более благоприятных (естественных) условиях, наблюдается более сбалансированное соотношение между про- и противовоспалительными цитокинами, способствующее поддержанию гомеостаза и улучшению адаптивных реакций.

Цель. Основная цель настоящего исследования – выявить корреляцию между параметрами сердечного ритма и уровнем цитокинового профиля у молодняка крупного рогатого скота в раннем неонатальном онтогенезе.

Материалы и методы. Для изучения характера взаимосвязи между параметрами сердечного ритма и уровнем цитокинов у молодняка крупного рогатого скота в раннем неонатальном онтогенезе на территории ООО «Чапаевское СП» случайным образом были отобраны 50 однодневных телят в возрасте 5 дней.

В первой опытной группе после отела новорожденный теленок проходил первичный ветеринарный осмотр, после чего его оставляли в группе с матерью, имитируя естественные условия на весь период эксперимента.

Во второй экспериментальной группе уход за телятами осуществлялся в соответствии с практикой промышленного животноводства. Новорожденных телят отделяли от матери сразу после рождения и кормили колострумом: два литра в течение 1-2 часов после рождения, а затем еще два литра к 12-му часу жизни. Такой подход подвергал животных повышенному адаптационному и одомашненному стрессу. Статистическую значимость определяли по отношению ко второй опытной группе.

Телятам всех групп в 5-дневном возрасте проводили исследование сердечного ритма в положении стоя, в стойле и в положении лежа на боку на изолированной поверхности с помощью диагностического прибора – одноканального электрокардиографа ЭК1Т-07 «Аксион».

Образцы крови собирали асептически из хвостовой вены каждой экспериментальной группы с помощью пробирок S-Monovette объемом 1,2 мл (66x8 мм) с KZ-EDTA. В стабилизированных образцах уровень цитокинов в плазме крови измеряли методом проточной цитометрии на приборе Bio-Plex Protein Assay System (Bio-Rad, США). Для анализа использовали набор реагентов Human 8-Plex Cytokine Panel в соответствии с инструкцией производителя. В результате исследования было проведено количественное определение четырех типов цитокинов: интерлейкина-2 (ИЛ-2), интерлейкина-4 (ИЛ-4), интерлейкина-8 (ИЛ-8) и интерлейкина-10 (ИЛ-10).

Для обеспечения достоверности данных концентрацию цитокинов определяли в трех независимых экспериментальных сериях, как для калибровочных растворов, так и для анализируемых образцов. Количественное определение проводили в пг/мл с помощью программы Bio-Plex Manager 6.1 (Bio-Rad) на основе стандартных калибровочных кривых. Полученные данные обрабатывали с помощью описательной и структурной статистики.

Для анализа взаимосвязи между различными параметрами сердечного ритма и уровнем цитокинов у молодняка крупного рогатого скота использовали статистический метод корреляции Пирсона (r), определяющий степень и направление связи между переменными, что крайне важно для понимания физиологических процессов и их влияния на здоровье животных.

Результаты. Повышенная активность вегетативных механизмов, регулирующих частоту сердечных сокращений, у новорожденных телят была связана со снижением функции регуляторов врожденного иммунитета (IL-8), специфических иммунных реакций (IL-2 и IL-4) и цитокинов, участвующих в воспалительных процессах (IL-10). Также была выявлена слабая связь между активностью вегетативной нервной системы, отраженной в очень низкочастотной составляющей (VLF) вариабельности сердечного ритма, и уровнем IL-4. Усиление влияния центральной нервной системы на сердечную деятельность, включая активацию гипоталамо-гипофизарной оси, сопровождается повышением концентрации IL-4, который играет важную роль в дифференцировке лимфоцитов и развитии иммунного ответа, в том числе воспалительных реакций.

Заключение. Анализ динамики сердечного ритма подтвердил, что в условиях стресса наблюдается активация автономного контура регуляции, что может негативно сказаться на здоровье телят. Повышение активности низкочастотных волн связано с усилением симпатической активности и стрессом, в то время как высокочастотные волны коррелируют с активностью парасимпатической нервной системы и улучшением адаптивных механизмов.

Таким образом, данное исследование подчеркивает исключительную важность оптимизации условий содержания новорожденных телят. Коррекция факторов окружающей среды и минимизация стресса необходимы для обеспечения гармоничного взаимодействия между центральной и вегетативной

регуляцией. Это, в свою очередь, может способствовать улучшению здоровья, усилению иммунного ответа и повышению выживаемости новорожденного потомства, а также эффективности адаптации молодняка крупного рогатого скота в раннем неонатальном онтогенезе.

Ключевые слова: сердечный ритм; уровни цитокинового профиля; крупный рогатый скот; неонатальный онтогенез

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Introduction

During ontogenesis, animals undergo interrelated changes in morphology, biochemistry, and body functions. Understanding changes in functional and biochemical blood parameters in cattle is an important element for targeted breeding of young animals and maintaining the health of dairy herds. Optimal parameters at all stages of individual development are the key to maximizing genetic potential [1; 11].

Cytokines are proteins that serve as chemical messengers that regulate the innate and adaptive immune response. Changes in blood cytokine levels provide valuable information for understanding pathophysiological processes and monitoring disease progression and inflammation [6; 7]. Recent trends in scientific research have focused on cytokines and their importance in the pathogenesis of many diseases. This has led to an intensification of the study of their functions and interactions in the context of various pathologies, among which infectious diseases occupy a special place. Evaluation of the cytokine profile in the blood serum of calves has practical significance, since it allows predicting the ineffectiveness of preventive programs and making the necessary adjustments in the preventive and therapeutic approach [2; 15].

The study of electrocardiographic parameters and heart rate variability plays an important role in diagnostics, enabling the assessment of vegetative homeostasis and the functional capabilities of the cardiovascular system in animals. The indicators of variation pulsometry of the heart rate systematically change depending on the type of vegetative regulation affecting the work of the heart [9; 12].

Cardiac rhythm, determined by the frequency and regularity of heart contractions, is regulated by a complex network of neurohumoral factors and autonomic regulation. In neonatal calves, the establishment of a stable cardiac rhythm is necessary for optimal physiological functioning, since any violation can lead to a deterioration in health. Understanding the correlation between cardiac parameters and cytokine levels during this critical period of development can provide important information about the overall health and resilience of young animals [3; 8; 14].

Cytokines, which act as key mediators of the immune response, affect various physiological processes including inflammation, growth and metabolism. Their levels can serve as indicators of the health of the animal and its ability to adapt to external stress factors [4; 11]. At the same time, cardiac parameters such as heart rate and variability are important indicators of cardiovascular health and can reflect the animal's response to stress and immune challenges [5; 9; 14].

The early neonatal period in cattle is characterized by rapid physiological changes that are critical for survival and development. During this period, the correlation between cardiac parameters and cytokine levels becomes an important issue, since both factors have a significant impact on the overall health and well-being of young animals. Studies show that during this period, young animals are exposed to various stress factors, including changes in temperature, housing conditions, and interaction with their mother, which can affect their immune status and cardiovascular system [4,5,13]. Thus, studying the correlation between heart rate parameters and the level of the cytokine profile in young cattle in early neonatal ontogenesis can help improve the diagnosis and prognosis of diseases, as well as determine the effectiveness of preventive measures.

Purpose. The main objective of the present research is to find out the correlation between cardiac rhythm parameters and cytokine profile levels in young cattle during early neonatal ontogenesis.

Materials and methods

To study the nature of the correlation between the parameters of the heart rate and the levels of cytokines in young cattle in early neonatal ontogenesis, 50 one-day-old calves aged 5 days were randomly selected at the premises of Chapaevskoye SP LLC.

In the first experimental group, after calving, the newborn calf underwent a primary veterinary examination, after which it was left in a group with its mother, simulating natural conditions for the entire duration of the experiment.

In the second experimental group, calves were managed according to industrial livestock farming practices. Newborn calves were separated from their mothers immediately after birth and fed with colostrum: two liters within 1-2 hours after birth, followed by an additional two liters by the 12th hour of life. This approach subjected the animals to higher adaptive and domestication stress. Statistical significance was determined in relation to the second experimental group.

The calves of all groups underwent heart rate analysis at 5 days of age; the animals were examined in a standing position, in a stall, and in a lateral lying position on an isolated surface using a diagnostic device, a single-channel electrocardiograph EK1T-07 "Axion".

Blood samples were collected aseptically from the tail vein of each experimental group using S-Monovette 1.2 ml (66x8 mm) KZ-EDTA tubes. In stabilized samples, cytokine levels in blood plasma were measured using flow cytometry on a Bio-Plex Protein Assay System (Bio-Rad, USA). The Human 8-Plex Cytokine Panel reagent kit was used for the analysis according to the manufacturer's instructions. As a result of the study, four types of cytokines were quantitatively measured: interleukin-2 (IL-2), interleukin-4 (IL-4), interleukin-8 (IL-8), and interleukin-10 (IL-10).

To ensure data reliability, cytokine concentrations were determined in three independent experimental series, both for calibration solutions and for the analyzed samples. Quantification was determined in pg/ml using Bio-Plex Manager 6.1 software (Bio-Rad) based on standard calibration curves. The obtained data were processed using descriptive and structural statistics.

To analyze the relationships between various heart rate parameters and cytokine levels in young cattle, the statistical method of Pearson correlation (r) was used, determining the degree and direction of the relationship between variables, which is critical for understanding physiological processes and their impact on animal health.

Results

In the process of studying the cytokine profile of young cattle in the early neonatal period, kept in simulated natural conditions, as well as within the framework of industrial livestock farming technology, statistically significant changes in the levels of interleukins IL-2, IL-4, IL-8 and IL-10 were identified (Table 1).

Table 1.

Interleukin levels in calves of the study groups

Interleukin (pg/ml)	First experimental group	Second experimental group	Background norm
IL-2	30.5+0.05	34.8+0.05	20-25
IL-4	23.8+0.04	29.5+0.04	15-20
IL-8	31.1+0.06	48.7+0.06	20-25
IL-10	19.3+0.03	26.1+0.03	10-15

According to the data presented in Table 1, the level of interleukin 2 (IL-2) in the calves of the first experimental group was 30.5±0.05 pg/ml, which is 1.22 times higher than the background level. This indicates a significant activation of T-lymphocyte proliferation, which may be associated with adaptation to the living conditions. The level of interleukin 4 (IL-4) was recorded at 23.8±0.04 pg/ml (exceeding the background level by 1.19 times), indicating active differentiation of T-helpers and increased humoral immune response. The concentration of interleukin 8 (IL-8) was 42.1±0.06 pg/ml, which is 1.24 times higher than the background level, indicating the presence of an inflammatory reaction, although to a lesser extent compared to the second group. The level of interleukin 10 (IL-10) was 24.3±0.03 pg/ml (exceeding the background norm by 1.29 times), which confirms its role in the regulation of inflammatory processes and the protective function of the body.

At the same time, in calves of the second experimental group, the level of IL-2 was 34.8±0.05 pg/ml, which exceeds the background norm by 1.39 times, indicating a higher activity of T-lymphocyte proliferation. The level of IL-4 was also elevated, amounting to 29.5±0.04 pg/ml (exceeding the background norm by 1.48 times), which indicates a significant increase in the humoral immune response under the influence of stressful conditions associated with separate housing of calves and early feeding with colostrum. The IL-8 concentration reached 48.7±0.06 pg/ml, which is 1.95 times higher than the control values, reflecting pronounced inflammation and active participation of neutrophils in the immune response. The IL-10 level in this group was 26.1±0.03 pg/ml (exceeding the background norm by 1.74 times), which is also higher than in the first group, confirming the presence of a more pronounced inflammatory response and activation of inflammatory regulation mechanisms.

Analysis of interleukin levels revealed that in the first experimental group, where the calves were with their mother, exhibited lower levels of inflammatory markers, such as interleukin-2 and interleukin-4, indicating a more stable immune response. While in the second group, where the calves were raised according to industrial livestock technology, the level of these cytokines was significantly higher. This may indicate the development of acute inflammatory processes. In addition, the levels of interleukin-8 and -10 were also elevated in this group, which serves as additional confirmation of the presence of inflammatory reactions.

During the analysis of the dynamics of cardiac rhythm regulation dynamics in newborn calves under two different housing conditions, specific characteristics of their physiological state were identified. In the first experimental group, where the calves were kept with their mother, the predominance of central mechanisms in cardiac rhythm regulation was observed. This is due to the fact that natural housing conditions contributed to a decrease in stress and activation of mechanisms responsible for the harmonization of the cardiovascular system. While in the second experimental group, where the calves were taken from their mother immediately after calving and fed with collected colostrum, activation of the autonomous cardiac rhythm regulation circuit was recorded. This indicates increased adaptive-domestication pressure, which could lead to a state of “tension” in the regulatory systems.

Spectral analysis of heart rate variability revealed that young animals with elevated cytokine levels exhibited increased activity in both low-frequency (LF) and high-frequency (HF) waves. This indicates the active participation of both the central and autonomous cardiac rhythm regulation circuits. In particular, it was found that with an increase in the level of IL-2 and IL-4, a positive correlation with high-frequency waves is observed, which may indicate greater activity of the parasympathetic nervous system and improved adaptive mechanisms. At the same time, an increase in the levels of IL-8 and IL-10 is associated with the activation of low-frequency waves, which may indicate stress reactions and increased sympathetic activity.

Comparison of heart rate parameters and cytokine levels confirmed the presence of weak negative relationships between high-frequency waves and levels of inflammatory markers in the second group. This highlights the importance of choosing optimal housing conditions for newborn calves, as these can significantly influence their health and adaptation in early life (Fig. 1).

According to the graph, in the first experimental group it was found that all the studied cytokines demonstrate a negative correlation with the heart rate. This indicates that the increase in the levels of these interleukins leads to a decrease in low-frequency (LF) and high-frequency (HF) waves, which may indicate a depressing effect of inflammatory processes on the cardiovascular system of calves. Particularly noticeable is the effect of IL-2, which showed the greatest negative relationship, which may indicate its important role in regulating the heart rate under inflammatory or stressful conditions.

In the second group, a positive relationship was recorded between all the studied cytokines and the heart rate. This indicates that the increase in interleukin levels is associated with an increase in the activity of low-frequency (LF) and high-frequency (HF) waves of the heart rate, which is due to the activation of compensatory mechanisms of the body aimed at maintaining homeostasis under stress or changes in the physiological state. This positive interaction may indicate that increased levels of interleukins such as IL-2, IL-4, IL-8 and IL-10 may serve as indicators of adaptive responses of the body that contribute to the improvement of cardiac activity in response to stress factors.

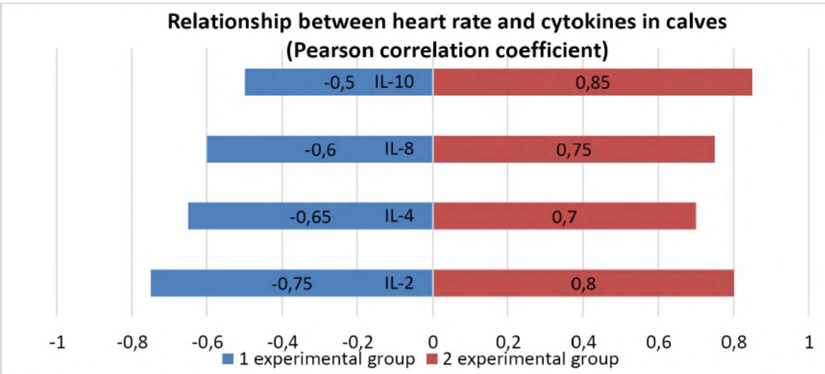

Fig. 1. Correlation between heart rate parameters and cytokine profile in calves according to Pearson

Thus, increased activity of the autonomic mechanisms regulating heart rate in newborn calves was associated with reduced function of innate immunity regulators (IL-8), specific immune responses (IL-2 and IL-4), and cytokines involved in inflammatory processes (IL-10). A weak relationship was also found between the activity of the autonomic nervous system, reflected in the very low frequency component (VLF) of heart rate variability, and the level of IL-4. The increased influence of the central nervous system on cardiac activity, including activation of the hypothalamic-pituitary axis, is accompanied by an increase in the concentration of IL-4, which plays an important role in the differentiation of lymphocytes and the development of the immune response, including inflammatory reactions.

Conclusion

The study showed that the studied groups of calves had increased levels of interleukins, indicating activation of their immune system. The second group showed a more pronounced immune response, with an increase in the levels of IL-2, IL-4, IL-8 and IL-10, exceeding the norm by 1.39, 1.48, 1.95 and 1.74 times, respectively. This indicates a more intense inflammatory response and activation of T-lymphocytes under stress. The findings underscore the importance of monitoring the immune status of animals to improve their overall health and productivity. Furthermore, they confirm that stress factors significantly impact the immune response in calves.

As a result of the study on the correlation between the parameters of the heart rate and the level of the cytokine profile in young cattle in early neonatal ontogenesis under various conditions of maintenance, significant differences in the immune response and physiological state of the animals were revealed. It was found that calves kept with their mother demonstrated a more stable immune response with low levels of inflammatory markers, indicating less stress and better adaptation to the environment. At the same time, calves exposed to stressful conditions of separate housing and early feeding showed increased levels of interleukins, such as IL-2, IL-4, IL-8 and IL-10, indicating activation of acute inflammatory processes and stress reactions.

Analysis of the heart rate dynamics confirmed that under stress conditions, an activation of the autonomous regulatory circuit is observed, which can negatively affect the health of calves. An increase in the activity of low-frequency waves is associated with increased sympathetic activity and stress, while high-frequency waves correlate with the activity of the parasympathetic nervous system and improved adaptive mechanisms.

Thus, the study highlights the critical importance of optimizing housing conditions for newborn calves. Correction of environmental factors and minimization of stress are essential to ensure harmonious interaction between central and autonomic regulation. This, in turn, can contribute to improved health, strengthening of the immune response and increased survival of newborn offspring, as well as the effectiveness of adaptation of young cattle in early neonatal ontogenesis.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

FEEDING SPECIFICS OF THE AUSTRALIAN RED CLAW CRAYFISH *CHERAX QUADRICARINATUS* (VON MARTENS, 1868) IN AQUACULTURE

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Abstract

Background. The selection of optimal feed formulations is a primary factor determining the efficiency and sustainability of aquaculture. The Australian Red Claw Crayfish, *Cherax quadricarinatus* (von Martens, 1868), known for its high growth rates and tolerance to water quality parameters, is a popular aquaculture species worldwide. However, the development of specialized feeds for this species remains insufficiently addressed. In practice, prepared feeds for other crustaceans or for sturgeon are commonly used for its cultivation. In natural habitats, the diet of this crayfish consists primarily of macrophytes (up to 87.5%) and detritus (42.8%), with the proportion of the plant component increasing with body size. The omnivorous feeding type creates opportunities for finding cheaper protein sources compared to fishmeal. Analysis of scientific research has shown that black soldier fly larvae and yellow mealworm can be used as alternatives to fishmeal in feeds for the Australian crayfish. Among plant-based raw materials, soybean, rapeseed, and peanut meal are unsuitable components. The specific feeding behavior of the Red Claw Crayfish necessitates sufficient stabilization and binding of feed pellets. Furthermore, the shape of the feed pellets must be considered, with the prism shape being the most preferable. Developing feed formulations that account for the biological specifics of the Red Claw Crayfish will enhance the efficiency of its aquaculture and reduce costs for farmers.

Purpose. To identify the main dietary characteristics and nutritional requirements of the Australian red claw crayfish *Cherax quadricarinatus* in order to develop feed formulations that ensure high farming efficiency and economic sustainability in aquaculture.

Materials and methods. A comparative – analytical approach was applied in this study. The information base was formed through the analysis of more than 150 scientific publications from both domestic and international sources. Literature searches were conducted in databases such as eLibrary, ScienceDirect, ResearchGate, Google Scholar, Wiley, and others, using keywords in both Russian and English.

Results. The analysis revealed that *Cherax quadricarinatus* is capable of effectively digesting both plant- and animal-based dietary components. Protein was identified as the primary limiting nutrient, with an optimal content for juveniles ranging between 30-33%. As an alternative to fish meal – the most expensive component of aquafeeds – promising protein sources include black soldier fly larvae, yellow mealworms, poultry by-products, and microbial protein DREAMFEED. The species' specific feeding behavior necessitates high water stability and mechanical strength of feed pellets, as well as adjustment of their shape and size according to crayfish age; prismatic pellets are considered optimal. Experimental studies of both domestic and international feed formulations demonstrated that the use of alternative protein sources and locally available raw materials can reduce feed costs without compromising growth rates or survival.

Conclusion. The efficiency of *Cherax quadricarinatus* aquaculture is largely determined by the quality and nutritional balance of the feed. The biological features of this species, including its versatile digestive system and ability to process a wide range of organic substances, provide a basis for the development of diets using alternative protein sources. Diets that maintain an optimal balance of proteins, lipids, carbohydrates, vitamins, and minerals contribute to enhanced productivity, survival, and profitability of aquaculture farms. The improvement of feed formulations and manufacturing technologies aimed at increasing water stability and adapting pellet size to different developmental stages represents a key direction for the further advancement of *Cherax quadricarinatus* aquaculture.

Keywords: Red Claw Crayfish; *Cherax quadricarinatus*; feeds; aquaculture; feed formulations; feed additives; probiotics

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Научная статья

ОСОБЕННОСТИ КОРМЛЕНИЯ АВСТРАЛИЙСКОГО КРАСНОКЛЕШНЕВОГО РАКА *CHERAX QUADRICARINATUS* (VON MARTENS, 1868) ПРИ ВЫРАЩИВАНИИ В АКВАКУЛЬТУРЕ

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Аннотация

Обоснование. Подбор оптимальных рецептур кормов является основным фактором, который определяет эффективность выращивания и устойчивость аквакультуры. Австралийский красноклешневый рак *Cherax quadricarinatus* (von Martens 1868), обладая высокими темпами роста и толерантностью к показателям качества воды, является популярным объектом аквакультуры во всем мире. Тем не менее, вопрос разработки специализированных кормов не полностью раскрыт. В практике выращивания этого вида используют готовые корма для других ракообразных, либо для осетровых рыб. В естественных местах обитания основой пищи раков составляют макрофиты (до 87,5%) и детрит (42,8%), причем с увеличением размера тела увеличивается доля растительного компонента в питании красноклешневых раков. Всеядный тип питания создает возможность для поиска более дешевых источников белка по сравнению с рыбной мукой. Анализ научных исследований показал, что в качестве альтернативы рыбной муке в кормах для австралийского рака возможно использование личинок черной львинки и желтого мучного червя. Среди растительного сырья неподходящими компонентами являются соевая, рапсовая и арахисовая мука. Особенность пищевого поведения красноклешневого рака обуславливает необходимость в достаточной стабилизации и закреплении кормовых гранул. Кроме того, необходимо учитывать форму гранул корма, среди которых наиболее предпочтительной формой является призма. Создание кормовых рецептур с учетом особенностей красноклешневого рака позволит повысить эффективность аквакультуры этого объекта и снизит затраты фермеров.

Цель. Определить основные особенности питания и кормовых потребностей австралийского красноклешневого рака *Cherax quadricarinatus* с целью разработки рационов, обеспечивающих высокую эффективность выращивания и экономическую устойчивость аквакультуры.

Материалы и методы. В исследовании применялся сравнительно-аналитический метод. Информационная база была сформирована на основе анализа более 150 научных публикаций, представленных в отечественных и зарубежных источниках. Поиск литературы осуществлялся в базах eLibrary, ScienceDirect, ResearchGate, Google Scholar, Wiley и других с использованием ключевых слов на русском и английском языках.

Результаты. Анализ показал, что австралийский красноклешневый рак способен эффективно усваивать как растительные, так и животные компоненты рациона. Основным лимитирующим элементом питания является белок, оптимальное содержание которого для молоди составляет 30-33%. В качестве альтернативы рыбной муке, являющейся наиболее дорогостоящим компонентом, перспективно использование белков из личинок черной львинки, желтого мучного червя, субпродуктов птицы и микробного белка. Отмечено, что особенности пищевого поведения данного вида требуют высокой водоустойчивости и механической прочности гранул, а также подбора их формы и размера в зависимости от возраста раков. Экспериментальные исследования отечественных и зарубежных рецептур показали, что использование альтернативных источников белка и местного сырья позволяет снизить себестоимость кормов без ухудшения показателей роста и выживаемости особей.

Заключение. Эффективность выращивания австралийского красноклешневого рака в аквакультуре определяется качеством и сбалансированностью кормов. Биологические особенности вида, включая универсальность пищеварительной системы и способность переваривать широкий спектр органических веществ, создают возможности для разработки рационов на основе альтернативных источников белка. Рационы, обеспечивающие оптимальное соотношение белков, жиров, углеводов, витаминов и минералов, способствуют повышению продуктивности, выживаемости и рентабельности хозяйств. Совершенствование рецептур и технологии производства комбикормов, направленное на повышение водоустойчивости и адаптацию гранул к разным возрастным группам, является важным направлением для дальнейшего развития аквакультуры *Cherax quadricarinatus*.

Ключевые слова: красноклешневый рак; *Cherax quadricarinatus*; корма; аквакультура; рецептуры корма; кормовые добавки; пробиотики.

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Introduction

The success of cultivating aquaculture species depends on feeding quality. Diet selection should be based on the biological characteristics of the species, age category, etc. The experience of feeding the Australian Red Claw Crayfish is based on diets specialized for other crustacean species, such as *Litopenaeus vannamei*, *Penaeus monodon*, and *Macrobrachium rosenbergii* [1]. In some cases, artificial feeds created for sturgeon are used for feeding Red Claw Crayfish. Despite good growth rates with such feeding, the development of specialized artificial feeds for this species is required.

Fig. 1. Appearance of a male *Cherax quadricarinatus*

Fig. 2. Appearance of a female *Cherax quadricarinatus*

The Australian Red Claw Crayfish *Cherax quadricarinatus* (von Martens, 1868) (Fig. 1) offers several advantages for aquaculture: high growth rates, tolerance to deteriorating water quality [1, 2], and an attractive appearance. From a consumer perspective, this species is also of interest due to its high yield of tender meat [3], constituting 30% of body weight [2]. The Australian Red Claw Crayfish is a tropical species, with an autochthonous range covering Northern Queensland, Australia. This species is cultivated in many countries worldwide, including Argentina, Mexico, Spain, the USA, Southeast Asia, and Central/South America [2], among others.

Enterprises specializing in the commercial cultivation of the Australian Red Claw Crayfish that lack their own broodstock must spend a substantial portion of their financial resources on purchasing juveniles. With this approach, it is important to ensure high survival rates of the aquaculture stock to achieve maximum possible profit. Research results have shown that diet type significantly influences the survival and growth rates of *C. quadricarinatus* [4]. When cultivated in ponds, crayfish consume natural food organisms; however, for production intensification, the additional introduction of artificial feeds is required. These feeds must account for all biological needs of the species and possess high water stability [2].

Objective

The object of the study is the Australian red claw crayfish *Cherax quadricarinatus* cultivated under aquaculture conditions, as well as its feeding characteristics and nutritional requirements that determine the effectiveness of formulated feed development and application for this species.

Materials and methods

A comparative-analytical method was applied during the research. The information base was formed through the analysis of data from open scientific publications. Literature searches were conducted in abstract and information databases, including eLibrary, the Russian State Library, ScienceDirect, ResearchGate, Google Scholar, National MedLine, the Wiley Online Library, and others. The following key terms were used as search queries: «*Cherax quadricarinatus*», «Australian red claw crayfish», «red claw crayfish», «aquaculture», «crustaceans», «feed», «diet» - both individually and in various combinations. No temporal restrictions were set during the search to cover the most representative body of publications. In total, over 150 literature sources were analyzed during the study.

Feeding Type

Analysis of the digestive tract contents of juvenile Australian Red Claw Crayfish (body size less than 28.7 mm) from natural water bodies showed that macrophytes constituted a significant portion of the food bolus (87.5%), with detritus content being second (12.1%). As crayfish grow, the quantity of food particles in the digestive system changes. In individuals with a body size greater than 56 mm, the content of macrophytes decreases (to 57.2%), while detritus consumption increases (to 42.8%) [5].

In the digestive system of juvenile Red Claw Crayfish, enzymes play a significant role. The activity of proteases – enzymes that break down proteins, including trypsin, astacin, exopeptidase, and aminopeptidase – is most pronounced [6, 7]. However, their activity and concentration change depending on age and diet. Ontogenetic changes in *C. quadricarinatus* lead to high activity of general proteases in juveniles, which decreases with growth [8].

The entire genus *Cherax* possesses a large number of carbohydrase enzymes: amylase, cellulase, endo-β1,4-glucanase, β-glucosidase, laminarinase, lichenase, xylanase, endochitinase, and N-acetyl-β-D-glucosaminidase, which ensure the breakdown of starch, oligosaccharides, and other carbohydrates. The activity of cellulase indicates that dietary cellulose is assimilated and can serve as an energy source at all free-living stages, as this enzyme is present at all growth stages and can be synthesized by the organism of the Australian Red Claw Crayfish itself [8]. It is important to note that cellulase activity was observed in the smallest crayfish even before first feeding, indicating an ability to use plant material as food from the moment yolk absorption is completed. The cellulase enzymes of the Red Claw Crayfish demonstrate broad substrate specificity, hydrolyzing polysaccharides containing β-1,4 and mixed β-1,4 and β-1,3 glycosidic bonds, but showing a preference for soluble substrates [9]. The diversity of digestive enzymes (proteases, carbohydrases, and lipases) confirms the ability of Red Claw Crayfish to successfully digest various types of food [10]. Thus, the enzymatic system of *C. quadricarinatus* is universal and plastic: high protease activity ensures the assimilation of protein substrates, the presence of cellulases and other carbohydrases allows for the effective use of plant-based carbohydrate sources, and a developed lipase system promotes lipid assimilation. The presence of such an enzymatic apparatus allows for the creation of feed formulations characterized by greater availability and lower overall production costs.

Nutrient Requirements of Australian Red Claw Crayfish in Feed Composition

The most limiting element at any growth stage of the Australian crayfish is protein, which is simultaneously the most expensive component of compound feeds in aquaculture. The protein content in the diet of aquaculture species influences the cost of compound feeds, which can account for up to 70% of all expenses on an aquaculture farm. Regarding the Australian Red Claw Crayfish, it is reported that for juveniles weighing 1 g, a sufficient level of crude protein is 31%, while for early juveniles weighing 0.022 g, 33% crude protein is necessary [11]. It has been established that for juveniles aged from 9 to 19 weeks, the rational use of feeds with a protein content of 30% is recommended [12].

Among the essential amino acids, lysine and threonine determine the growth success of Australian Red Claw Crayfish [10] because they cannot be synthesized in the body and must be supplied through feed. The addition of 0.4% threonine to the diet significantly increases crayfish growth rates ($P < 0.05$), feed digestibility, enhances antioxidant status, and stabilizes intestinal microbiota [13].

Lipids also play an important role in the functioning of the Australian Red Claw Crayfish organism, and the requirement for these substances must be considered in artificial feeds. They provide the organism with energy and essential fatty acids, sterols, phospholipids, and fat-soluble vitamins necessary for proper physiological functioning and maintaining the biological structure and functions of cell membranes. Soybean oil has been proposed as a lipid source. Experiments have shown that when soybean oil was included in artificial feeds at 40 g/kg dry matter and 60 g/kg dry matter, the growth rate of juvenile crayfish was significantly higher than at 20 g/kg, 80 g/kg, and 100 g/kg dry matter ($P < 0.05$). It was established that the optimal lipid level in the diet of *C. quadricarinatus* is 9.67% [14].

Features of Juvenile Feeding in Aquaculture

A peculiarity of the feeding behavior of the Australian Red Claw Crayfish is the slow consumption of feed particles and the performance of a series of manipulations with them (transfer between pereiopods), which necessitates sufficient stabilization and binding of feed particles. Furthermore, the shape of the feed particles also matters for feeding success. In a study by Cheng S. et al., it was shown that the most preferable pellet shape is a prism compared to a column, granule, or tablet [4]. Existing scientific recommendations regarding the feeding of juvenile Red Claw Crayfish can be summarized in several theses:

- Supplemental feeding should begin after the yolk sac disappears;
- Feed should be provided twice a day (morning and evening);

- The size and shape of the feed particle must be suitable for holding by the pereiopods [4].

Testing of experimental feed formulations demonstrated good growth and survival indicators for juvenile Red Claw Crayfish with an average weight of 0.024 g on a diet consisting of 85% feed mixture + 14% *Artemia* + 1% spirulina powder. Additionally, it was shown that feeding with *Artemia* could improve trypsin activity in juvenile Australian Red Claw Crayfish and thus promote their growth [4].

Some juvenile crayfish cultivation technologies involve the use of natural feeds. In a study by Muhammad Safir, Akbar Marzuki Tahya, and Hikmah Asdin, crayfish growth rates were analyzed when fed carrots, golden snails, earthworms, and anchovies. The obtained results indicate the high effectiveness of a diet consisting of the worms *Lumbricus rubellus*. The daily growth increment with such feeding was 0.69% (compared to 0.40%, 0.43%, and 0.13% with other diets) [15].

Alternative Protein Sources for Feeds

In most artificial feed formulations for aquaculture, fishmeal is used as the protein source [16] in amounts of 20-50% [1]. This component is expensive [17], which increases feed costs and raises the production cost of commercial Australian Red Claw Crayfish products. The omnivorous feeding type, as well as the effective enzymatic system in the gastrointestinal tract of *C. quadricarinatus*, allows for the use of alternative protein sources of plant origin. The success of this approach has been proven in feeding the crustaceans *Eriocheir sinensis*, *Pacifastacus leniusculus*, *Macrobrachium nipponense*, and *L. vannamei*.

In many aquaculture sectors, researchers are conducting work on selecting alternative protein sources [18]. The selection of alternative protein sources from plant raw materials requires careful analysis of their impact on the crayfish organism. In an experiment by Dunwei Qian, it was shown that the introduction of soybean meal into the crayfish diet adversely affects the organism's condition. An increase in malondialdehyde levels and a decrease in acid phosphatase were recorded. Peanut meal is also an unsuitable replacement for fishmeal for Red Claw Crayfish, as it leads to high activity of glutathione peroxidase, alanine aminotransferase, aspartate aminotransferase, and reduced lipase activity. When rapeseed meal is introduced into the diet, detachment of the peritrophic membrane and lower lipase activity are recorded [1].

Insect meal is recognized as a promising replacement for fishmeal [19], particularly meal from black soldier fly larvae [20]. The use of yellow mealworm meal is possible, which increases superoxide dismutase activity and reduces malondialdehyde content in the crayfish hepatopancreas [11]. The use of poultry by-product meal as an inexpensive alternative to fishmeal is also being considered. During experimental feeding of juvenile Red Claw Crayfish (average weight 13.0±0.03 g), no differences in growth indicators were found between a diet based on fishmeal and one based on poultry by-product meal and plant components [21].

Exogenous enzymes are often present in feeds for aquaculture species [22]. These proteins contribute to improved digestibility of complex polymeric compounds, better feed utilization, energy conversion, and reduced nutrient loss [23]. In the work of E.S. García Martínez et al., the growth rates of juvenile Red Claw Crayfish (average weight 1.5 g) were analyzed upon the introduction of a multi-enzyme extract obtained from waste of the Argentine shrimp *Pleoticus muelleri* into the diet. The feed base consisted of plant (65%) and animal (25%) components. After feeding the crayfish for 90 days, it was established that the introduction of exoenzymes significantly modulates the animals' digestive enzymes. For example, the activity of endogenous digestive peptidases increased, and a tendency for increased lipase activity was shown. The experimental group recorded lipid accumulation in the hepatopancreas and increased glycogen in the muscles [23].

Reducing the production cost of pond-cultivated products is possible by making feeds cheaper through the omission of vitamin and mineral additives. In a study by Yuka Kobayashi et al., weight gain indicators of juvenile *C. quadricarinatus* (average weight 15.7±1.0 g) were analyzed on a diet with added premixes (control) and without added premixes (experimental). After 105 days of cultivation in ponds (pond area 0.02 ha) at a density of 3.2 ind./m², no statistical differences ($P>0.05$) were found in the feed conversion ratios for the groups of juveniles receiving different diets [24].

Compound Feed Components for *Cherax quadricarinatus*

To develop cost-effective diets, it is necessary to understand how farmed organisms utilize energy. Energy from non-protein sources (lipids, carbohydrates) must be supplied in the diet in sufficient quantity relative to the protein level so that protein is used for tissue synthesis, as it is considered the most expensive major component of crustacean diets. If the ratio of non-protein energy to protein in the diet is insufficient, then dietary protein may be catabolized and used as an energy source for maintaining vital functions, rather than for somatic growth.

A balance of basic nutrients determines the optimal composition of feeds for the Australian Red Claw Crayfish: protein, fat, and mineral components, as well as carbohydrates and vitamins. The growth rate and protein content directly depend on the content of protein components in the feed; sources such as fishmeal, meat-and-bone meal, shrimp meal, and crab meal are used for this purpose. In turn, fat components provide essential fatty acids; the presence of lipids supports the growth process, and the presence of carbohydrates in the crustacean diet is used as an energy source. Mineral components and vitamins are aimed at maintaining normal body function and increasing overall survival.

Examples of Feed Formulations.

Australian FRDC Project (92/119) Compound Feeds

In the mid-1990s, large-scale research was conducted in Australia to determine optimal diets for cultivating *C. quadricarinatus*. During the FRDC project (92/119) under the direction of C.M. Jones and I.M. Ruscoe, six different diets were tested – five pelleted compound feeds and one "natural" diet (a mixture of whole rice, lupin seeds, and raw potatoes) in pond cage and laboratory aquarium conditions. The feed compositions varied significantly in protein content: from 18 to 42%. The diets included commercial crayfish feeds, shrimp feed (*Penaeus monodon*), fish feed, and a specially developed "reference diet" for Red Claw Crayfish, which included fishmeal (21%), meat-and-bone meal, soybean meal, cottonseed cake, cereals, amino acid supplements (lysine, methionine, threonine), and a vitamin-mineral premix.

The cultivation results showed that all feeds provided satisfactory growth: over 5 months, crayfish weight increased from 10 to 25-65 g, with individual specimens reaching over 100 g. The highest efficiency was noted for one of the commercial crayfish compound feeds – the average weight at harvest was 45.8 g, which was significantly higher ($p < 0.01$) than when using the other diets (31.3-38.5 g). Meanwhile, the "natural" diet demonstrated the worst results, despite its high caloric content.

Escapes and predators complicated survival in the trials, which prevented a reliable assessment of the diet's influence on this indicator. Nevertheless, the obtained data confirmed that a complex of factors could determine formulating diets with high protein content does not always guarantee better results, and feed efficiency. The conclusions of the 1996 research formed the basis for industrial feed production.

Compound Feed with DREAMFEED Additive

Formulations of compound feeds for *C. quadricarinatus* have now been developed and are in use, in which part of the fishmeal is replaced with the microbial protein DREAMFEED to reduce costs. This is a concentrate of microbial protein from an inactivated cell culture of *Methylococcus capsulatus* (strain GBS-15), grown on methane. Its chemical composition is characterized by high crude protein content (70-80%), lipids (9-14%), ash (6-10%), and low moisture. Trials of compound feeds with the DREAMFEED additive were conducted in two stages: on juveniles (with 20% additive content) and on adults (with 15% additive content). The percentage composition of components in the control and experimental types of compound feeds is presented in Table 1.

Table 1.

Formulation of control and experimental compound feeds for *Cherax quadricarinatus*

Components, %	Control	Feed with DREAMFEED – Juveniles	Feed with DREAMFEED – Adults
Fishmeal	72	52	57
Wheat Gluten	15	15	15
Blood Meal	3	3	3
Premix	1	1	1
Grape Pomace Meal	1	1	1
Krill Meal	5	5	5
DREAMFEED	-	20	15
Fish Oil	3	3	3

According to the research by Ponomorev S., the compound feeds with microbial protein DREAMFEED did not differ from the control feed in organoleptic characteristics; differences were manifested in the higher nutritional value of the compound feed with the DREAMFEED additive, where protein content reached 67% and lipids about 10%, as well as in its greater water stability. Over the first two months, the weight gain in the group with the additive was 11.57% higher compared to the control. The average daily gain was 3.87% versus 3.69% in the control group, and the mass accumulation coefficient was also higher (5.6% vs. 5.3%). Furthermore, weight distribution within the population was more uniform: the control group had more individuals with low weight (2-3 g and 3-6 g), whereas the experimental group had a larger proportion in the heavier size classes (7-10 g). However, juvenile survival remained approximately the same in both groups (69-70%), which is associated with the high frequency of molting and the vulnerability it causes [25].

In the second stage of the experiment, when crayfish were cultivated for another three months, the differences in results were less pronounced. The absolute weight gain was 25.49 g in the experimental group and 24.83 g in the control, meaning the difference in favor of the feed with the additive was only 2.66%. The average daily gain also differed insignificantly (1.38% vs. 1.44%). However, a significant advantage of the experimental feed was the higher survival of adults – 100% against 94% in the control group [25].

Compound Feed by «KazNRI of Processing and Food Industry» LLP

In Kazakhstan, a specialized production compound feed for the Australian Red Claw Crayfish based on locally produced ingredients was developed for the first time. «KazNRI of Processing and Food Industry» LLP carried out its creation and testing in 2021-2023 in recirculating aquaculture systems (RAS). The imported feed “Aller Aqua” (Denmark), traditionally used in aquaculture, was used as a control in the experiments [26].

The composition of the compound feed changed during the refinement of the formulation. The basis was formed by fishmeal (10-25%), meat-and-bone meal (10-15%), corn gluten (5-15%), wheat (14-25%), soybean meal (up to 12%), feed yeast (10-18%), vegetable oils (soybean and rapeseed), as well as mineral and vitamin additives (monocalcium phosphate, premixes, lecithin, betaine, flavorings). The feed was balanced in protein (38-41%), fat (8-12%), and mineral substance content, corresponding to the physiological needs of crayfish.

In 2021, for juveniles, the average daily weight gain was 0.17 g with a feed conversion ratio (FCR) of 1.5 and a survival rate of 74%, while the control feed indicators were slightly higher (0.19 g, 1.2, and 78%, respectively). In 2022, for marketable specimens, weight gain reached 12.3 g over 30 days with a survival rate of 93%, which was comparable to the results with “Aller Aqua”. In 2023, high survival rates (94-95%) were observed with similar values for weight gain and feed conversion ratios. Thus, the differences between the experimental and control groups were statistically insignificant.

The developed Kazakh specialized compound feed has a balanced composition, is well assimilated by crayfish, and provides satisfactory growth and survival indicators comparable to imported feeds. Its main advantage is a significantly lower cost due to the use of local raw materials, making it economically viable for the industrial cultivation of *C. quadricarinatus*. The use of local formulations contributes to reducing the cost of aquaculture products and developing import-substituting technologies in the republic.

Feeds by Ridley Agri Products Pty Company

In feeds for *C. quadricarinatus* produced by Ridley Agri Products Pty Company, plant proteins are primarily used – cereals, legumes, and oilseed crops, completely excluding fishmeal, which allows for a significant reduction in production costs. However, research into their effectiveness has revealed a number of serious limitations directly affecting cultivation outcomes.

The key problem was the low water stability of the pellets. Experiments showed that standard industrial pellets with a diameter of 4.5 mm retain their structure in water for no more than 10-15 minutes before beginning to disintegrate. The second important limitation was the uniform pellet size. The industry produces only feed with a pellet diameter of 4.5 mm; juveniles and grow-out individuals cannot efficiently consume such large particles. As a result of studying feeding responses, it was noted that feeds with a fully plant-based composition have reduced attractiveness for crayfish [27].

Within the research of Thobejane T. R., attempts were made to improve feed efficiency; the greatest effect was achieved by introducing binding additives, particularly alginate at a dosage of 4.4% of dry mass [27]. This modification increased pellet water stability: 24 hours after immersion in water, the pellets retained their structure, and the level of dry matter loss decreased to 16.2%, which is significantly better compared to 23.8% for the standard feed. It was established that a three-level scheme is optimal: pellets with a diameter of 1.0 mm for juveniles weighing 5-8 g, 2.0 mm for grow-out individuals weighing 15-25 g, and 3.0 mm for adult crayfish weighing 35-50 g. This approach significantly improved feed utilization efficiency and reduced its losses.

Results

The study established that the Australian red claw crayfish *Cherax quadricarinatus* exhibits high dietary plasticity and can efficiently utilize feeds of various origins. The key factor determining the growth rate and development of juveniles is the protein level in the diet, which should be maintained at approximately 30–33%. The species' feeding behavior necessitates optimization of the physical properties of feed pellets, including high water stability and the adjustment of pellet shape and size according to the developmental stage of the animals. Experimental evaluation of domestic and international feed formulations demonstrated that the use of alternative protein sources and locally available raw materials can reduce feed costs without compromising growth performance and survival rates.

Conclusion

The analysis of the feeding specifics of the Australian Red Claw Crayfish has shown that the efficiency of aquaculture cultivation of this species is largely determined by the composition and quality of feeds. The biological characteristics of the species, including an omnivorous feeding type, a broad spectrum of enzymes, and the ability to assimilate both animal and plant components, create opportunities for developing diverse and economically accessible diets. At the same time, unbalanced feeding or the use of unsuitable ingredients leads to slowed growth, reduced survival, and increased production costs. Diets for the Australian Red Claw Crayfish must ensure a balance of proteins, fats, carbohydrates, vitamins, and minerals. The use of alternative components, such as microbial and plant proteins, allows for a reduction in feed costs; however, it requires consideration of their impact on crayfish growth and survival. Improving feed formulations and compound feed technology, including enhancing water stability and adapting pellet sizes for different age groups, is an important condition for increasing the efficiency of *Cherax quadricarinatus* aquaculture.

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Original article

DETERMINATION OF THE LIMITING STATIC CLIMBING ANGLE OF A MODULAR POWER AND TECHNOLOGICAL VEHICLE

A.V. Lavrov

Abstract

Background. Agricultural production is facing a shortage of tractors due to insufficient available machinery. To address this issue, a technological module was developed to increase the versatility of Class 1.4 tractors by upgrading them to a higher traction class. To assess the operational safety of a tractor equipped with a technological module, the maximum static climbing angle was calculated.

Purpose. Theoretical calculations were conducted to determine the maximum static climbing angle of a modular power and technological vehicle.

Materials and methods. The stability of the MTZ-82 tractor equipped with a technological module, including the coordinates of the overall center of gravity and the maximum static climbing (slope) angle, was analyzed using computational models.

Results. The horizontal and vertical coordinates of the center of gravity of the tractor and technological module were found to be 0.38 m and 0.885 m respectively. The maximum static climbing angle of the MTZ-82 tractor with technological module was found to be 71.7°.

Conclusion. Theoretical calculations of the maximum static angle of ascent have shown that the modular energy technology device is capable of performing the full range of technological operations without compromising operational safety.

Keywords: center-of-mass coordinates; climbing angle; energy module; technological module; modular energy technology vehicle

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Научная статья

ОПРЕДЕЛЕНИЕ ПРЕДЕЛЬНОГО СТАТИЧЕСКОГО УГЛА ПОДЪЕМА МОДУЛЬНОГО ЭНЕРГОТЕХНОЛОГИЧЕСКОГО СРЕДСТВА

А.В. Лавров

Аннотация

Обоснование. Технологическая обеспеченность сельскохозяйственного производства техникой характеризуется дефицитом тракторов. Для решения данной проблемы разработан технологический модуль, позволяющий повысить универсальность тракторов класса 1,4, путем перевода их в более высокий тяговый класс. Для оценки безопасности при эксплуатации трактора с технологическим модулем проведен расчет предельного статического угла подъема.

Цель. Провести теоретические расчеты по определению предельного статического угла подъема модульного энерготехнологического средства.

Материалы и методы. Для исследования устойчивости трактора МТЗ-82 с технологическим модулем с помощью расчетных схем определены координаты суммарного центра тяжести и предельный статический угол подъема трактора МТЗ-82 с технологическим модулем.

Результаты. Определены горизонтальная и вертикальная координаты центра тяжести агрегата, состоящего из трактора и технологического модуля: 0,38 м, и 0,885 м соответственно. Определен предельный статический угол подъема трактора МТЗ-82 с технологическим модулем: 71,7°.

Заключение. Проведенные теоретические расчеты предельного статического угла подъема показали, что модульное энерготехнологическое средство способно выполнять весь спектр технологических работ без ограничений по безопасности.

Ключевые слова: координаты центра масс; угол подъема; энергетический модуль; технологический модуль; модульное энерготехнологическое средство

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Introduction

According to the Agricultural Engineering Development Strategy for the Period up to 2030, it is assumed that the process of consolidation of agriculture will lead to an increase in demand for medium-power (100 to 200 hp) and high-power (over 200 hp) tractors [1]. However, as research has shown, agricultural production in Russia is characterized by a severe shortage and high depreciation of equipment, with the number of tractors and self-propelled harvesting machines having decreased more than threefold over the past 30 years [2]. The current shortage of tractor equipment in all traction classes except 1.4 leads to significant losses and shortfalls in agricultural yields.

To address the shortage of tractors in traction class 2, a technological module was designed and manufactured using commercially available components, allowing for an increase in the traction class of the commercially available 1.4-class tractor (MTZ-82) [3; 4]. The general appearance of the agricultural modular energy-technological vehicle is shown in Fig. 1.

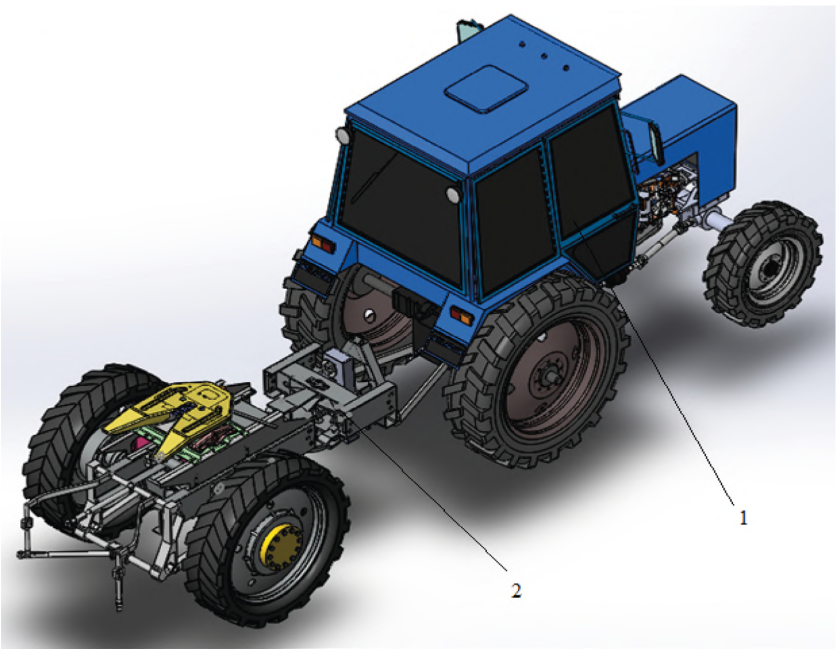

Fig. 1. Modular energy technology vehicle:
1 – power tractor, 2 – technological module

The basic requirements for the technological module were developed taking into account the existing scientific and technical background in the field of agrotechnical requirements for agricultural machinery [5-6].

The design and engineering development of the technological module was performed by scientists with experience in similar developments [7-10]. As a result of this research, a technological module design was developed that meets agricultural technology requirements and is compatible with MTZ-82 tractors.

To ensure the safe operation of the tractor–machine unit equipped with a technological module, it is necessary to determine its stability parameters, including the maximum static climbing angle, taking into account the design features of the modular power unit.

The static stability of agricultural tractors is influenced by various factors, including the tractor's mass-dimensional parameters, chassis design, mounted technological equipment, and attached agricultural implements. Tractor stability is critical when operating under soil and climatic conditions that involve fields with significant surface gradients.

According to Iovlev and Goldina [11], a comprehensive study was conducted on the influence of drawbar load on the tractor's longitudinal stability. The critical longitudinal and lateral stability angles were determined during operation with different types of agricultural implements.

Safety issues related to the operation of tracked tractors during technological processes are discussed by Lipkovich et al. [12]. The authors analyzed how the design characteristics of the undercarriage system and the attached implements affect the limiting static stability angles of tracked tractors. Gorobey and Moskalevich [13] proposed a method for calculating the maximum elevation angle of a tracked tractor equipped with mounted equipment.

The principal differences in the rollover dynamics of three-wheeled and four-wheeled tractors were analyzed by Pliev [14], who derived analytical expressions to determine the limiting stability angles of three-wheeled tractors. To assess the longitudinal stability of wheeled tractors, the concept of a Longitudinal Stability Index, which accounts for the tractor's mass and geometric parameters, was introduced in [15].

The authors of [16] proposed a method for calculating the maximum static angles of longitudinal and lateral stability when a tractor is equipped with gas cylinders.

Purpose. Theoretical calculations were conducted to determine the maximum static climbing angle of a modular energy-technology tool.

Materials and methods

To assess the stability of the MTZ-82 tractor equipped with a technological module, it was necessary to determine the combined center of gravity of the tractor and technological module. The calculation scheme shown in Fig. 2 was used to determine the combined center of gravity of the tractor and technological module.

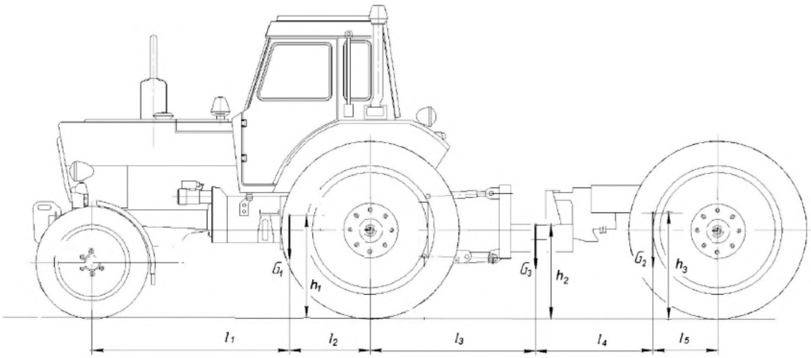

Fig. 2. Calculation scheme for determining the coordinates of the total center of gravity

The maximum static climbing angle of the MTZ-82 tractor equipped with a technological module was analyzed using calculation models presented in Fig. 3.

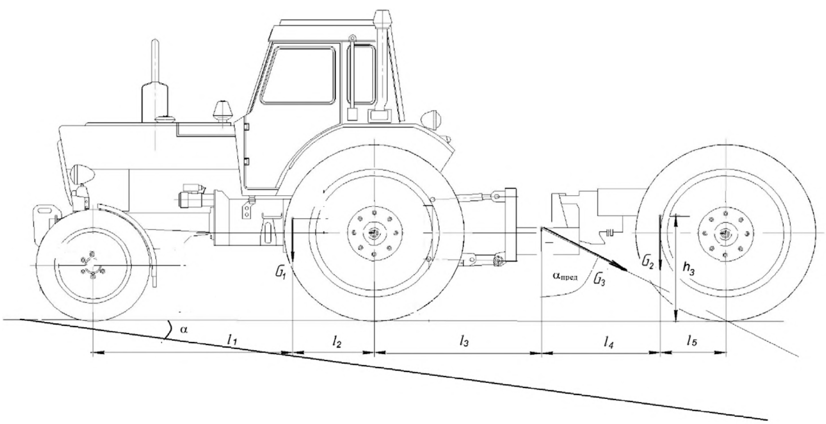

Fig. 3. Calculation scheme for determining the maximum static angle of ascent

Initial data for the calculation.

Tractor weight: G_1 = 3500 kg;

Weight of the technological module: G_2= 1500 kg;

Distance from the front axle to the tractor's center of gravity: l_1= 1,74 m;

Distance from the rear axle to the tractor's center of gravity: l_2= 0,7 m;

Distance from the axis of the process module to the center of gravity of the process module: l_5= 0,5 m.

Distance from the axis of the technological module to the rear axle of the tractor: $l_3+l_4+l_5$= 3,06 m.

Vertical coordinate of the tractor's center of gravity: h_1 = 0,95 m.

Vertical coordinate of the center of gravity of the technological module: h_2 = 0,85 m.

Results

The moment generated by the unit, consisting of the tractor and the technological module, relative to any point, must be equal to the sum of the moments created relative to that point by the tractor and the technological module according to the calculation scheme (Fig. 2), we write the following equation:

$$G_3 l_3 = G_2((l_3 + l_4 + l_5) - l_5) - G_1 l_2.$$

where G_3 is the weight of the modular energy-technological facility (kg);

G_2 is the weight of the technological module (kg);

G_1 is the tractor weight (kg);

l_3 is the distance from the rear axle to the center of gravity of the modular energy-technological vehicle (m);

l_4 is the distance from the center of gravity of the technological module to that of the modular energy-technological facility (m);

l_5 is the distance from the axis of the process module to its center of gravity (m);

l_2 is the distance from the rear axle to the center of gravity of the tractor (m).

Hence, given that $G_3 = G_1 + G_2$, we will receive:

$$l_3 = \frac{G_2((l_3+l_4+l_5)-l_5)-G_1 l_2}{G_1+G_2}.$$

Then

$$l_3 = \frac{1500(3,6-0,7)-3500*0,7}{3500+1500} = 0,38 \text{ m}.$$

The vertical coordinate of the center of gravity of the unit consisting of a tractor and a technological module:

$$G_3 h_3 = G_2 h_2 + G_1 h_1,$$

where h_3 is the vertical coordinate of the center of gravity of the modular energy-technological facility (m);

h_2 is the vertical coordinate of the center of gravity of the technological module (m);

h_1 is the vertical coordinate of the tractor’s center of gravity (m).

Given that $G_3 = G_1 + G_2$, the following relation can be obtained:

$$h_3 = \frac{G_2 h_2 + G_1 h_1}{G_1 + G_2}.$$

$$h_3 = \frac{1500 * 0{,}85 + 3500 * 0{,}95}{3500 + 1500} = 0{,}885\ m.$$

The tangent of the maximum static climbing angle of the MTZ-82 tractor equipped with a technological module was determined based on the calculation scheme presented in Figure 3.

$$tg(x_{max}) = \frac{l_4 + l_5}{h_3} = \frac{3{,}06 - 0{,}38}{0{,}885} = 3{,}03.$$

Therefore, the maximum longitudinal stability angle of the MTZ-82 tractor with a technological module:

$$x_{max} = argtg\ 3{,}03 = 71{,}7°.$$

Tangent of the maximum longitudinal stability angle of the MTZ-82 tractor:

$$tg(x_{max.tr}) = \frac{l_2}{h_1} = \frac{0{,}7}{0{,}95} = 0{,}74.$$

Hence the maximum longitudinal stability angle of the MTZ-82 tractor:

$$x_{max} = argtg\ 0{,}74 = 36{,}5°$$

Discussion

Theoretical calculations determined the maximum static climbing angle of the MTZ-82 tractor to be 36.5º. In [16], similar calculations for the MTZ-82 tractor were performed, resulting in a maximum static lift angle of 39.9º. In [15], the calculated maximum static climbing angle was 43.22°. The deviation between the results was 3.4° (9.3 %) in the first case and 6.7° (18.3 %) in the second, which indicates the reliability of the proposed calculation approach.

The maximum static lift angle of the MTZ-82 tractor with the technological module increased to 71.7º, compared to the tractor without the technological module, indicating improved operational stability of the MTA based on the modular energy-technological unit.

For the MTZ-82 tractor equipped with gas cylinder equipment, the maximum static climbing angle was 37.4° with the cylinder cassette mounted on the roof and 42.7° when installed at the front section [16].

When aggregated with various agricultural implements, the maximum static climbing angles of the MTZ-82 tractor were 42° 6′ with the 2PTS-6 trailer, 39°

12′ with the KPD-6 cultivator, 42° 15′ with the PPTS-6 semi-trailer, and 42° 6′ with the PTS-10 semi-trailer [11].

The obtained value of 71.7° achieved through the use of the technological module significantly enhances the longitudinal stability of the mobile energy-technological system, while the agricultural implements coupled with the MTZ-82 tractor have a negligible impact on its longitudinal stability. Moreover, the obtained value exceeds the agrotechnical standard for permissible field surface inclination of 8° [6].

Conclusion

Theoretical calculations of the maximum static lift angle of a tractor equipped with a technological module showed that the use of the technological module allows this figure to be increased to 71.7º.

Therefore, the use of a modular power and technological vehicle enables the full range of technological operations to be performed without compromising safety.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

THE INFLUENCE OF HEAT TREATMENT REGIMES ON THE MECHANICAL PROPERTIES OF UNSATURATED POLYESTER RESIN COMPOSITES REINFORCED WITH FIBERGLASS FOR AGRICULTURAL MACHINERY WORKING PARTS

I.R. Antypas

Abstract

Background. In modern agriculture, enhancing the durability and efficiency of machinery components, such as soil tiller blades, is crucial for improving productivity and sustainability. In this context, the study of advanced materials like glass fiber-reinforced unsaturated polyesters presents a relevant challenge.

Purpose. The aim of this research was to experimentally investigate the possibility of improving the properties of this composite material for the production of agricultural machinery parts.

Materials and Methods. For the study, samples were made from glass fiber-reinforced unsaturated polyester with various proportions of added components. The samples were divided into two groups: one group underwent thermal treatment, while the other remained untreated. Mechanical property testing was conducted using standard tensile tests to determine the values of tensile strength. Observations were also made regarding changes in mechanical properties under prolonged heat exposure.

Results. The results showed that samples with optimized proportions of added components, without direct thermal treatment, exhibited lower tensile strength values compared to samples that underwent thermal treatment. However, with prolonged application of heat over a relatively long period, the strength values began to decrease significantly. This indicates that extended heating leads to increased brittleness of the polyester composition and enhances reactions occurring within the mixture, negatively affecting the strength properties of the material under investigation.

Conclusion. The obtained data indicate a complex relationship between thermal treatment and the strength characteristics of the material. While thermal treatment may initially improve properties, prolonged heat exposure can lead to structural degradation and reduced strength. These results highlight the importance of optimizing technological processes in the production of soil tiller bladeto achieve a balance between enhancing mechanical properties and preventing undesirable changes associated with thermal treatment. Tensile test results showed that proportions approved for the production of glass fiber-reinforced unsaturated polyester soil tiller blade without direct thermal treatment lead to lower tensile strength values compared to thermally treated samples. This suggests incomplete curing of the mixture, resulting in a reduction of the studied mechanical properties. Furthermore, prolonged heat exposure for a relatively long duration (up to 72 hours) caused a significant decrease in tensile strength values. This indicates that prolonged heating enhances the reactions occurring within the mixture, leading to increased brittleness of the polyester composition and adversely affecting its strength characteristics. The study demonstrated that the correct choice of component proportions and thermal treatment regimes is critical for achieving optimal mechanical properties of glass fiber-reinforced unsaturated polyesters. These results could serve as a foundation for further research and development in materials science aimed at creating more efficient and durable materials for use in agricultural machinery.

Keywords: fiberglass reinforced plastic; polyester; soil tiller blade; Thermal treatment; composite material

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Научная статья

ВЛИЯНИЕ РЕЖИМОВ ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА МЕХАНИЧЕСКИЕ СВОЙСТВА ИЗДЕЛИЙ ИЗ НЕНАСЫЩЕННОГО ПОЛИЭФИРНОГО СВЯЗУЮЩЕГО, АРМИРОВАННОГО СТЕКЛОВОЛОКНОМ, ДЛЯ РАБОЧИХ ОРГАНОВ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

И.Р. Антибас

Аннотация

Обоснование. В современном сельском хозяйстве повышение долговечности и эффективности компонентов машин, таких как лопасти почвообрабатывающих фрез, имеет решающее значение для роста производительности и устойчивого развития. В этом контексте исследование перспективных материалов, например, ненасыщенных полиэфиров, армированных стекловолокном, представляет собой актуальную задачу.

Цель. Целью данного исследования было экспериментальное изучение возможности улучшения свойств этого композиционного материала для производства деталей сельскохозяйственных машин.

Материалы и методы. Для исследования были изготовлены образцы из ненасыщенного полиэфира, армированного стекловолокном, с различным соотношением компонентов. Образцы разделили на две группы: одну группу подвергли термической обработке, а другую оставили без обработки. Механические свойства испытывали с помощью стандартных испытаний на растяжение для определения прочности. Также проводили наблюдения за изменением механических свойств при длительном тепловом воздействии.

Результаты. Результаты показали, что образцы с оптимизированным составом, но без термообработки, демонстрировали более низкую прочность при растяжении по сравнению с обработанными образцами. Однако при длительном тепловом воздействии значения прочности начали существенно снижаться. Это указывает на то, что продолжительный нагрев приводит к повышению хрупкости полиэфирной композиции и интенсификации протекающих в ней реакций, что негативно сказывается на прочностных свойствах исследуемого материала.

Заключение. Полученные данные свидетельствуют о сложной взаимосвязи между термообработкой и прочностными характеристиками материала. В то время как кратковременная термическая обработка может улучшать свойства, длительное тепловое воздействие вызывает структурную деградацию и снижение прочности. Эти результаты подчеркивают важность оптимизации технологических процессов при производстве лопастей для достижения баланса между улучшением механических свойств и предотвращением нежелательных изменений, связанных с нагревом. Результаты испытаний на растяжение показали, что выбранный состав для производства лопастей почв фрезы без термообработки приводит к более низкой прочности по сравнению с термообработанными образцами. Это позволяет предположить неполное отверждение смеси, что и вызывает снижение механических свойств. Кроме того, длительное тепловое воздействие (до 72 часов) вызывало значительное падение прочности. Это свидетельствует о том, что продолжительный нагрев усиливает реакции в материале, приводя к повышению хрупкости полиэфирной композиции и ухудшению её прочностных характеристик.

Ключевые слова: стеклопластик; полиэфирная смола; изделия; термическая обработка; композиционный материал

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Introduction

Fiberglass-reinforced plastics (FRP) have found extensive applications in various industries due to their excellent strength-to-weight ratio, corrosion resistance, and ease of processing [1–5]. The mechanical performance in the manufacture of composite soil tiller blade depends on the properties of the polymer matrix, the quality and configuration of the fiber reinforcement, and the curing regime applied during fabrication.

The polymerization and curing of unsaturated polyester (UPR) resins can be effectively controlled through adjustments in the initiator and accelerator ratios, as well as by applying post-curing heat treatment [6; 7]. Previous studies [8; 9] have shown that both material composition and processing temperature have a pronounced influence on tensile strength, stiffness, and brittleness of polyester composites.

Recent investigations [10] confirmed that the incorporation of mineral fillers such as sodium aluminosilicate and talc significantly enhances the stiffness and tensile strength of UPR-based composites. However, comprehensive experimental research on the combined effects of heat-treatment duration and temperature on the mechanical behavior of fiberglass-reinforced UPR remains limited-especially for large structural components such as soil tiller blade.

In recent years, several studies have examined related aspects of post-curing, thermal aging, and heat treatment of polyester and other thermosetting resin composites. For instance, it was shown that bending strength and viscoelastic performance of polyester materials increase notably when post-cured at moderate temperatures (40–60 °C) over controlled exposure durations [11].

Moreover, subsequent investigations [12] demonstrated that moderate post-curing temperatures around 60 °C can improve ductility and tensile strength, whereas excessive thermal exposure tends to reduce elongation and induce brittleness.

Similarly, in [13], the authors reported that prolonged exposure of UPR–glass composites to elevated temperatures (60–150 °C) may initially enhance certain mechanical parameters, but higher temperatures can compromise dimensional stability.

Furthermore, [14] explored the combined effect of chopped glass fibers and TiO_2 nanoparticles, revealing that both heat resistance and tensile strength can be substantially improved through the synergistic action of optimized reinforcement and appropriate curing regimes.

These studies indicate that the temperature, duration, and additives in UPR composites have important and interdependent effects on mechanical properties. However, there remains a gap in identifying the precise curing regimes (initiator %, heat-treatment temperature, time) that optimize tensile strength without leading to brittleness or structural defects in full materials. The **aim** of the work was to determine the optimal content of the MEKP initiator and the subsequent heat treatment regime (temperature, time) to maximize the tensile strength of a fiberglass-reinforced unsaturated polyester-based composite.

Materials and methods

In the experimental study, samples based on unsaturated polyester resin reinforced with (4-6-8) consecutive layers of random glass fibers were prepared using the following materials:

1. Matrix: unsaturated polyester resin, as it is one of the most important thermosetting resins used in fiber-reinforced composite materials (Fig. 1), the main properties of which are presented in Table 1.

Table 1.

Main properties of unsaturated polyester resin

Main properties	Значение	Размерность
Pink viscous liquid		
Viscosity at 30 °C	450-650	Cps
Gelation time at 30 °C with addition of 1.5% MEKP	15-20	минут
Flash point	34	°C
Срок хранения	4	месяцев

Fig. 1. Unsaturated polyester

2. Reinforcement: Random-oriented glass fibers (11.2 g/m²), providing strength, chemical stability, and low density. This type of fiber has found wide application in various technical fields (Fig. 2).

Fig. 2. Glass fiber used

3. Reaction initiator: Methyl ethyl ketone peroxide (MEKP) was used to convert unsaturated polyester, helping to transform it into a solid state. The curing time of the process is controlled by the percentage content of this material. In an experimental study to investigate the influence of percentage content on stress, three different percentages of this material were used (1%, 1.5%, and 2%).

4. Reaction accelerator: A solution of cobalt naphthenate was used to accelerate the process. Accelerators increase the rate of peroxide penetration into free radicals, aiding in controlling the polymerization rate of polyester resins.

5. Mold: An aluminum mold measuring 20 x 20 x 0.5 cm was used for sample fabrication, facilitating the extraction of samples after curing.

2.1 Sample preparation method

The test samples were prepared using a hand lay-up method, which is traditional in composite soil tiller blade manufacturing and is known for its low cost.

In the first step, the mold is prepared and cleaned, removing any dust and dirt [9]. Then, several layers of wax are applied to the inner surface of the mold to prevent materials from sticking to the walls during curing. Next, a layer of unsaturated polyester is manually applied to the inner surface of the mold using a paintbrush. The fibers are trimmed to fully cover the sample. Catalyzed resin is then applied using the brush. This process is repeated using a roller and adding resin as needed until all white areas on the fibrous material disappear and no air bubbles remain. A mohair roller is ideal for achieving uniform resin distribution and removing any remaining air bubbles, while a corrugated plastic or aluminum roller helps effectively eliminate bubbles.

Samples with varying numbers of layers of random glass fiber (4-6-8) were manufactured using the hand lay-up method with different percentages of the initial MEKP material (1%, 1.5%, and 2%). They were then subjected to thermal treatment according to the following system: the samples were placed in an oven at a temperature of 60 °C for different time intervals: 2, 24, 48, and 72 hours.

2.2 Measurement methodology

Tensile test samples with dimensions of 2 x 24 cm were cut from thermally treated plates. The rectangular shape of the samples was chosen due to the lack of a specific geometric form for conducting tensile tests. The rectangular shape of the samples is widely used when working with non-polyester compounds, as the relative deformation of such compounds is minimal. The length of the working part of the sample is not significant, as this allows for the use of samples of varying lengths depending on the testing machine used. Tensile testing of the samples was conducted in accordance with ISO 6259 on a universal testing machine at a speed of 5 mm/min (Fig. 3).

Fig. 3. Tensile testing machine and test samples

Results and discussion

Fig. 4 shows the values of tensile stresses at break in terms of both the number of reinforcing layers and the percentage content of peroxide primer (MEKP). As can be seen, the strength values at break increase with an increase in the number of reinforcing layers. It can also be observed how the added percentage of peroxide affects the results, with the best values obtained by samples containing 1% peroxide. This result is unexpected due to its inconsistency with the recommendations accompanying the original material, which suggest that the optimal peroxide content should be 1.5%.

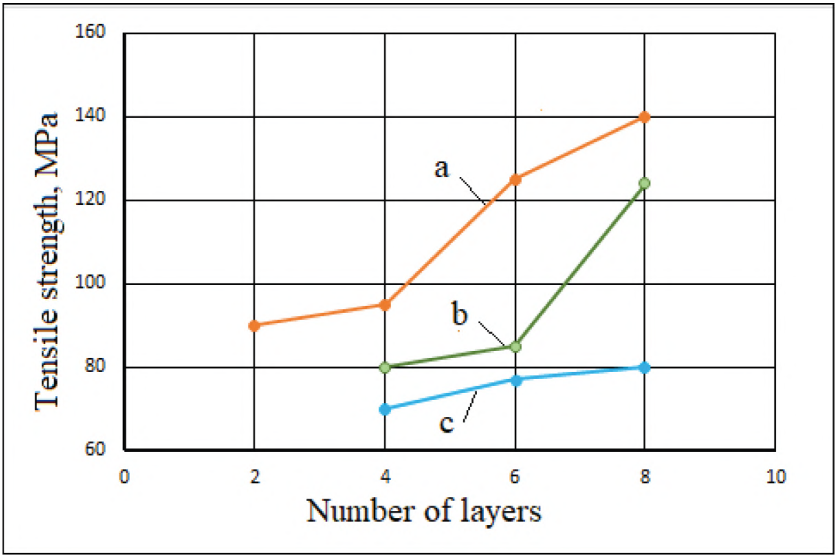

Fig. 4. Tensile stress at break curve variations depending on the number of random glass fiber layers in UPR matrix and catalyst content: a) -1%, b) - 1.5%, c) - 2%

It should be noted that the time period between sample preparation and testing varied, as samples containing 1% peroxide were aged for a longer period (about 4 months) compared to samples containing 1.5% and 2% (approximately 1 month).

This allowed the first samples a better chance of complete curing relatively, which explains why the test results of samples with 1% peroxide content were better than those with 1.5% content. On the other hand, the test results of samples with 2% peroxide content showed a clear and significant decrease in tensile stress values at break. The reason for this is that an excess of peroxide contributes to the formation of shape defects, such as microcracks, which act as stress concentrators in the sample structure, leading to a decrease in tensile stress values at break.

In order to eliminate the influence of time discrepancy on test results, the experiment was repeated in accordance with the manufacturer's recommendations at a 1.5% peroxide content with subsequent heat treatment immediately after production.

Accelerating the polymerization of unsaturated polyester resin mixtures is possible regardless of the proportions of the materials involved by preparing the final product in a thermal environment, as is the case when thermosetting paint materials are used to speed up the curing of car paint layers, a process that is carried out at a temperature of around 60°C. Therefore, this process can be accelerated using the following heat treatment methodology:

1. The heat treatment temperature is set at 60°C, recommended by many studies [4].
2. Heat treatment durations in hours: 2, 24, 48, and 72.

The tensile strength tests conducted on the samples clearly demonstrated the effectiveness of the chosen heat treatment method based on the property under study, and the results presented in Fig. 5 prove its enhancement.

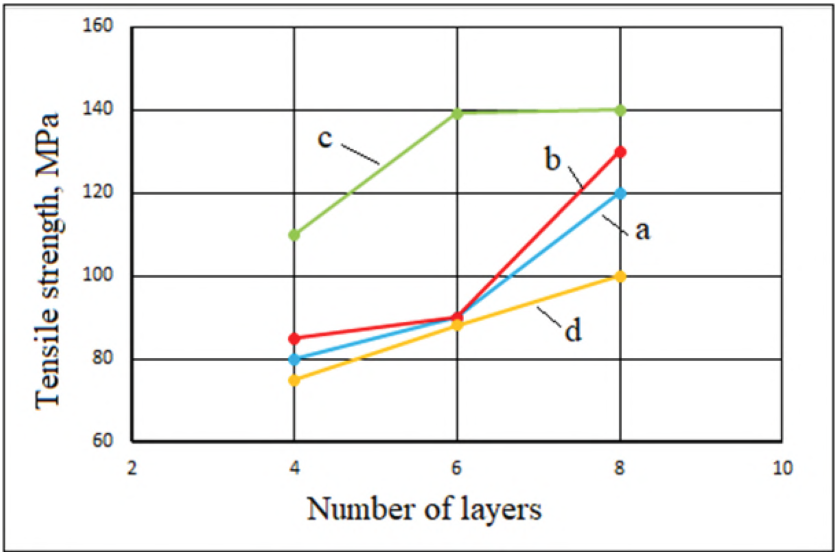

Fig. 5. Change in tensile strength at break of samples made of unsaturated polyester resin reinforced with fiberglass, with a 1.5% initiator content after: a) - 2 hours of heat treatment, b) - after 24 hours of heat treatment, c) - after 48 hours of heat treatment, d) - after 72 hours of heat treatment

In addition, the results of heat treatment showed a significant improvement in tensile strength at break, with the best results obtained after 48 hours of treatment. This indicates incomplete curing of the material at a 1.5% peroxide content and the need for further research to achieve complete curing.

The experimental study demonstrated a clear improvement that can be achieved by heat treating the samples at a temperature of 60°C for 48 hours.

The reason for this is that such a temperature regime promotes the activation of free radical formation in the mixture, as the cold curing process requires more time to complete, and mechanical processing is needed to accelerate it.

However, it cannot be certain that the chosen heat treatment regime ensures complete curing of the product and that the improvement in strength properties obtained from the treatment enhances the structural properties of the unsaturated polyester mixture and makes it more resistant to tensile stress. Finding the most suitable heat treatment regime remains an open field for scientific research, as researchers always strive to find a processing system that provides the best strength performance according to the composition of the mixture used.

Conclusion

1. The curing behavior of unsaturated polyester depends strongly on the initiator and accelerator concentrations, as well as on the thermal regime applied.

2. An initiator content of 1.5 % MEKP combined with post-curing at 60 °C for 48 h yields the highest tensile strength, indicating near-complete polymerization.

3. Excess initiator (2 %) or prolonged heating (72 h) results in microstructural defects and brittleness, reducing mechanical strength.

4. Controlled heat treatment enhances mechanical performance, but over-exposure leads to thermal degradation.

5. Optimizing the curing process is essential for improving the durability and reliability of soil tiller blade made from fiberglass-reinforced unsaturated polyester composites.

Recommendations

* Conduct microstructural (SEM) and DSC analyses to monitor crosslink density and degradation onset.

* Evaluate fatigue and environmental aging to simulate real operating conditions of soil tiller blade s.

* Develop a kinetic model describing the relationship between temperature, initiator content, and mechanical strength.

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Original article

USE OF BIOTECHNOLOGICAL METHODS FOR ACCELERATED IMPROVEMENT OF KALMYK CATTLE

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Abstract

Background. The reduction in the number of some domestic breeds raises concerns among livestock experts. One of the reasons for the reduction in the number of livestock is the lack of purebred bulls, which are able to preserve the breed. Kalmyk breed of cattle is the only ancient aboriginal domestic breed of meat direction. It is kept on year-round pasture keeping, thus on productivity indicators it is not inferior to foreign breeds of meat direction. In this connection preservation and improvement of the gene pool of this breed is important. Kalmyk cattle breed is one of the few indigenous Russian breeds that still possesses unique genetics.

Currently, the breed needs to be restored and protected. In order to increase the number and improve the breed qualities of Kalmyk animals, selection is necessary, which should be based on reliable information about the origin of animals and identification of candidate genes marking productive and reproductive qualities. Restoration and improvement of breed qualities of Kalmyk cattle is possible only under the condition of accelerated reproduction of purebred genotyped stock with the use of biotechnological methods in reproduction. The analysis of complex evaluation of animals showed the variability of live weight of bulls-producers and cows in different periods of growth, from 20, 22 kg at birth to 320, 380 kg at 15 months. Evaluation of the genetic structure of the Kalmyk population for meat productivity genes CAPN1, TG5, GH, revealed a high level of homozygous individuals with desirable genotypes, more than 40%. The average level of heterozygous individuals is 30%. The results obtained on the genetic structure of Kalmyk cattle in the Republic of Kalmykia demonstrate a moderate level of genetic diversity and suggest the possibility of restoring a "pure" gene pool. The selected schemes of hormonal polyovulation for the arid breed revealed a high percentage of fertilization (81%) and 92.3% of donor cows responding with superovulation. On average, 8.8% of embryos were obtained per donor, and 5.5% of them were suitable. Thus, the results of research work on the use of biotechnological methods in reproduction of indigenous breeds confirm the fact of successful approbation and further utilization of genetic potential of highly valuable animals.

Purpose. The aim of the research is to study the way of using biotechnological methods for accelerated improvement of Kalmyk cattle breed.

Materials and methods. As part of the research work conducted at Kalmyk University on the use of biotechnological methods in indigenous animal husbandry, the Kalmyk breed of cattle bred in breeding farms of the Republic of Kalmykia served as an object of research. Animals were annually evaluated for purebredity in a complex way. We have processed and analyzed the data on animals: primary accounting on productivity indicators, genealogical affiliation (data of 33,135 heads, year of birth 2014-2023 were studied). When analyzing the complex evaluation, we relied on the methodology of evaluating the breeding value of beef cattle, approved by the Eurasian Economic Commission, for further implementation of the evaluation of the breeding value of the Kalmyk breed.

Results. Identification of candidate genes associated with qualitative and quantitative indicators of meat were investigated in breeding farms of the Republic of Kalmykia. Population analysis was carried out in steers of Kalmykian breed at the age of 8 months. 1626 heads were studied and live weight of young animals was evaluated. The data on genotypes associated with live weight are shown in the diagram.

Conclusion. Experimental studies conducted on the experimental herd on the use of biotechnological methods in the reproduction of indigenous breeds have shown the fundamental possibility of using reproductive biotechnology in the reproduction of Kalmyk meat breed. During the research work more than 150 pieced with Kalmyk cattle embryos were received and frozen.

Keywords: indigenous breed; variants of selective breeding; domestic livestock breeding; biotechnology in purebred breeding

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Научная статья

ИСПОЛЬЗОВАНИЕ БИОТЕХНОЛОГИЧЕСКИХ МЕТОДОВ ДЛЯ УСКОРЕННОГО СОВЕРШЕНСТВОВАНИЯ КРУПНОГО РОГАТОГО СКОТА КАЛМЫЦКОЙ ПОРОДЫ

Н.В. Чимидова, А.В. Убушиева, З.В. Бочкаева, А.И. Хахлинов, В.С. Убушиева

Аннотация

Обоснование. Сокращение численности некоторых отечественных пород вызывает опасения у экспертов-животноводов. Одной из причин сокращения численности поголовья является нехватка чистокровных быков-производителей, которые способны сохранять породу. Калмыцкая порода крупного рогатого скота – это единственная древнейшая аборигенная отечественная порода мясного направления. Содержится на круглогодичном пастбищном содержании, при этом по показателям продуктивности не уступает зарубежным породам мясного направления. В связи с этим сохранение и улучшение генофонда данной породы важно. Калмыцкая порода КРС одна из немногих коренных российских пород, до сих пор обладающая уникальной генетикой. В настоящее время порода нуждается в восстановлении и защите. Для увеличения численности и совершенствования породных качеств калмыцких животных необходима селекция, которая должна опираться на достоверную информацию о происхождении животных и выявлении кандидатных генов, маркирующих продуктивные и воспроизводственные качества. Восстановление и улучшение породных качеств калмыцкого скота возможно лишь при условии ускоренного размножения чистопородного генотипированного поголовья с использованием биотехнологических методов в воспроизводстве. Анализ комплексной оценки животных показал вариабельность живой массы быков-производителей и коров в разные периоды роста, от 20, 22 кг при рождении до 320, 380 кг в 15 месяцев. Оценка генетической структуры калмыцкой популяции по генам мясной продуктивности CAPN1, TG5, GH, выявила высокий уровень гомозиготных особей с желательными генотипами, более 40%. Средний уровень имеют гетерозиготные особи - 30%. Полученные результаты о генетической структуре калмыцкого скота в Республике Калмыкия демонстрируют умеренный уровень генетического разнообразия и предлагают возможность восстановления «чистого» генофонда. Подобранные схемы гормональной полиовуляции для аридной породы выявили высокий процент оплодотворяемости (81%) и получения 92,3% среагировавших суперовуляцией коров-доноров. В среднем на одного донора получено 8,8% зародышей, пригодные из них оказалось 5,5%. Таким образом, результаты НИР об использовании биотехнологических методов в воспроизводстве аборигенной породы подтверждают факт успешной апробации и дальнейшего использования генетического потенциала высокоценных животных.

Цель. Цель исследования изучить способ использования биотехнологических методов для ускоренного совершенствования крупного рогатого скота калмыцкой породы.

Материалы и методы. В рамках научно-исследовательской работы, проведенной в Калмыцком университете, по использованию биотехнологических методов в аборигенном животноводстве, объектом исследований служила калмыцкая порода КРС, разводимая в племенных хозяйствах Республики Калмыкия. Животные ежегодно комплексно оценивались на чистопородность. Нами были обработаны и проанализированы данные о животных: первичный учёт по показателям продуктивности, генеалогическая принадлежность (исследовано данных 33135 голов, год рождения 2014-2023 гг.). При анализе комплексной оценки опирались на методику оценивания племенной ценности мясного скота, утвержденной Евразийской Экономической Комиссией, для дальнейшего внедрения оценки племенной ценности калмыцкой породы.

Результаты. Определение кандидатных генов, связанные с качественными и количественными показателями мяса, были исследованы в племенных хозяйствах Республики Калмыкия. Популяционный анализ проводился у бычков калмыцкой породы в возрасте 8 месяцев. Было исследовано 1626 голов, а также проведена оценка живой массы молодняка. Данные о генотипах, ассоциированных с живой массой, отображены в диаграмме.

Заключение. Экспериментальные исследования, проведенные на опытном стаде по использованию биотехнологических методов в воспроизводстве аборигенной породы, показали принципиальную возможность применения репродуктивных биотехнологий в воспроизводстве калмыцкой мясной породы. За время проведения научно-исследовательской работы было получено и заморожено более 150 пайет с эмбрионами калмыцкого скота.

Ключевые слова: аборигенная порода; варианты селекционного разведения; отечественное животноводство; биотехнология в чистопородном разведении

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Introduction

The development of specialized beef cattle breeding in the Russian Federation is necessary for the stability and independence of the national market, while it is important to stimulate the production of high-quality and competitive products [1; 2].

Candidate genes of meat productivity in cattle (cattle) play an important role – they determine the potential of animals to fat deposition and meat quality [3; 4]. Research in this area is actively continuing on indigenous breeds, including domestic breeds [5; 6; 7].

Research in the genetics of meat productivity continues to this day, the search for new candidate genes can be revealed as genomic technologies like genomic sequencing and genome association studies are developed [8; 9; 10].

One of the modern reproductive technologies in beef cattle breeding today is embryonic transplantation, which can significantly improve the genetic characteristics of the herd [11; 12; 13].

Specialized beef cattle breeding requires breeds to comply with the following parameters: 1) maternal instinct and pasture instinct, 2) energy cost savings achieved by eliminating and reducing many energy-intensive technological processes, 3) use of cheaper voluminous fodder [14]. Kalmyk breed meets these requirements [14; 15]. Thus, the development of specialized meat cattle breeding based on the Kalmyk breed allows to solve the problem of high-quality beef production and gives the opportunity to provide the meat processing industry with domestic raw materials, thereby increasing the food security of the country [16; 17]. However, despite the unique biological and economically useful qualities of the Kalmyk breed, the current state causes concerns [18]. According to Federal State Budgetary Scientific Institution All-Russian Research Institute of Breeding Business (2024), a significant decrease in the number of animals is observed in the cattle of the oldest domestic Kalmyk breed. Thus, in 2024 the specific weight of this population in the total balance of all meat breeds of the country stopped at the boundary of 33.5% with the number of cattle of 86990 heads, while in the initial year 2010 this indicator was – 49.3% with the number of animals in the amount of 131153 heads [19]. As the data of the International Union for Conservation of Nature show, almost one third of native breeds in Russia have disappeared in recent decades, and about 20% have critical status [20]. Aboriginal domestic breed of meat direction of productivity has truly unique qualities, genetics, and therefore needs to be restored and protected [21; 22; 23]. In connection with the above, the scientists of Kalmyk State University conducted research on accelerated reproduction of the gene pool Kalmyk breed using embryo transplantation biotechnology. In our research we developed methods for superstimulation of polyovulation in the indigenous Kalmyk breed. Eggs of donor cows were fertilized with sperm of highly productive bulls, using artificial insemination, which is also considered as a kind of breakthrough in reproduction of indigenous breeds, which are characterized by their "wildness". These studies serve as an example in increasing the genetic progress of the Kalmyk population. The possibilities of using genetically valuable bulls that may not be available for natural insemination due to pronounced breed characteristics are shown.

Materials and methods

As part of the research work conducted at Kalmyk University on the use of biotechnological methods in indigenous animal husbandry, the Kalmyk breed of cattle bred in breeding farms of the Republic of Kalmykia served as an object of research. Animals were annually evaluated for purebredity in a complex way. We have processed and analyzed the data on animals: primary accounting on productivity indicators, genealogical affiliation (data of 33,135 heads, year of birth 2014-2023 were studied). When analyzing the complex evaluation, we relied on the methodology of evaluating the breeding value of beef cattle, approved by the Eurasian Economic Commission, for further implementation of the evaluation of the breeding value of the Kalmyk breed.

Polymorphism of beef productivity genes CAPN1, TG5, GH was determined by molecular genetic analysis in the genomics laboratory of Kalmyk University according to the defined Scheme.

To determine polymorphisms of candidate genes CAPN1, TG5, and GH, polymerase chain reaction was performed using oligonucleotide primers. Detection was performed in agarose gel.

Commercial reagent kits were used for DNA isolation from biological material of animals (blood): MagnoPrime VET in the amount of 100µl (Fig. 1).

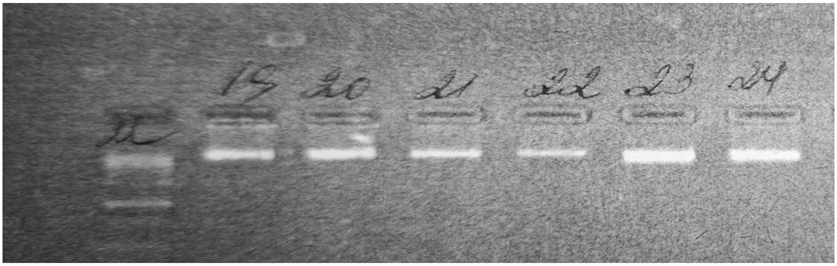

Fig. 1. Example of determination of DNA isolation from blood of Kalmyk animals using MagnoPrime VET reagent kit

The nucleotide sequences were determined using the Sanger method. Before sequencing, PCR products were pre-purified from the reaction mixture using a commercial kit by spin-column method.

Sequencing was performed using capillary electrophoresis of a Nanofor 05 genetic analyzer. Mutation Surveyor software (USA) was used to decipher capillary electrophoresis data.

The methodological basis of the study is based on generally accepted methods of systematization and analysis.

Official materials of yearbooks on breeding work in beef cattle breeding (editions of All-Russian Research Institute of Breeding Business), Federal State Statistics Service of the Russian Federation and analytical reviews of NRA (National Rating Agency) served as the information base.

During experimental researches scientists constantly increased the welfare of experimental animals, observed the norms of their protection in accordance with modern scientifically – substantiated requirements. Maintenance, feeding and veterinary care of animals, scientific purposes were carried out in accordance with the Recommendations of the Board of the Eurasian Economic Commission from November 14, 2023 N 33.

Experiment scheme

Studies on practical application of modern biotechnological methods in Kalmyk cattle were conducted in the period 2022-2024. The animals belonged to breeding farms of the republic: “Budda”, “Plodovitoe”, “Khoshud”, “Kirovsky”, “Agrofirma Uralan”. Ten bulls and 50 breeding stock from each farm were selected by sampling. Kalmyk animals were selected by year of birth, belonging to the same breed and phenotype expression (best meat forms). After that, a donor herd was formed on the basis of the Regional Research and Production Center for Reproduction of Farm Animals of the Federal State Budgetary Educational Institution of Higher Education “Kalmyk State University named after B.B. Gorodovikov”.

Results

The composite score on the average live weight of breeding bulls at different periods of growth and development (at birth, 205 days, 12 and 15 months) was 22.1, (SD – 5.3; Cv – 24.3), 205,3, (SD – 16.3; Cv – 6.7); 320,0 (SD – 24.2; Cv – 6.2); and 379.0 kg (SD – 26.0; Cv – 5.3) (Fig. 2).

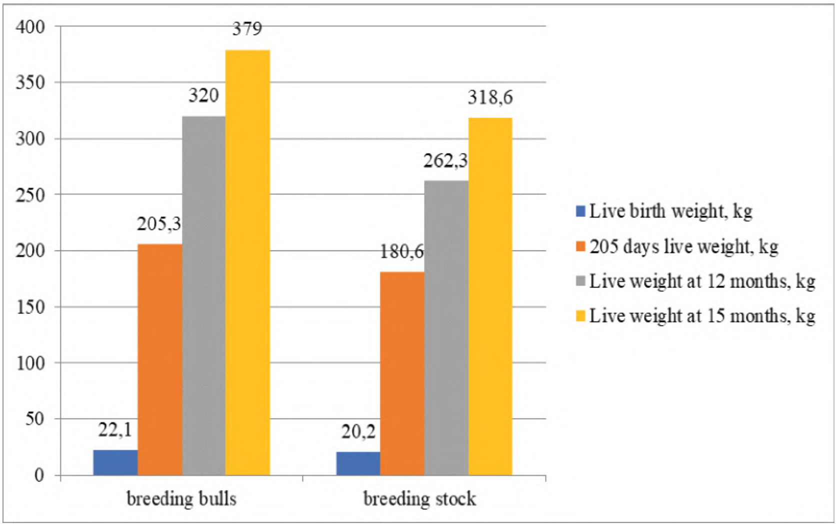

Fig. 2. Monitoring of animal live weight, kg

Results of tracking live weight of cows at different periods of growth and development – 20.2, (SD – 1.6; Cv – 8.0), 180.6, (SD – 14.0; Cv – 7.7), 262.3, (SD – 16.0; Cv – 6.0), 318.6 kg (SD – 15.4; Cv – 4.8) accordinglyThe classiness of the producers is rated as elite and elite-record.

For the first time the population features of the breed bred on the territory of the republic were studied. Identification of candidate genes associated with qualitative and quantitative indicators of meat were investigated in breeding farms of the Republic of Kalmykia. Population analysis was carried out in steers of Kalmykian breed at the age of 8 months. 1626 heads were studied and live weight of young animals was evaluated. The data on genotypes associated with live weight are shown in the diagram (Fig. 3).

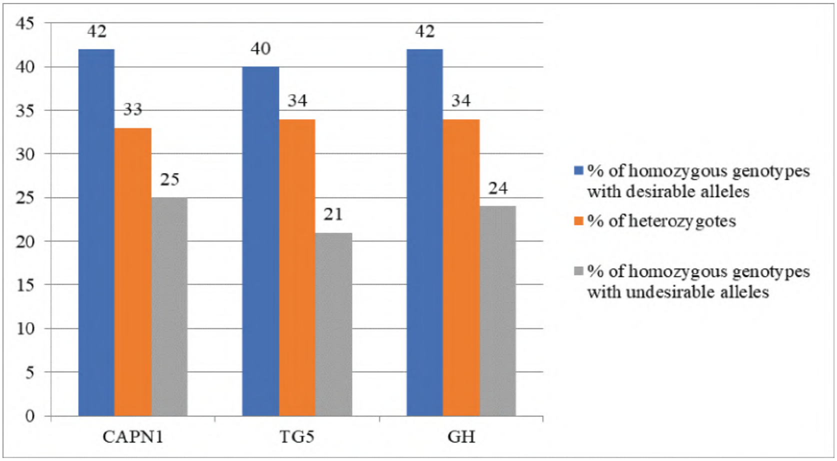

Fig. 3. Monitoring of steer genotypes, %

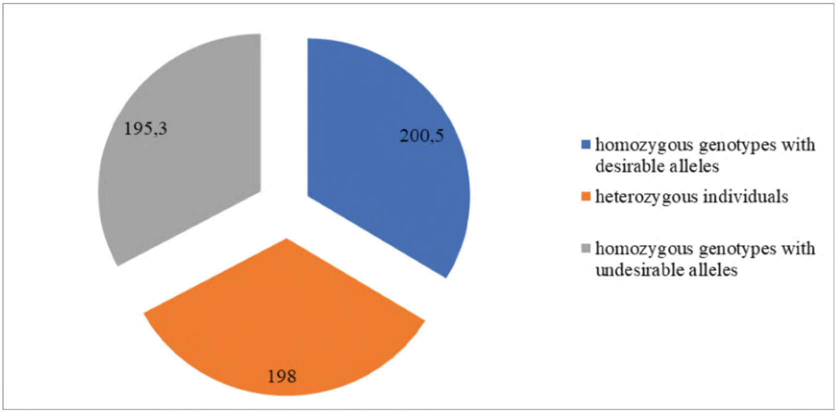

Fig. 4. Differences in live weight of young animals of different genotypes, kg

Evaluation of the genetic structure of the Kalmyk population for the candidate genes of meat productivity CAPN1, TG5, GH, revealed a high level of homozygous individuals with desirable genotypes, more than 40% of them. The average level has heterozygous individuals – more than 30%. The results obtained on the genetic structure of the Kalmyk cattle population in the Republic of Kalmykia demonstrate a moderate level of genetic diversity and suggest the possibility of restoring a "pure" gene pool.

A comparative analysis of the live weight of young Kalmyk cattle by different genotypes was carried out. The data is shown in the diagram (Fig. 4).

At 8 months of age, steers with homozygous genotype carrying desirable alleles outperformed their peers - heterozygotes and homozygotes with undesirable alleles in their genotypes – by 2.5 kg and 5.2 kg, respectively. This study can serve as a confirmation of the influence of the studied genes on the meat productivity of Kalmyk cattle.

The analysis of the obtained results on genotypes and their association with live weight indicates the possibility of improving the breed based on the use of genetic markers in the selection of animals. Kalmyk breed, being the only domestic aboriginal breed of meat direction of productivity, is of great value for breeders. Animals with genotypes CC, TT and VV have high live weight. Consequently, animals with specified genetic complexes should be used to a greater extent in selection and targeted breeding.

Within the framework of research work conducted by scientists from Kalmykia, a scientific experiment on the use of biotechnological methods in the reproduction of indigenous livestock and its approbation was conducted. The Kalmyk breed served as an example in the experiments. From the number of progenotyped animals 10 pedigree purebred cows and 4 bulls – producers of Kalmyk breed were selected as embryo donors according to the indicators of meat productivity taking into account the origin. The animals formed the core of the donor "elite" herd on the basis of the University.

As it is known, in the technology of embryo production the problem of obtaining stable results of polyovulation is especially acute. The existing generally accepted scheme of polyovulation stimulation for indigenous breeds is labor-intensive and often impossible. This problem was solved by the developed scheme of prolongation of follicle-stimulating hormone (FSH) action with the help of polyvinyl alcohol. According to the stimulation scheme, the number of injections was reduced to 3 instead of the generally accepted 8.

In the experiment on implementation of embryo transplantation biotechnology methods in application to Kalmyk breed, 3 donor cows with established sexual cycle were used. Injections were administered subcutaneously in the area of the scapula on days 9, 10 and 11 of the sexual cycle, observing an interval of 24 hours. Total FSH was injected in a total dose of 50 units. On the 11th day of the cycle, prostaglandin "estrophan" was injected intramuscularly in a dose of 500 mcg.

Artificial insemination of donor cows was performed with freshly obtained chilled semen, 3 cows were inseminated twice, the interval was 60 hours and 72 hours after estrophan administration.

Polyovulation was established by rectal examination in all 3 donors, which allowed for embryo retrieval.

The procedure was performed in a standardized manner – a non-surgical method was used. A rubber Folley catheter with an air bubble-fixer was used in uterine horn washing. Dulbecco's medium consisted of gentamicin (300 ml volume) and bovine serum albumin (300 ml volume).

A total of 23 embryos and oocytes were obtained from donor cows. By evaluating the quality, 10 excellent and good embryos were identified (Fig. 5). Thus, the yield of quality embryos of Kalmykian breed was 3.3 on average per donor, summarizing, a positive result was obtained, which indicates the possibility of using biotechnological methods of reproduction of Kalmykian breed of cattle.

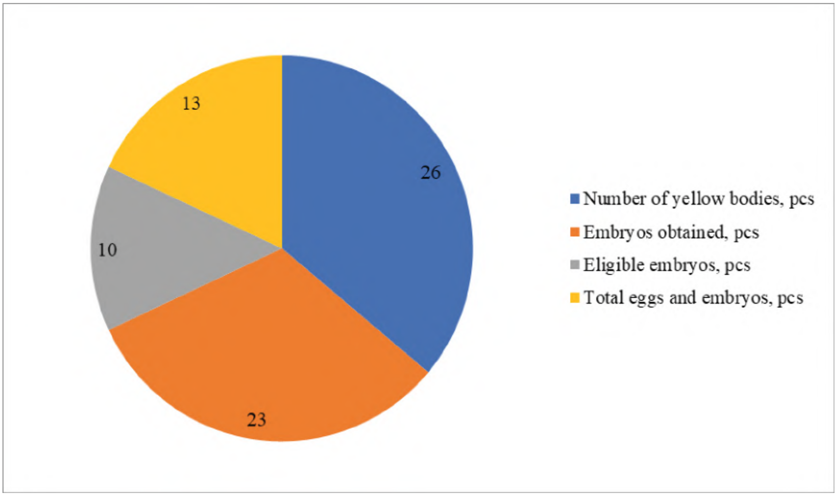

Fig. 5. Results on the use of biotechnological methods 1 stage

In this experiment, excellent and good embryos in the morula-blastocyst stage of development were cryopreserved for later transplantation.

The second stage of research work on the introduction of biotechnological methods of reproduction in the Kalmyk breed was the development of polyovulation induction. The improved scheme of hormonal treatment consisted in a single injection of a prolonged form of FSH-p in a dose of 50 units of Armorov standard with an additional injection of 500 IU of follimag.

According to the developed scheme, hormonal polyovulation was carried out, which was induced 13 times in 10 donor cows of the donor herd. Donor cows were stimulated with prostaglandin F2α "Estrophan" and then inseminated with fresh chilled semen of breeding bulls – producers carrying desirable alleles in their genotypes. The results of stimulation of donor cows are presented in Fig. 6.

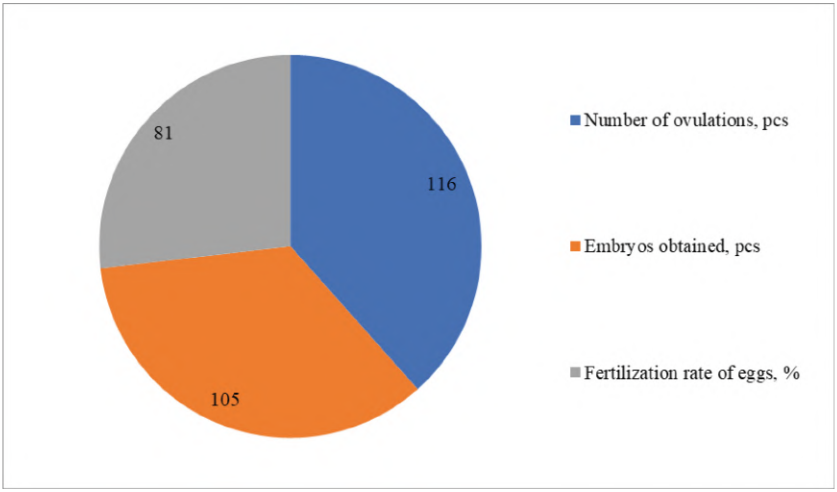

Fig. 6. Results on the use of biotechnological methods Stage 2

The experiment on approbation of the new prolonged FSH action scheme proved to be effective and the yield of quality embryos was significantly increased.

Conclusion

The search for marker genes associated with qualitative and quantitative production indicators in Kalmyk cattle revealed different frequencies of genotypes. The frequency of animals with desirable alleles is relatively high, more than 40% in the study population. There is a high rate of heterozygous individuals, their frequency was equal to 30%. These results can speak about the probability of obtaining desirable genotypes under the condition of selection of animals with given complexes. Monitoring of live weight of steers of different genotypes, determined differences in the results obtained, the difference was 2.5 kg and 5.2 kg. These studies confirm that CAPN1, TG5, GH genes are associated with meat productivity in Kalmyk cattle breed.

Experimental studies conducted on the experimental herd on the use of biotechnological methods in the reproduction of indigenous breeds have shown the fundamental possibility of using reproductive biotechnology in the reproduction of Kalmyk meat breed. During the research work more than 150 pieced with Kalmyk cattle embryos were received and frozen.

Thus, the results of research work on introduction of biotechnological methods in reproduction of indigenous breed, confirm the fact of successful utilization of genetic potential of highly valuable animals. Two variants of selective breeding of the domestic meat breed – Kalmyk cattle, considered and tested by us, proved to be effective in increasing the productivity of cattle and accelerating its reproduction.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Научная статья

ЭКОЛОГО-БИОЛОГИЧЕСКИЕ ОСОБЕННОСТИ ВИДОВ РОДА ACER L., ПРОИЗРАСТАЮЩИХ ВДОЛЬ АВТОМАГИСТРАЛЕЙ

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Аннотация

Обоснование. На современном этапе развития городов Донбасса особую остроту приобрела проблема экологического состояния окружающей среды и оценки устойчивости экосистем, усугубляемая воздействием новых антропогенных и техногенных факторов. Одной из приоритетных задач региона является подбор видов и научное обоснование списка основных лесообразующих видов Донбасса.

Цель. Цель данного исследования заключается в оценке экологических и биологических свойств видов рода *Acer* L., произрастающих в условиях изменяющегося климата Донбасса и антропогенной нагрузки.

Материалы и методы. Полевые исследования и сбор материала осуществляли в период с 2023 по 2025 г. вдоль автомагистралей города Донецка и парковых зонах. В ходе исследования были оценены деревья шести видов рода *Acer* L. в условиях степной зоны Донбасса: *Acer campestre* L., *Acer negundo* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Acer saccharinum* L., *Acer tataricum* L. Жизнеспособность деревьев оценивали с помощью интегральной шкалы Алексеева. Для оценки прочности и механической устойчивости древесных растений, произрастающих в условиях урбанизированного города, использовали следующие параметры: сопротивление изгибу, предельно допустимая нагрузка и масса, относительное сопротивление изгибу.

Результаты. В результате проведенных исследований описаны эколого-биологические свойства шести видов рода *Acer* L. Определена жизнеспособность, морфометрические параметры и возрастная структура насаждений *Acer* L. С позиций биомеханики живых систем виды с более высокой плотностью древесины и эластичностью волокон *A. campestre* и *A. platanoides*, демонстрируют повышенную устойчивость к механическим повреждениям, что позволяет им выдерживать экстремальные погодные явления и сохранять свою структуру в условиях техногенного воздействия. Для растений *A. negundo* с позиций анатомических особенностей древесины и физико-механических свойств тканей в условиях городской среды уже после 35 лет происходит снижение механической устойчивости на ~60 %, что отражается на аварийности таких деревьев. *A. tataricum* сохраняет стабильные физико-механические характеристики как в условиях контроля, так и на территориях, подверженных антропогенному воздействию. Это обстоятельство указывает на потенциальную целесообразность его применения в проектах озеленения. Однако, учитывая его агрессивность, рекомендуется не масштабное, а выборочное использование, например, для формирования живых изгородей или аллейных посадок.

Заключение. Полученные результаты могут быть использованы для разработки стратегий озеленения городов с учетом устойчивости и адаптивности различных видов рода *Acer* L. Это позволит создать более устойчивые и функциональные городские экосистемы в условиях изменяющегося климата, а также способные выдерживать действие антропогенных факторов и обеспечивать благоприятные условия для жизни человека и животных.

Ключевые слова: *Acer* L.; экологические факторы; биомеханика живых систем; механическая устойчивость растений; адаптации; Донбасс

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Original article

ECOLOGICAL AND BIOLOGICAL FEATURES OF SPECIES OF THE GENUS ACER L. GROWING ALONG THE HIGHWAYS

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Abstract

Background. At the present stage of urban development in Donbass, the problem of the ecological state of the environment and the assessment of ecosystem sustainability has become particularly acute, aggravated by the impact of new anthropogenic and manmade factors. One of the priority tasks of the region is the selection of species and the scientific substantiation of the list of the main forest-forming species of Donbass.

Purpose. The purpose of this study is to evaluate the ecological and biological properties of species of the genus *Acer L.*, growing in the changing climate of Donbass and anthropogenic stress.

Materials and methods. Field research and material collection were carried out in the period from 2023 to 2025 along the highways of Donetsk city and park areas. During the study, trees of six species of the genus Acer L. were evaluated. in the conditions of the steppe zone of Donbass: *Acer campestre L., Acer negundo L., Acer platanoides L., Acer pseudoplatanus L., Acer saccharinum L., Acer tataricum L*. The viability of the trees was assessed using the Alekseev integral scale. To assess the strength and mechanical stability of woody plants growing in an urbanized city, the following parameters were used: bending resistance, maximum permissible load and weight, relative bending resistance.

Results. As a result of the conducted research, the ecological and biological properties of six species of the genus *Acer L*. are described. The viability, morphometric parameters, and age structure of Acer L. plantings have been determined. From the standpoint of biomechanics of living systems, species with higher wood density and fiber elasticity, *A. campestre* and *A. platanoides*, demonstrate increased resistance to mechanical damage, which allows them to withstand extreme weather events and maintain their structure in conditions of anthropogenic impact. For plants *A. negundo*, from the standpoint of the anatomical features of wood and the physico-mechanical properties of tissues in an urban environment, after 35 years, mechanical stability decreases by ~60%, which affects the accident rate of such trees. *A. tataricum* retains stable physico-mechanical characteristics both under control conditions and in areas exposed to anthropogenic influences. This fact indicates the potential expediency of its use in landscaping projects. However, given its aggressiveness, selective rather than large-scale use is recommended, for example, for the formation of hedges or alley plantings.

Conclusion. The results obtained can be used to develop urban greening strategies, taking into account the sustainability and adaptability of various species of the genus *Acer L*. This will create more stable and functional urban ecosystems in a changing climate, as well as capable of withstanding anthropogenic factors and providing favorable conditions for human and animal life.

Keywords: *Acer* L.; ecological factors; biomechanics of living systems; mechanical stability of plants; adaptations; Donbass

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Введение

На современном этапе развития городов Донбасса особую остроту приобрела проблема экологического состояния окружающей среды и оценки устойчивости экосистем, усугубляемая воздействием новых антропогенных и техногенных факторов [1-16]. Решение этой многоаспектной задачи требует консолидированных усилий Правительства Донецкой Народной Республики, соответствующих министерств и ведомств, Российской академии наук, ведущих высших учебных заведений и научно-исследовательских институтов региона, направленных на разработку и внедрение эффективных стратегий экологической реабилитации и устойчивого развития.

Министерство природных ресурсов и экологии Донецкой Народной Республики в сфере охраны окружающей среды и лесного хозяйства определило перечень первоочередных экологических проблем и задач, требующих незамедлительного решения в 2025 году и на ближайшую пятилетнюю перспективу:

– подбор пород и научное обоснование списка основных лесообразующих пород для Донецкой Народной Республики;

– исследование причин массового усыхания хвойных пород на территории Донецкой Народной Республики и разработка эффективных мер для предотвращения данного процесса;

– комплексные обследования и оценка текущего состояния особо охраняемых природных территорий;

– состояние флоры, фауны и ландшафтов Донбасса;

– разработка первоочередных мер по обеспечению сохранности природных комплексов особо охраняемых природных территорий ДНР;

– подготовка перечня инвазивных видов растений и животных, представляющих угрозу для особо охраняемых природных территорий ДНР. Разработка первоочередных мер по борьбе с данными видами.

Поставленные задачи только подтверждают актуальность настоящих исследований по оценке флоры Донбасса, адаптивных способностях древесных растений в условиях изменяющегося климата, новых антропогенных и техногенных факторов.

В условиях Донбасса, где экологическое равновесие подвержено постоянным испытаниям, механическая устойчивость древесных растений приобретает особое значение, дополняя классические эколого-биологические характеристики [2, 5, 7, 11, 13, 14, 17-23]. Принципы биомеханики становятся незаменимым инструментом при определении предельных нагрузок, которые способны выдержать скелетные ветви и стволы деревьев [2, 11, 13, 22, 23].

Устойчивость растений к механическим повреждениям определяется целым рядом взаимосвязанных факторов [2, 5, 7, 11, 20, 22, 23]:

– Направление нагрузки: в условиях современного Донецка, где нарушение целостности дендроценозов привело к формированию новых ветровых коридоров, учет направления нагрузки становится особенно актуальным. Возникновение этих «ветровых окон» изменяет привычные векторы воздействия на древесные насаждения.

– Физико-механические свойства древесины: модуль упругости (MOE), предел прочности при изгибе (MOR) и плотность древесины (ρ) являются ключевыми показателями, определяющими способность дерева сопротивляться деформации и разрушению.

– Влажность древесины: содержание влаги в древесине (MC, %) оказывает существенное влияние на ее механические свойства.

– Возраст растений: с возрастом структура древесины претерпевает изменения, что, в свою очередь, сказывается на ее механической устойчивости.

– Условия произрастания: факторы окружающей среды, включая уровень антропогенной нагрузки, оказывают непосредственное воздействие на развитие и механические свойства древесных растений.

Видоспецифичность биомеханических свойств растений обуславливает необходимость углубленных исследований для выявления наиболее адаптированных видов, способных не только выдерживать специфические нагрузки городской среды, но и демонстрировать устойчивость к ее неблагоприятным факторам. Учитывая ограниченность научных данных, преимущественно сосредоточенных на технической древесине или живых деревьях в узколокализованных ареалах, экстраполяция этих значений на городские насаждения сопряжена с риском значительных погрешностей. Чувствительность физико-механических параметров древесины к условиям произрастания и экологическим факторам требует осторожного подхода к оценке механической устойчивости городских деревьев [2, 5, 7, 11, 13]. В условиях антропогенного загрязнения и под воздействием природно-климатических факторов влияние биомеханики тканей древесных растений на формирование устойчивых насаждений остается областью, требующей дальнейшего изучения.

В контексте изменяющегося климата Донбасса и высокого уровня техногенной нагрузки комплексная оценка экосистем и их компонентов представляет собой сложную задачу. Изменения физических и механических характеристик древесных растений являются адаптивной реакцией на экологические факторы [24], включая повреждения, наносимые паразитами и травоядными животными [25]. Следовательно, жизнеспособность древесных растений в условиях антропогенного загрязнения во многом определяется физико-механическими свойствами их тканей, подвергающимися интенсивному давлению естественного отбора [25]. Механические свойства древесины играют определяющую роль в выполнении экологических функций деревьев в городской среде [5, 7, 22, 23, 26-30].

The aim of the work is to present the ecological and biological characteristics of species of the genus *Acer L.* under anthropogenic load.

Материалы и методы

Предмет исследования. В ходе проведения мониторинговых исследований комплексно проанализировали шести видов рода *Acer* L.: *Acer campestre* L., *Acer negundo* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Acer saccharinum* L., *Acer tataricum* L. Общее количество растений, произрастающих на территории с повышенным уровнем антропогенной нагрузки, составило 1798 ед., на контрольной территории была сформирована группа из 300 деревьев.

Область исследования. Полевые исследования и сбор материала осуществляли в период с 2023 по 2025 г. вдоль автомагистралей города Донецка (Fig. 1, позиция 1-5). Дополнительно были изучены растения, произрастающие в условиях относительного контроля на территории Донецкого ботанического сада (северный и южный массивы), а также парковых зон (центральный парк культуры и отдыха имени А.С. Щербакова, парк культуры и отдыха имени Ленинского комсомола, бульвар Пушкина, парк кованых фигур) (Рис. 1, позиция 6 и 7). Дальнейшую камеральную обработку первичного материала и анализ данных осуществляли на базе научно-исследовательской лаборатории мониторинга и прогнозирования экосистем Донбасса.

Рис. 1. Область исследований *Acer L.,* произрастающего вдоль автомобильных дорог города Донецка (1-5) и растущего в контрольных условиях (6-7).

Обозначения: 1 – ул. Скорса; 2 – ул. Артема; 3 – пр. Ватутина; 4 – ул. Университетская; 5 – пр. Ильича; 6 – Парк культуры и отдыха имени Ленинского комсомола; 7 – Парк культуры и отдыха имени Щербакова.

Анализ антропогенной нагрузки на исследуемую территорию. Интенсивность движения транспортных средств на исследуемых участках оценивалась путем подсчета количества точек измерения, проходимых конкретными типами транспортных средств за единицу времени (ГОСТ 20444-85 «Шум»).

Уровни шума измерялись с помощью портативного шумомера Benetech (точность ±1 дБА). Оценка нормирования уровней зашумления вдоль автомагистралей проводилась по SP 51.13330.2011: Noise Protection (Updated SNiP 23-03-2003), согласно которому уровень звука в течение дня не должен превышать 55 дБА (в дневное время), а максимальный уровень звука не более 70 дБА.

Дендрологические исследования. Оценку жизнеспособности проводили с использованием интегрированной шкалы Алексеева с модификациями для оценки повреждений ствола и кроны [31]: 1 балл – здоровое растение; 2 – ослабленное; 3 – сильно ослабленное; 4 – отмирающее; 5 – сухостой. При этом учитывали состояние кроны (оценка листового аппарата, формы, плотности, механических повреждений, общей архитектоники), состояние ствола (оценка повреждений и дефектов, поражений различными заболеваниями и вредителями).

Данные визуального осмотра изучаемых деревьев были задокументированы с помощью камеры Nikon Coolpix S2600 (Япония). Последующая офисная обработка и анализ изображений были выполнены в программном обеспечении AxioVision Rel. 4.8 с эталонным масштабированием. Было проанализировано более 1700 цифровых изображений для изучения архитектуры кроны и дефектов ствола. Диаметр ствола измеряли с помощью штангенциркуля Haglöf Mantax (Швеция).

Биомеханические методы исследования. Для оценки прочности и механической устойчивости древесных растений, произрастающих в условиях урбанизированного города, использовали следующие параметры:

P_{cr} и m_{cr} – предельно допустимая нагрузка и масса, при действии которой происходит необратимая деформация скелетной ветви или ствола, начало разрыва (микроразрывы) тканей и даже облом скелетной ветви или ствола растения [32, 33]:

$$P_{cr} = \frac{\pi^2 EI}{2l^2}, \quad (1),$$

$$m_{cr} = \frac{P_{cr}}{g}, \quad (2),$$

где I – момент инерции сечения, l – длина ствола или скелетной ветви, g – ускорение силы тяжести.

RRB –относительное сопротивление изгибу [33]:

$$RRB = \frac{r^2 E}{4\rho}, \quad (3),$$

где, r – радиус основания ствола или скелетной ветви, E – модуль упругости тканей древесины, ρ – плотность древесины.

В частности, способность сопротивляться изгибу определяется как произведение модуля упругости (E) и второго момента сечения (I) ствола (5). [34]:

$$\text{Сопротивление изгибу} = E \cdot I \quad (4),$$

где, $I = \dfrac{\pi D^4}{4}$, (5); d – диаметр ствола или скелетной ветви.

Модуль упругости (модуль Юнга) определяли по величине изгиба цилиндра обрезанной ветви, горизонтально защемлённой в тисках, в ответ на приложение силы на её свободном конце по формуле [32]:

$$E = \frac{64Cl^3}{3\pi d^4} \quad (6),$$

где C – жёсткость цилиндра, l – его длина, d – диаметр.

Жёсткость защемлённого одним концом цилиндра рассчитывали как:

$$C = \frac{m \cdot g}{x} \quad (7).$$

где m – масса приложенного груза, g – ускорение силы тяжести, x – смещение свободного конца цилиндра.

Погрешность измерения модуля упругости для различных образцов варьировала от ~5 до ~12% от измеренного значения.

The Microsoft® Excel® LTSC MSO (version 2505, Assembling 16.0.18827.20102) (Microsoft Corporation) был использован для статистической обработки данных. Зависимость критической массы (mcr), сопротивления изгибу (EI) и RRB от коэффициента d/l и диаметра ствола для исследуемых растений была установлена с использованием степенной регрессионной модели.

Результаты исследования

Результаты анализа антропогенной нагрузки на исследуемую территорию. Результаты оценки антропогенной нагрузки на пробных площадях представлены в таблице 1-2. Интенсивность транспортного потока отражает высокий (ул. Артема, пр. Ильича, ул. Университетская) и средний (пр. Ватутина, ул. Щорса) уровень нагрузки на зелёные насаждения, произрастающие вдоль автомагистралей. В среднем, на всех изученных участках, преобладающим видом транспорта являются легковые автомобили. Доля иностранных авто составляет около 70 %. На долю легковых внедорожников приходится до 15%. На долю транспорта, вызывающего критическое зашумление территории (~90 дБА) приходится до 7 %.

Таблица 1.

Средние значения интенсивности транспортного потока в будние дни вдоль центральных автомагистралей г. Донецка

№	Вид транспорта				Итого, ед./час*
	Грузовой*		Пассажирский*		
	Легкий	Тяжелый	Легковой	Автобусы	
1	7±2	10±1	625±71	0	642±74
2	15±3	5±2	1209±225	12	1241±242
3	17±6	38±14	409±34	0	465±54
4	70±31	18±14	1140±599	92±8	1330±686
5	77±5	17±9	1268±87	63±5	1424±60

Примечания: 1 – ул, Скорса.; 2 – ул. Артема; 3 – пр. Ватутина; 4 – ул. Университетская.; 5 – пр. Ильича; * стандартное отклонение зависело от квартала (участка) и особенностей проезда на территории.

Анализ нормирования шума на участках показал значительные превышения, как по эквивалентному значению, так и по максимумам (Таблица 2).

Таблица 2.

Вибрационно-акустическое зашумление в будние дни вдоль центральных автомагистралей г. Донецка

Номер	max	min	Среднее значение ± SD
1	81,7±3	61,6±2	73,7±2
2	88,9±6	69,4±3	80,7±2
3	78,8±1	62,8±2	72,5±3
4	87,1±3	58,4±3	75,5±3
5	85,4±3	68,8±1	77,1±4

Примечания: 1 – ул, Скорса.; 2 – ул. Артема; 3 – пр. Ватутина; 4 – ул. Университетская.; 5 – пр. Ильича.

В среднем на участках с высокой интенсивностью движения зашумление по эквивалентному значению превысило 40%, по максимумам 24,5%, а для территорий со средней загруженностью транспортными средствами эквивалентное значение шума было превышено на 31-34%, по максимумам превышение составило в среднем не более 14 %.

Эколого-биологическое описание объектов исследования. *Acer campestre* L. – вид аборигенной флоры Донбасса [35]. Представленность в современном городе Донецке низкая, в совокупности с *A. saccharinum* и *A. tataricum* в обследованных насаждениях составила менее 1%. Если взять более широкую территорию Донбасса, вид чаще встречается в зеленых насаждениях Макеевки, Харцызска, Красноармейска, Славянска, Авдеевки и др. [36]. Снижение жизнеспособности наблюдается после 45-50 лет, что является отличным показателем для урбанизированных территорий. *Acer negundo* L. – клён ясенелистный одним из первых использовался в озеленении Юзовки, эти следы до сих пор присутствуют в зелёных насаждениях современного города. Представленность *A. negundo* составляет около 3 % от общего количества древесных пород [37, 38]. Расценивается как агрессивный, инвазивный вид-трансформер, представляющий угрозу аборигенным растительным сообществам. В условиях Донбасса старение и ухудшение жизнеспособности деревьев клена ясенелистного наблюдается после 30-35 лет. Плотность тканей снижается (в том числе из-за дендрофильных насекомых), древесина становится рыхлой, что отражается на аварийности деревьев и не редко в Донецке наблюдается выпадение растений данного вида после ветровалов, снежных и ледяных бурь. Особенно опасными считаются температурные флуктуации внутри сезона вследствие изменения климата в регионе. *Acer platanoides* L. – входит в состав аборигенной фракции местной флоры [39]. Репрезентативность в насаждениях составила ~9 %. Относительно устойчив к комплексному воздействию транспортного потока как основного источника антропогенной нагрузки в возрасте 30 лет и более. Молодые саженцы, произрастающие вдоль центральных автомагистралей, испытывают серьёзный антропопрессинг и по результатам биоиндикационных исследований находятся в стрессе (ул. Университетская (особенно район АВ «Южный»), пр. Ильича (особенно территория Макеевского шоссе), ул. Артема (стадион «Олимпийский»)). Вид в целом пригоден для посадки в первом ряду вдоль автомагистралей, однако перспективнее его использовать во втором ряду при удалении на 4-5 метров от источника загрязнения, а также при формировании лесозащитных полос. Декоративен в течение всего периода вегетации. В условиях ветровалов и зимних природных аномалий (снежные и ледяные бури) Донецка, вид устойчив к действию механических нагрузок. *Acer pseudoplatanus* L.– один из наиболее многочисленных видов в зелёных насаждениях Донецка, его представленность составляет чуть более 6 % в дендроценозах центральных автомагистралей города и около 2% от всех видов древесных растений Донецка. При недостатке влаги и механических повреждениях снижаются прочность древесины и механическая устойчивость дерева, в связи, с чем растения требуют регулярной обрезки сухих и поврежденных побегов. Высокие температуры могут отражаться на физиологическом состоянии растений (некроз и преждевременное опадание листьев, усыхание отдельных побегов), особенно в летний период для растений 1 ряда вдоль автомагистралей. *Acer saccharinum* L. – в насаждениях современного Донецка составляет около 0,3% от всех видов древесных растений. С позиций биомеханики вид является среднеустойчивым в условиях сухой степи, т.к. в нем сочетаются древесина с низкими значениями физико-механический свойств тканей (E, ρ) и высокими морфометрическими показателями ствола и кроны (Рис. A, B, D). При достижении критического возраста в условиях города Донецка становится аварийным, а с учетом повреждения древесины вредителями, часто выпадает даже при незначительных ветровалах (Рис. 2 B-D).

Рис. 2. Состояние старовозрастных деревьев Acer saccharinum L. в Донецке. Обозначения: А – старовозрастной экземпляр (73-75 лет) в парке кованых фигур; В-С – выпавшее старовозрастное дерево достигшее критического возраста на бул. Пушкина; D – спил с текстурой тканей растения из ксилотеки научно-исследовательской лаборатории мониторинга и прогнозирования экосистем Донбасса (ДонГУ).

Acer tataricum L. – вид аборигенной флоры Донбасса. В условиях города это дерево до 7 метров высотой с густой кроной. Выдерживает морозы и весенние перепады температуры характерные в условиях изменяющегося климата, декоративен, засухоустойчив, что особенно ценно в сухой степи Донбасса, устойчив к промышленным выбросам.

По результатам экоморфного анализа *A. negundo* по отношению к свету является Heliosciophytes, виды *A. campestre, A. platanoides, A. pseudoplatanus* и *A. tataricum* – Sciophytes, а вид *A. saccharinum* – Heliophytes [36]. Что важно в понимании устойчивости экосистем (или конкретных дендроценозов, состоящих из данных видов) в условиях Донбасса.

Дендрологические исследования. По результатам полевых исследований и дальнейшей камеральной обработки данных провели обобщение средних дендрометрических показателей *Acer* L. (Таблица 3). Установили, что диаметр ствола у основания достоверно ($p<0.05$) был выше на территории с высокой антропогенной нагрузкой на 11 % для *Acer campestre* L. и на 26 % для *A. pseudoplatanus*. В условиях относительного контроля деревья *A. saccarinum* значительно (на 70% по высоте и в 3 раза по диаметру) превосходят в размерах растения, произрастающие под влиянием антропогенной нагрузки. Для аборигенного вида *A. tataricum* превышение морфометрических параметров составляло 50% (высота) и 24 % (диаметр основания).

Возрастная структура насаждений *Acer* L. неравномерна по всему городу, в том числе и на выбранных модельных территориях. Например, при создании парка имени А.С. Щербакова в первые годы для массового озеленения территории степи использовали виды *Acer* L. и *Robinia* L., а уже с 50-х годов при озеленении автомагистралей Донецка чаще использовали виды рода *Populus* L. [22]. В Донецком ботаническом саду произрастают растения как под контролем сотрудников сада (северный массив) с учетом омоложения коллекций, так и исторически сложившиеся коллекции (без ухода, произрастают в естетсвенных условиях степной зоны) на территории дендрария (южный массив). Оценивая спелые насаждения, ценные с точки зрения экологической безопасности региона, можно сделать вывод о доминировании аборигенных видов *Acer campestre* L., *Acer platanoides* L. и *Acer tataricum* L. с точки зрения жизнеспособности. Растения себя отлично чувствуют в дендроценозах парков и относительного контроля, но также и в условиях антропогенного загрязнения.

С позиции экологии интересен вид *A. saccarinum*. Он единственный из видов рода *Acer* L. представлен в перечне выдающихся видов Донецка (возраст, размеры, состояние). Однако он и несет наибольшую опасность в условиях изменяющегося климата (участившиеся ветровалы, пылевые бури, перепады температуры внутри сезона и т.д.). Растение имеет значительные размеры: до

25 метров в высоты с диаметром около 60 см. При дополнительном уходе, такие растения являются украшением дендрофлоры города, однако всё чаще при повреждении тканей вредителями становятся аварийными и падают в условиях высокой рекреационной нагрузки (например, бульвары, парки).

Таблица 3.

Лесоводственно таксационная характеристика спелых насаждений Acer L. в возрасте 40-60 лет в городе Донецке

Вид	Высота ± SD, ь	D_{base}± SD, ь	% от выборки	Оценка жизнеспособности дерева ± SD
В условиях антропогенного загрязнения				
Acer campestre L.	12,0±1,0	0,35±0,05	54	2±1
Acer negundo L.	14±2,8	0,39±0,13	40	4±1
Acer platanoides L.	15,0±3,1	0,27±0,11	39	2±1
Acer pseudoplatanus L.	13,3±4,0	0,35±0,04	13	3±1
Acer saccarinum L.	13,8±1,2	0,17±0,02	41	3±1
Acer tataricum L.	3,0±0,5	0,17±0,05	2	2±1
В условиях относительного контроля				
Acer campestre L.	11±1,1	0,31±0,03	38	2±1
Acer negundo L.	14,4±0,9	0,41±0,07	16	3±1
Acer platanoides L.	21,9±1,3	0,28±0,05	21	2±1
Acer pseudoplatanus L.	12,9±0,6	0,26±0,02	11	2±1
*Acer sacca*rinum L.	23,5±1,5	0,59±0,15	51	3±1
Acer tataricum L.	4,5±0,5	0,21±0,05	1	2±1

Результаты биомеханического исследования. Необходимость изучения биомеханических свойств древесины городских насаждений обусловлена их значительным влиянием на устойчивость к ветровым нагрузкам и снегопадам, особенно в регионах с нестабильными климатическими условиями, таких как Донбасс. Биомеханические исследования видов рода *Acer* L. показали, что виды с более высокой плотностью древесины и эластичностью волокон *A. campestre*, *A. platanoides*, демонстрируют повышенную устойчивость к механическим повреждениям, что позволяет им выдерживать экстремальные погодные явления и сохранять свою структуру в условиях техногенного воздействия (Рис. 3, 4, 5). У молодых особей клёна остролистного, в период до достижения 25-летнего возраста, наблюдается повышенная восприимчивость к механическим напряжениям. В это время, адаптивные механизмы растения ориентированы на обеспечение большей гибкости, нежели жёсткости структуры. Однако, по мере достижения зрелости, функциональность растительного организма претерпевает изменения, направленные на повышение устойчивости к деформациям, обусловленным динамическими нагрузками. Отмечается, что прочность ствола и крупных ветвей клёна характеризуется последовательным увеличением, которое пропорционально возрастает с увеличением статической и динамической нагрузки, действующей на дерево по мере его старения.

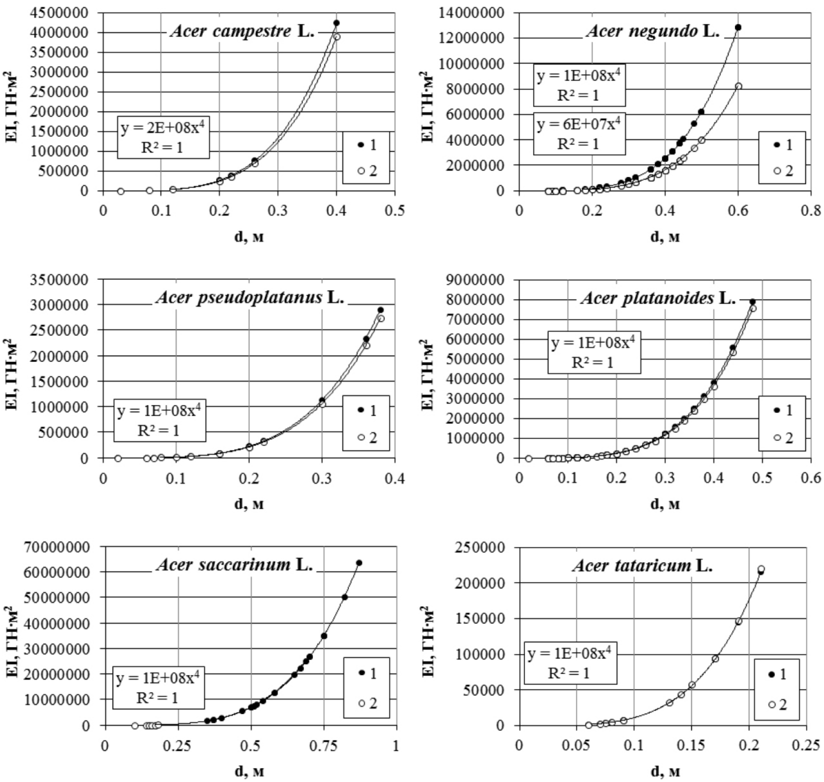

Рис. 3. Зависимость жёсткости на изгиб от диаметра ствола для видов рода *Acer* L.

Для деревьев *A. negundo* произрастающих в условиях относительного контроля зависимость жёсткости на изгиб устойчива и имеет высокие показатели, однако в условиях городской среды уже после 35 лет (с учетом повреждения тканей дереворазрушающими вредителями) механическая устойчивость снижается (на ~60 %), что отражается на аварийности таких деревьев.

Анатомические особенности древесины *A. negundo* характеризуется более рыхлой структурой древесины и крупными сосудами, что делает его более уязвимым к воздействию патогенов и механическим повреждениям. Полученные данные свидетельствуют об исключении использования данного вида в урбоэкосистемах.

A. tataricum демонстрирует постоянство своих физико-механических свойств как в условиях контроля, так и на антропогенно нарушенных территориях (Рис. 3, 4, 5). Этот показатель может быть использован в качестве маркера устойчивости при подборе видов для озеленения.

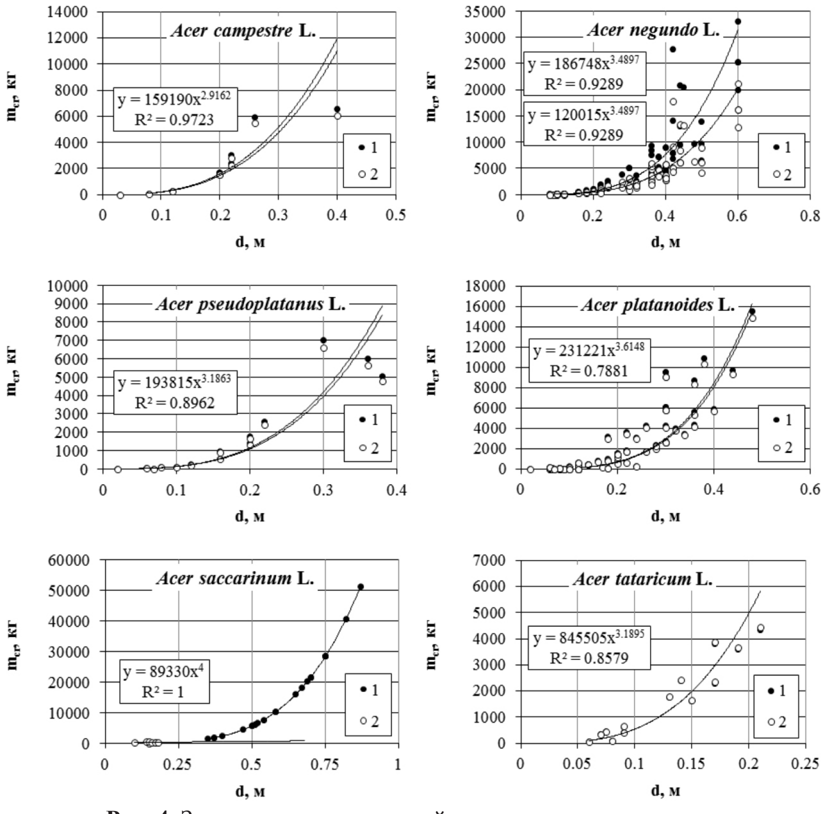

Рис. 4. Зависимость критической массы от диаметра ствола для видов рода *Acer* L.

В условиях относительного контроля деревья *A. saccharinum* компенсируют недостатки физико-механических свойств внушительными размерами ствола и кроны (Рис. 3-5). Регрессионная зависимость носит степенной характер, демонстрируя кратное увеличение критической массы на каждые 10 сантиметров диаметра, особенно выраженное после достижения d = 0,5 м (Рис. 4). Однако в условиях антропогенного загрязнения устойчивость этих растений снижается (после 30 лет), усугубляясь значительными повреждениями тканей, вызванными дендрофильными насекомыми. Полученные данные свидетельствуют об ограничении целесообразности использования данного вида в урбоэкосистемах.

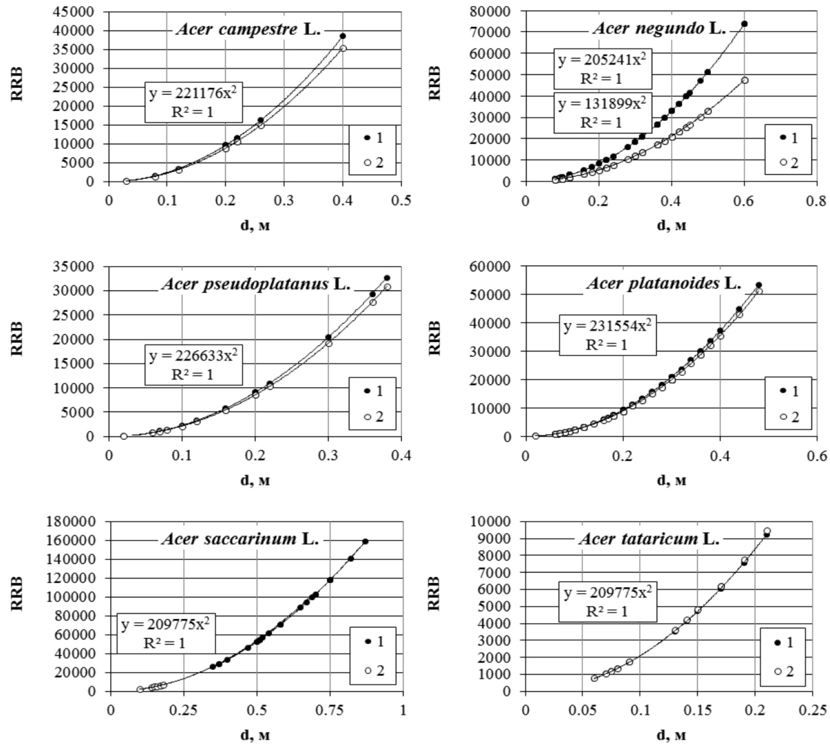

Рис. 5. Зависимость относительного сопротивления изгибу от диаметра ствола для видов рода *Acer* L.

Механическая устойчивость *A. pseudoplatanus* в степных условиях существенно зависит от действия экологических факторов, таких как высокие летние температуры и уровень влажности почвы, а также от аутэкологических особенностей явора. Древесина этого вида восприимчива к поражению грибом *Cryptostroma corticale* (Ellis & Everh., 1889), что влечет за собой значительное снижение физико-механических свойств живых тканей растения, ослабляя его общую структуру и сопротивляемость внешним воздействиям. Развитие корневой системы явора происходит преимущественно в горизонтальной плоскости, вблизи поверхности почвы. Следовательно, при посадке в ограниченные по площади лунки корневая система не имеет возможности полноценного развития и функционирования, что негативно сказывается на стабильности и жизнеспособности дерева.

Полученные результаты могут быть использованы для разработки стратегий озеленения городов с учетом устойчивости и адаптивности различных видов рода *Acer* L. Это позволит создать более устойчивые и функциональные городские экосистемы в условиях изменяющегося климата, а также способные выдерживать действие антропогенных факторов и обеспечивать благоприятные условия для жизни человека и животных.

Заключение

Определена антропогенная нагрузка изученных территорий Донецка, где произрастают различные виды рода *Acer* L. Интенсивность транспортного потока отражает высокий (более 1200 ед./час – ул. Артема, пр. Ильича, ул. Университетская) и умеренный (400-700 ед./час – пр. Ватутина, ул. Щорса) уровень нагрузки на зелёные насаждения, произрастающие вдоль автомагистралей. На участках с высокой интенсивностью движения зашумление по эквивалентному значению превысило 40 % от предельного уровня, по максимумам 24,5 %. Для зон с умеренной транспортной нагрузкой зафиксировано превышение эквивалентного уровня шума на 31-34%, при этом максимальные значения превышают норму в среднем не более чем на 14%.

Описаны эколого-биологические свойства шести видов рода *Acer* L. в условиях степной зоны Донбасса: *Acer campestre* L., *Acer negundo* L., *Acer platanoides* L., *Acer pseudoplatanus* L., *Acer saccharinum* L., *Acer tataricum* L. Определены морфометрические параметры спелых насаждений *Acer* L. Установили, что диаметр ствола у основания достоверно ($p<0.05$) был выше на территории с высокой антропогенной нагрузкой на 11 % для *A. campestre* и на 26 % для *A. pseudoplatanus*. В условиях относительного контроля деревья *A. saccarinum* значительно (на 70% по высоте и в 3 раза по диаметру) превосходят в размерах растения, произрастающие под влиянием антропогенной нагрузки. Для аборигенного вида *A. tataricum* превышение морфометрических параметров составляло 50% (высота) и 24% (диаметр основания).

Распределение возрастных групп в древостоях, образованных кленами рода *Acer* L., характеризуется неоднородностью. Анализ, проведённый с учётом представленности и жизнеспособности спелых насаждений в регионе, указывает на доминирование аборигенных видов *A. campestre, A. platanoides* и *A. tataricum* (2±1 балл). Указанные виды кленов демонстрируют высокую адаптивность и успешно развиваются в условиях относительного контроля, а также в условиях повышенного антропогенного загрязнения.

С позиций биомеханики живых систем виды с более высокой плотностью древесины и эластичностью волокон *A. campestre* и *A. platanoides*, демонстрируют повышенную устойчивость к механическим повреждениям, что позволяет им выдерживать экстремальные погодные явления и сохранять свою структуру в условиях техногенного воздействия. Для растений *A. negundo* с позиций анатомических особенностей древесины и физико-механических свойств тканей в условиях городской среды уже после 35 лет происходит снижение механической устойчивости на ~60%, что отражается на аварийности таких деревьев. Полученные данные свидетельствуют об исключении использования данного вида в урбоэкосистемах. Исследования показали, что *A. tataricum* сохраняет стабильные физико-механические характеристики как в условиях контроля, так и на территориях, подверженных антропогенному воздействию. Это обстоятельство указывает на потенциальную целесообразность его применения в проектах озеленения. Однако, учитывая его агрессивность, рекомендуется не масштабное, а выборочное использование, например, для формирования живых изгородей или аллейных посадок.

Полученные результаты могут быть использованы для разработки стратегий озеленения городов с учетом устойчивости и адаптивности различных видов рода *Acer* L. Это позволит создать более устойчивые и функциональные городские экосистемы в условиях изменяющегося климата, а также способные выдерживать действие антропогенных факторов и обеспечивать благоприятные условия для жизни человека и животных.

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Original article

ESSENTIAL CHARACTERISTICS OF THE REGULATORY FRAMEWORK FOR MANAGING THE FORMATION OF A NEW TECHNOLOGICAL STRUCTURE IN AGRICULTURAL SECTOR

M.A. Kholodova, M.N. Kabanenko, O.A. Kholodov, O.A. Zubareva, S.Sh. Muradova

Abstract

Background. The article discusses the issues of methodological formation of the regulatory framework for managing the formation of a new technological structure in agriculture. It is proved that in the modern period of the revival and formation of the national strategic planning system, methodological and methodological approaches, algorithms and methods for calculating indicators (standards, standards) of production and economic activity in the agricultural sector, allowing to substantiate strategic guidelines for the development of individual sub-sectors in the short, medium and long term, are missing, outdated or do not correspond to modern economic conditions.. The necessity of timely updating of the central link of the regulatory framework - the system of norms and regulations, as well as updating the methods of its development is argued.

Purpose. The main goal of this article is to substantiate the role and significance of the essential characteristics of the regulatory framework for managing the formation of a new technological order in the agricultural sector in the strategic planning system.

Materials and methods. The work uses works of modern authors such as I. S. Belik, S. E. Demidova, E. V. Zhiryaeva, A. V. Kalina, V. V. Krivorotova et al., when highlighting issues of state regulation of the economy, much attention is paid not to the system of norms and regulations, but to macroeconomic indicators that determine the contour of the development of the national economy, based on set priorities and strategic goals, and including interrelated thresholds of targets that must be achieved within the framework of the established organizational and economic mechanism of management and existing at the disposal of financial, logistical, labor and other types of resources.

The theoretical and methodological basis and methodological approaches to the formation of a system of norms and regulations in agriculture at the corporate level in a planned economy are studied in sufficient detail in the works of R. A. Korenchenko, T. D. Kurkin, N. I. Prok, V. F. Nesterov, I. N. Soldatov, etc. The issues of the formation of the regulatory framework as a tool for long-term and long-term policy planning are studied in sufficient detail in the works of L. B. Shabanova et al. The development of annual operational planning at the corporate level is highlighted in the works of M. A. Bashin, V. K. Bekleshov, V. I. Belotserkovsky, A. A. Zvyagina.

Methodological approaches adapted to the market economy are highlighted in the publications of M. I. Bukhalkov, N. F. Gaivoronskaya, V. V. Garkavogo, G. V. Grigorieva, V. Ya. Kavardakov, V. V. Kuznetsov, A. V. Derevyankin, A. F. Zakharov and others.

Results and conclusion. The regulatory framework for managing the formation of a new technological structure in the agricultural sector is focused on the development of target indicators or thresholds for key strategic planning documents based on progressive scientifically based values that allow the formation of objective and achievable indicators of the strategic development of the industry at all levels of government (federal, regional, territorial, corporate). In this regard, it is within the framework of the formation of the regulatory framework for strategic planning that the concept of state regulation of agriculture is being developed, which allows economic methods to reorient the business entities of the agricultural sector to develop certain industries, carry out technical and technological modernization, digital transformation of production, etc. At the same time, the system of norms and regulations within the framework of the regulatory framework of management acts as an assessment measure, a reference indicator that contributes to the speedy transition of agricultural producers to a new technological order.

Keywords: system of norms and regulations; regulatory framework; agriculture; technological structure; strategic planning

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Научная статья

ОСНОВНЫЕ ХАРАКТЕРИСТИКИ НОРМАТИВНО-ПРАВОВОЙ БАЗЫ УПРАВЛЕНИЯ ФОРМИРОВАНИЕМ НОВОГО ТЕХНОЛОГИЧЕСКОГО УКЛАДА В АГРАРНОМ СЕКТОРЕ

М.А. Холодова, М.Н. Кабаненко, О.А. Холодов, О.А. Зубарева, С.Ш. Мурадова

Аннотация

Обоснование. В статье рассматриваются вопросы методологического формирования нормативно-правовой базы управления формированием нового технологического уклада в сельском хозяйстве. Обосновывается, что в современный период возрождения и становления отечественной системы стратегического планирования методологические и методические подходы, алгоритмы и методики по расчету индикаторов (нормативов, стандартов) производственно-хозяйственной деятельности в аграрном секторе, позволяющие обосновать стратегические ориентиры развития отдельных подотраслей на краткосрочную, среднесрочную и долгосрочную перспективу отсутствуют, устарели или не соответствуют современным условиям хозяйствования. Аргументирована необходимость своевременного обновления центрального звена нормативной базы - системы норм и нормативов, а также актуализации методик ее разработки.

Цель. Основная цель данной статьи – обосновать роль и значение сущностных характеристик нормативно-правовой базы управления формированием нового технологического уклада в аграрном секторе в системе стратегического планирования.

Материалы и методы. В работе использованы труды современных авторов, таких как И. С. Белик, С. Е. Демидова, Е. В. Жиряева, А. В. Калина, В. В. Криворотова и др., освещая вопросы государственного регулирования рыночной экономики, большое внимание уделяется не системе норм и нормативов, а макроэкономическим показателям, которые образуют систему индикативного стратегического планирования, выступая в качестве ориентира, меры, критериального показателя развития и функционирования экономики, ее подсистем и объектов, параметров, определяющих границы, пороговые значения, в частности, в рамках которых технологические звенья, организационные механизмы, финансовые, материально-технические потоки и потоки трудовых ресурсов направлены на реализацию национальных целей и приоритетов. Индикаторами могут быть финансовые, социальные, производственные показатели, а также показатели структуры экономики, эффективности и т. д.

Теоретические и методологические аспекты формирования структурных элементов нормативной базы применительно к внутрихозяйственному планированию в административно-командной экономике взяты из работ Р. А. Коренченко, Т. Д. Куркина, Н. И. Прока, В. Ф. Нестерова, И. Н. Солдатова и др. Вопросы формирования нормативной базы как инструмента долгосрочного и перспективного планирования политики достаточно подробно изучены в работах Л. Б. Шабановой и др. Вопросы развития годового оперативного планирования на корпоративном уровне освещены в работах М. А. Башина, В. К. Беклешова, В. И. Белоцерковского, А. А. Звягиной.

Методологические подходы, адаптированные к рыночной экономике, освещены в публикациях М. И. Бухалкова, Н. Ф. Гайворонской, В. В. Гарькавого, Г. В. Григорьевой, В. Я. Ковалева, В. В. Кавардакова, В. В. Кузнецова, А. В. Деревянкина, А. Ф. Захарова и др.

Результаты и заключение. Нормативно-правовая база для управления формированием нового технологического уклада в аграрном секторе ориентирована на разработку целевых индикаторов или пороговых значений ключевых документов стратегического планирования на основе прогрессивных научно обоснованных величин, позволяющих формировать объективные и реализуемые показатели стратегического развития отрасли на всех уровнях управления (федеральном, региональном, территориальном, корпоративном).

В связи с этим именно в рамках формирования нормативной базы стратегического планирования разрабатывается концепция государственного регулирования сельского хозяйства, которая позволяет экономическими методами переориентировать хозяйствующие субъекты аграрного сектора на развитие определенных отраслей, осуществлять техническую и технологическую модернизацию, цифровую трансформацию производства и т.д. При этом система норм и нормативов в рамках нормативно-правовой базы управления выступает в качестве меры оценки, эталонного показателя, способствующего скорейшему переходу сельскохозяйственных товаропроизводителей на новый технологический уклад.

Ключевые слова: система норм и правил; нормативная база; сельское хозяйство; технологическая структура; стратегическое планирование

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Introduction

Exploring the complex and multifaceted process of forming a modern scientific methodology of the strategic planning system in the agricultural sector, it should be pointed out that the process of technical re-equipment of agriculture annually increasingly requires the adaptation of laws, principles, methods and methodologies for the development of planning and forecasting documents to the conditions of the formation of a new technological order in order to substantiate the most effective directions for the implementation of state policy in areas of technical and technological modernization of the industry, to increase its economic efficiency of production and economic activity and competitiveness.

It follows from the large economic dictionary that, regardless of the type of economic system, the “norm” as an economic category was and remains “a guiding principle, a rule, a model, a recognized mandatory order, an established measure, an average value of something”, determining the proportions between the elements of the process of social production (labor resources, machinery, technologies etc.) [1; 2].

The standard is a calculated value, a quantitative scientifically based value, the content and form of manifestation of something, for example, in the agricultural sector, the seeding rate per unit area of million pcs/ ha, kg/ha or feed consumption per 1 head of EKE cattle, etc.

According to Nobel laureate D. North: “Economics It cannot develop without norms and rules that are established by society and accepted by all. Without them, it will be a gangster economy, when everyone is trying to deceive each other...”.

From a practical point of view, norms and regulations are unified long-term source data used in strategic planning of the agricultural sector development, both for the development of forecasts and analysis, regulation, distribution, exchange and control over the functioning of agricultural sub-sectors at all levels of management. Therefore, rationing continues to be a key tool for strategic planning of sectors of the national economy, including agriculture, acting as a measure of the effectiveness of economic and technical and technological development, competitiveness at all levels of government.

The system of norms and regulations, which combines a set of methodological approaches, methodological techniques, automated calculation algorithms and scientific substantiation of an ordered set of reference qualitative and quantitative characteristics of agricultural development, is a regulatory management framework that can be used to unify non-standard tasks.: - a comprehensive analysis of the current situation in the agricultural sector, substantiating the optimal agricultural structure and its resource potential, stimulating the intensity of the implementation of innovative biological, technical, technological, organizational processes in priority sub-sectors; - scenario forecasting of production and socio-economic parameters of agricultural development, taking into account the current level of technological development; - calculation of thresholds for agricultural producers' needs for machinery, material and technical resources, seed stock, labor, financial resources, as well as cost standards for the implementation of various technologies for cultivating crops and raising farm animals in order to increase the efficiency of production and economic activities of business entities, increase the competitiveness of agricultural products on national and global markets, ensuring the food security of the state; - state regulation of the industry by creating conditions that stimulate the accelerated transition of the industry to domestic machinery and technologies, seed material, etc. For example, due to the significant dependence of the industry on imported technologies, machinery, and seeds in the face of sanctions pressure, a new version of the country's Food Security Doctrine came into force in January 2020, which contains a new regulatory indicator for the provision of agricultural production with seeds of domestic breeding at a level not lower than 75.0%.

The work uses works of modern authors such as I. S. Belik, S. E. Demidova, E. V. Zhiryaeva, A. V. Kalina, V. V. Krivorotova et al., when highlighting issues of state regulation of the economy, much attention is paid not to the system of norms and regulations, but to macroeconomic indicators that determine the contour of the development of the national economy, based on set priorities and strategic goals, and including interrelated thresholds of targets that must be achieved within the framework of the established organizational and economic mechanism of management and existing at the disposal of financial, logistical, labor and other types of resources.

The theoretical and methodological basis and methodological approaches to the formation of a system of norms and regulations in agriculture at the corporate level in a planned economy are studied in sufficient detail in the works of R. A. Korenchenko, T. D. Kurkin, N. I. Prok, V. F. Nesterov, I. N. Soldatov, etc. The issues of the formation of the regulatory framework as a tool for long-term and long-term policy planning are studied in sufficient detail in the works of L. B. Shabanova et al. The development of annual operational planning at the corporate level is highlighted in the works of M. A. Bashin, V. K. Bekleshov, V. I. Belotserkovsky, A. A. Zvyagina.

Methodological and methodological approaches adapted to the market economy are presented in the publications of M. I. Bukhalkov, N. F. Gaivoronskaya, V. V. Garkavogo, G. V. Grigorieva, V. Ya. Kavardakov, V. V. Kuznetsov, A. V. Derevyankin, A. F. Zakharov and others [3-9].

Results

The detailed classification of the above approaches allowed us to form a modern model of the regulatory framework for management in agriculture within the framework of the formation of a new technological order, consisting of three key elements: a subsystem of development and creation; a subsystem of updating and improvement; a subsystem of implementation. Thus, the first element of the model is based on the concept of metrological standardization, reflecting the vector of modern technological and scientific-technical policy in the agricultural sector, the target parameters of which act as a guideline, an assessment measure. The second element is focused on the development of unified progressive methods, automated algorithms for calculating scientifically based values of the functioning and development of the industry. The third element involves the application of the developed system of norms and regulations in practice in the process of industry management at all levels of management in the formation of strategic planning documents and the implementation of activities planned in them. It should be noted that the connecting central link between the above-mentioned elements of the proposed model is a system of norms and regulations, which is a well-structured multiple set of calculated values that are closely interrelated, having a single methodological and methodological basis for development and updating, contributing to accelerated logistical modernization of agriculture in the implementation of key management functions: planning and forecasting, organization, accounting and monitoring. It is important that the calculated reference values being developed, their qualitative and quantitative characteristics reflect the average indicators of the prevailing industrial and economic conditions of the economy, are universal, consistent, comparable across industries and intersectoral sectors in order to ensure Decree of the President of the Russian Federation dated November 8, 2021 No. 633 "On approval of the Fundamentals of State Policy in the field of strategic planning in the Russian Federation" [4].

It should be noted that the norm is a function of the norm, therefore it has a validity period [5; 7], which is determined by the limit values of regulatory factors (1):

$$y=f(x)=\sum_{i=1}^{n} x, \tag{1}$$

where y – norm;

x_i - is the standard, the calculated value of the factor.

For example, the standards for the need for agricultural machinery, approved by the Ministry of Agriculture of the country in 2009, in terms of natural agricultural zones and types of individual machinery have lost their relevance, since the period of validity of the standard is limited to 10 to 15 years due to the rapid expansion of production capabilities of new high-tech agricultural machinery. In particular, currently, for the southern regions of the country, the regulatory requirement for wheeled tractors, taking into account the traction class and the energy intensity of modern machines, depending on the technology of crop cultivation, can range from 4.57 reference units per 1,000 hectares with intensive technologies to 2.97 reference units per 1,000 hectares with zero tillage technology (against the outdated standard of 7.6 reference units units per 1000 ha). This example shows that the introduction of modern high-tech machinery and equipment into agricultural production requires a review and adjustment of the existing regulatory framework for agricultural management within the framework of the formation of a new technological structure, which will subsequently allow to objectively determine the existing need for agricultural machinery and form target indicators for the technical and technological modernization of the branch of regional government programs. It should be noted that specialized scientific organizations are engaged in the development and formation of the regulatory framework for management, whose task is to update norms and standards in a timely manner, as well as to update methodological recommendations and algorithms for their calculation, on the instructions of the Ministry of Agriculture of the Russian Federation. The implementation of the developed system of norms and regulations is completed by the process of developing planning and forecasting documents at all levels of management. The development of a regulatory framework for managing the formation of a new technological order in agriculture involves timely updating of the system of norms and regulations, as well as updating methodological recommendations and algorithms for their calculation in accordance with current legislation, and is based on the following principles: – the principle of innovation, which strengthens the trends of innovation and the introduction of advanced technologies; – the principle of unity of use of methods and algorithms for the development of reference quantities; – the principle of comprehensive coverage or articulation of a multidimensional approach to all functions and levels of management of technical and technological modernization and digital transformation of agricultural sectors; – the principle of continuity and continuity; – the principle of compliance of regulatory products with the strategic goals of technical and technological development and digital transformation of agriculture, socio-economic development and national security of the state; – the principle of flexibility and adjustment; – the principle of efficiency and effectiveness.

The active influence of the state on the processes of technical and technological modernization and digital transformation of the agricultural sector, which form the fundamental basis for conducting competitive agricultural production, allows us to consider the regulatory framework as an economic regulator of the development of the agricultural sector in the context of the formation of a new technological order. The modern regulatory framework for managing the formation of a new technological order acts as a tool for developing and filling in the content of key strategic planning documents (Fig.1), in connection with which:

- the structural elements of the system of norms and regulations are determined based on its functions: economic foresight and forecasting, identification of the resource potential of the industry during the transition to a new technological order and growth reserves; methodological support for planning the processes of technical and technological modernization of the industry; regulation of the processes of technical and technological modernization; stimulating the introduction of innovations and digital technologies; effective redistribution of resources and results; formation of industry development targets, etc.;
- the stability and effectiveness of the regulatory framework are ensured by observing the totality of the principles of its organization: consistency, adaptability, unity, innovation, multi-aspect, long-term, etc.;
- continuity and consistency of the system of norms and regulations are ensured through their universal use in the sectoral and intersectoral cross-section, as well as in interconnection at all levels of management;
- various types of resources, individual progressive target indicators of technical, technological and digital transformation of agriculture, government levers and regulators, etc. can act as objects of rationing.;
- to ensure the principle of long-term sustainability, it is advisable to use a regulatory approach in the development of long-term, medium-term and short-term planning and forecasting documents.;
- ensuring methodological unity is achieved by coordinating such elements of methodological support as: strategy development and goal setting, possible development trajectories, development concepts and models, planning and forecasting methods, predictive models, probable development scenarios, assessment of the feasibility of strategic plans, the structure of strategic plans and their content, etc.

According to scientists, including N. F. Gaivoronskaya, G. V. Grigorieva, V. Ya. Kavardakov, V. V. Kuznetsov and others, the regulatory framework for managing the formation of a new technological order, which includes a large number of norms and standards, will be effective and viable if the normative indicators are systematized according to certain criteria. In particular, an enlarged model of the regulatory framework of sub-sectors of the agricultural sector for the development of indicators of long–term federal and regional strategies, programs, projects of technical and technological modernization of agriculture using intensive and energy-saving technologies may consist of five enlarged groups of norms and standards (Table 1).

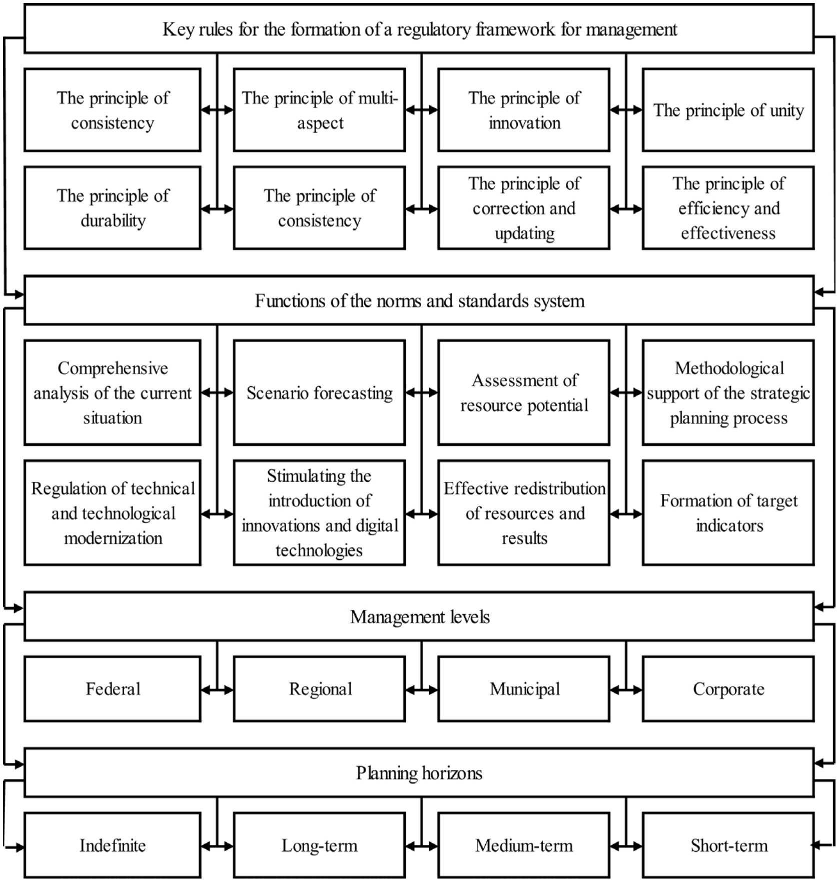

Fig. 1. Essential characteristics of the regulatory framework for managing the formation of a new technological order in the context of civilizational and scientific and technological transformations
Source: developed by the authors

In [4-6], special attention is paid to the technological development of the industry, which acts as the most important subsystem of crop and livestock production and involves a continuous process of replacing outdated technologies with improved or new technological solutions, when developing a regulatory framework for managing the formation of a new technological order in agriculture.

Table 1.

The structure of the regulatory framework model for the development of indicators of long-term federal and regional strategies, programs, projects of technical and technological modernization of agriculture

An enlarged group	The content of the elements of the regulatory framework of the enlarged group
Basic norms and regulations	Agricultural lands and their qualitative characteristics; livestock of farm animals; availability of labor, material, financial resources, agricultural machinery; production losses of products, etc.
Production standards and regulations	Seeds and planting material; forage production; means of mechanization, chemicalization, fertilizers, plant protection; veterinary services; use of labor, material and financial resources, enterprises.
Effective norms and regulations	Gross agricultural production; productivity; animal productivity; cost of production; profitability; labor productivity; resource efficiency; product quality, etc.
Regulatory internal rules and regulations	Remuneration; estimated prices; solvency; financial stability; efficiency of capital use; marketability of products, etc.
Regulatory external rules and regulations	Taxes, payments and deductions; prices, tariffs, duties; bank interest rate on loans; compensation, insurance payments, amount of state support; social benefits; depreciation

Source: calculated by the authors according to the data of the Ministry of Agriculture of the Rostov region

The main results of technological development are: increasing crop yields, productivity of farm animals; reducing labor, energy and material resources for production; improving the quality of products; reducing costs; increasing profitability and competitiveness of production.

Research has shown that, in general, the system of standards for state regulation of the agricultural sector can be classified according to three main characteristics (Fig. 2): developed by state structures and mandatory, developed by state and public structures as development benchmarks, developed by market participants as development benchmarks.

At the same time, each economic entity (agricultural producer, processor, realizer, intermediary, investor, etc.), as well as authorities at all levels should rely on this specific classification, which represents the regulatory framework for managing the formation of a new technological order.

In addition, the formation of a new technological structure in agriculture involves the development of a system of norms and regulations at the state level, represented mainly by enlarged macroeconomic indicators, normative indicators of technical modernization of agriculture, determining the effectiveness of its functioning, competitiveness, and the pace of transition to innovative tracks.

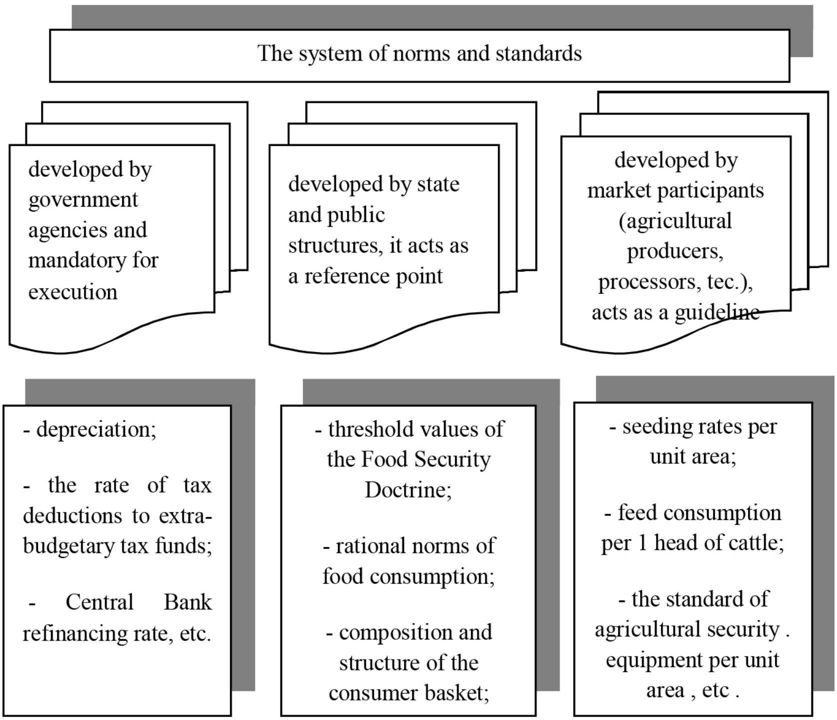

Fig. 2. Species classification of the system of norms and standards.
Source: [5, 6]

The achievement of the target aggregated indicators of agricultural development, laid down in key strategic planning documents, including government programs, is carried out through such instruments of state regulation as budget support, tax holidays, preferential bank interest rate and others.

Macroeconomic indicators include indicators of the complex qualitative dynamics of technical and technological modernization of the agricultural sector, including: the volume of production of the main types of agricultural products in value terms, labor productivity, labor stock, the number of high-performance jobs, etc., as well as indicators having a “threshold” or “limit” value, for beyond which there may be a threat of crisis phenomena and national security.

An example of individual indicators determining the normative (threshold) values of food security in the Russian Federation and relevant international databases is given in Table 3.

Let's pay attention to such an indicator as "Government expenditures on R&D in agriculture", reflecting the industry's ability to innovate and progress (Fig.3). If the value of this indicator is below the threshold of 2.0% of GDP, then this fact indicates a gradual degradation of the industry. In the domestic agricultural economy, this indicator leaves much to be desired.

Table 3.

Normative (threshold) indicators of food security of the Russian Federation and related indicators international databases

Indicator	Individual indicators according to Doctrine 2020	Food and Agriculture Organization of the United Nations (FAO)	Global Food Security Index (GIPI)
Food independence	Self-sufficiency: compliance of domestic consumption with the volume of production of agricultural products, %	Stability: insignificant specific weight of food imports in the consumption structure, %	Affordability: low level of tariff rates for food imports
Economic accessibility	Compliance of the actual established diet with the recommended norms of a healthy lifestyle	Availability: sufficiency of food, provision of food products containing protein of animal origin. Low obesity rate among economically active population, %	Quality and safety: availability of recommendations of the Ministry of Health on healthy nutrition within the country, taking into account its balance
Physical accessibility	Development of market infrastructure, %	Access: availability of paved roads and railways, development of logistics infrastructure	Availability: the level of funding for scientific research in the agricultural sector, in % of GDP; development of transport infrastructure
Quality and safety	Certification and veterinary supervision in the field of food	Usage: the level of drinking water availability,%; availability of accessible sanitary and hygienic conditions, %	Quality and safety: proportion of residents with free access to drinking water, %

Source: [10]

For example, if the value of such an aggregated indicator as "The level of financing of scientific research in the agricultural sector", demonstrating the processes of material and technical modernization of agriculture, turns out to be below 1% of GDP, then there will be no high-quality intensive economic growth in the industry.

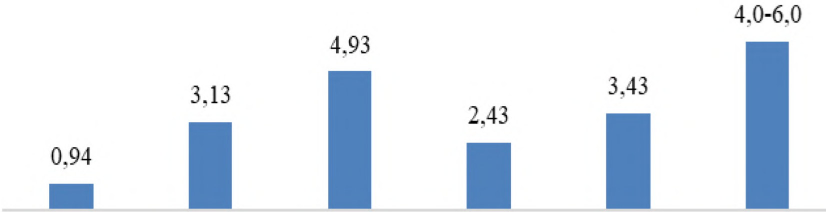

Fig. 3. Threshold values of government expenditures on R&D in agriculture in Russia and abroad, %
Source: [10]

Conclusion

In the process of establishing a new technological structure in agriculture, accompanied by increased sanctions pressure from Western countries, the regulatory framework of management serves as the main tool for developing targets for key strategic planning documents at all levels of government from federal (macroeconomic) to corporate (microeconomic). Currently, there is an increasing need to develop, improve and update methods and algorithms for calculating a system of progressive regulatory indicators that make it possible to predict the existing need for agricultural machinery, fertilizers, seeds, technologies and justify target indicators for the technical and technological modernization of the industry of federal and regional government programs, as well as business plans of agricultural producers.

The formation of the regulatory framework for management in the context of the formation of a new technological structure in agriculture is the final stage in the formation of the national strategic planning system in the agricultural sector of the economy. The core of the regulatory framework is a system of progressive regulatory indicators that serves as an assessment criterion, a control indicator, a lever and a regulator that stimulates the accelerated transition of the industry to a new technological order.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

SOFTWARE FOR MONITORING THE PRODUCTION PROCESS OF RICE AGROCENOSIS BASED ON A DATABASE

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Abstract

Background. The results of the study of the production process of intensive and extensive rice varieties are summarized in a single database (DB) registered in Rospatent No. 202462462. It includes two main parts: descriptions of the object of study and tabular data having a structure and interrelations according to the logical scheme, which was created in the Microsoft Access program. The latter manages the database (DBMS) of biological features that form the rice yield. The database contains data for identifying the interaction of biological features of plants with their optical characteristics in the formation of the yield of rice agrophytocenoses and the introduction of scientifically sound methods for monitoring the physiological state of crops and forecasting the yield. In vegetation and microfield experiments, the patterns of growth and formation of productivity of different types of rice varieties are considered. Particular attention is paid to the characteristics of donor-acceptor relationships in plants and crops as the main stage of the production process, determining the economic productivity of genotypes.

Purpose. The aim of the research is to study the production process of intensive and extensive rice varieties.

Materials and methods. The research was carried out in two experiments: a vegetation-microfield experiment and a field experiment (2017-2024).

Results. The developed database contains a set of data reflecting information on the biological characteristics of plants that determine rice yield. Research on monitoring rice crops was conducted in the physiology laboratory of the Federal State Budgetary Scientific Institution "Federal Scientific Center of Rice". The developed database is necessary to identify the interaction of biological characteristics of plants with their optical characteristics. In this version of the program, five basic forms are used to enter the initial data, with the help of which data is entered, edited and viewed: information on the yield and its structure (productivity); optical characteristics of the object (optical indicators); information on the research material (research material); information on climatic conditions (climatic data); Variety passport (characteristics of the variety under study).

Conclusion. The structure of the DB of morphophysiological features of rice plants is presented. Information support for monitoring rice agrophytocenoses is carried out based on the entered data on biological features that form rice yield. Specialists of rice-growing farms to monitor the state of rice crops, adjust nitrogen fertilization and forecast the yield use the presented DB.

Keywords: rice; production processes; information support for monitoring; database

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Научная статья

ПРОГРАММНОЕ ОБЕСПЕЧЕНИЕ ДЛЯ МОНИТОРИНГА ПРОЦЕССА ПРОИЗВОДСТВА АГРОЦЕНОЗА РИСА НА ОСНОВЕ БАЗЫ ДАННЫХ

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Аннотация

Обоснование. Результаты изучения производственного процесса интенсивных и экстенсивных сортов риса обобщены в единой базе данных (БД), зарегистрированной в Роспатенте № 202462462. Она включает две основные части: описание объекта исследования и табличные данные, имеющие структуру и взаимосвязи в соответствии с логической схемой, которая была создана в программе Microsoft Access. Последняя управляет базой данных (БД) биологических признаков, формирующих урожайность риса. База данных содержит сведения для выявления взаимодействия биологических признаков растений с их оптическими характеристиками в формировании урожайности рисовых агрофитоценозов и внедрения научно обоснованных методов мониторинга физиологического состояния посевов и прогнозирования урожайности. В вегетационных и микрополевых опытах рассмотрены закономерности роста и формирования продуктивности различных видов сортов риса. Особое внимание уделено особенностям донорно-акцепторных отношений в растениях и посевах как основного этапа продукционного процесса, определяющего хозяйственную продуктивность генотипов.

Цель. Целью исследования является изучения производственного процесса интенсивных и экстенсивных сортов риса.

Материалы и методы. Исследования проводились в двух экспериментах: вегетационно-микрополевом и полевом (2017-2024 гг.).

Результаты. Разработанная база данных содержит набор данных, отражающих информацию о биологических особенностях растений, определяющих урожайность риса. Исследования по мониторингу посевов риса проводились в лаборатории физиологии Федерального государственного бюджетного научного учреждения «Федеральный научный центр риса». Разработанная база данных необходима для выявления взаимодействия биологических характеристик растений с их оптическими характеристиками. В данной версии программы для ввода исходных данных используются пять основных форм, с помощью которых осуществляется ввод, редактирование и просмотр данных: информация об урожае и его структуре (продуктивность); оптические характеристики объекта (оптические показатели); информация о материале исследования (материал исследования); информация о климатических условиях (климатические данные); паспорт сорта (характеристика изучаемого сорта).

Заключение. Представлена структура БД морфофизиологических признаков растений риса. На основе введенных данных о биологических признаках, формирующих урожайность риса, осуществляется информационное обеспечение мониторинга рисовых агрофитоценозов. Специалисты рисоводческих хозяйств для мониторинга состояния посевов риса, корректировки азотных удобрений и прогнозирования урожайности используют представленную БД.

Ключевые слова: рис; производственные процессы; информационное обеспечение мониторинга; база данных

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Introduction

Until recently, remote sensing was used to inventory agricultural areas, identify areas of salinization, erosion, waterlogging and entanglement. Recently, there has been a need to forecast crop yields based on remote sensing data [1-4]. This has led to the need to conduct research and establish a relationship between plant productivity and remote sensing data in various soil and climatic conditions [5].

In plants, the production process includes all stages of their development. This includes the formation of shoots, tillering, nutrition, respiration, photosynthetic activity with the formation of metabolites, their transport and distribution among organs and storage, and the growth of fruit-bearing organs [6]. Shoot formation has a great influence on the crop yield. The number of productive shoots per unit area depends not only on the intensity of plant tillering, but also on the sowing qualities of seeds (their growth force), the density of seedlings (seeding rate), and the safety of lateral shoots [5; 7]. The productivity of rice varieties is greatly influenced by the water regime and optimal mineral nutrition. The water regime creates conditions for restorative processes that convert nitrogen from the soil and fertilizers into ammonium, and potassium and phosphorus into more accessible forms that are better absorbed by plants [8; 9].

In a similar way, phosphorus and potassium from mineral fertilizers and from natural soil reserves after restored processes in flooded conditions increase their availability for rice plants. Therefore, to enhance the production process in plants when applying phosphorus and potassium fertilizers, it is necessary to take into account their content in the soil [8].

The physiological state of agricultural crops is assessed not only by the area of their photosynthetic surface and the concentration of chlorophyll in the leaves, but also by the size of the vegetation index, which is an optical-biological characteristic of plants [10-13]. Establishing the mechanism of the relationship between these features will allow us to better study the physiology of growth and the production process of cereal crops. This is possible using not only experimental ground-based data, but also the results of remote sensing of the Earth. According to many scientists, the increase in the productivity of grain crops occurs not due to an increase in the intensity of the photosynthetic apparatus of plants, but due to an improvement in the donor-acceptor relationships of plants, as a result of which the influx of assimilates to the generative organs increases. At the same time, the mass of grain in the panicle and, accordingly, the yield increase [5; 14-17].

The above was confirmed in our works. The productivity of the studied varieties increased as a result of the increased influx of formed metabolites to the panicle, which increased the grain weight in it [18-21]. In addition, for the same reason, the coefficient of economic efficiency of photosynthesis also increased in these highly productive varieties [17; 22; 23]. But these varieties experienced a decrease in the weight of 1000 seeds, since it has a negative relationship with the grain weight from the panicle, plant and unit area of crops, and, consequently, with the yield of these varieties. The conducted research work made it possible to create a number of morphophysiological indicators for a qualitative assessment of the most adaptive and productive rice varieties. They should be used to assess the condition of crops and forecast yields in Kuban. It is combined into a single database (DB) and registered in Rospatent No. 20224624627 [24]. The aim of the study is to identify the relationship between the morphophysiological characteristics of rice crops and their optical characteristics using a database.

Purpose.

To systematize biological characteristics of rice plants with their optical parameters for analysis in a database.

Materials and methods

The experiments were carried out in vegetation micro-checks and field trials (2017-2024). In the first experiment, the following varieties were studied: Rapan (st), Vizit, Flagman (intensive), Stanichny, Sonata, Atlant (extensive) in concrete tanks with an area of 3.6 m^2. Meadow-chernozem soil for them was taken from rice fields. Fertilizers were applied according to the following scheme: 1 - control (without fertilizers); 2 - $N_{12}P_6K_6$ (medium background); 3 - $N_{24}P_{12}K_{12}$ (optimal background); 4 - $N_{36}P_{18}K_{18}$ (high background), g of active substance per 1 m^2 [25]. The plant density in the crop was 300 pcs./m^2. During the vegetation period of plants in all growth phases, their raw and dry biomass, total nitrogen were determined on the UDC 127 device, leaf surface area was measured, and the NDVI vegetation index was measured with a GreenSeeker Handheld Crop Sensor spectrometer [27]. Using the N-tester device, leaf diagnostics were performed to determine the nitrogen content in rice plants. Similar determinations of biological and optical characteristics of rice crops were carried out in a field experiment on the production crops of the “FNC Rice”.

Results

The created database contains a set of information about the biological features and optical characteristics of plants that affect productivity. The determination of the state of rice crops was carried out in the Laboratory of Physiology of the Federal Rice Research Center. The database allows us to identify the relationship between the biological and optical characteristics of rice plants.

Data is entered into the program using five main forms, in which editing and viewing of information is carried out: information on the structure of the crop and its (productivity); optical parameters of the object (optical indicators); initial values of the material being studied (research material); indications of meteorological conditions (climatic data); variety passport (data on the variety), which is accessed through the menu shown in Fig. 1. Fig. 2 shows the logical structure of the database.

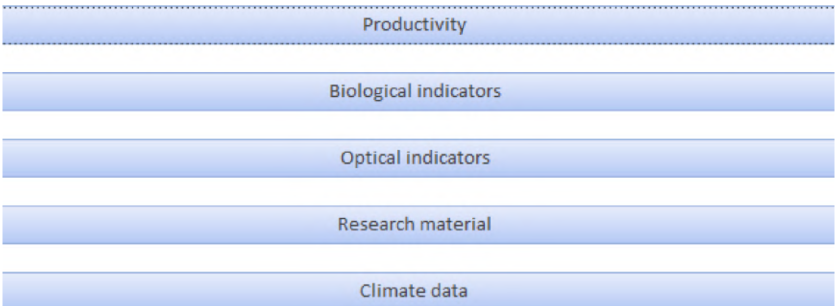


Fig. 1. Start panel for selecting the data entry form

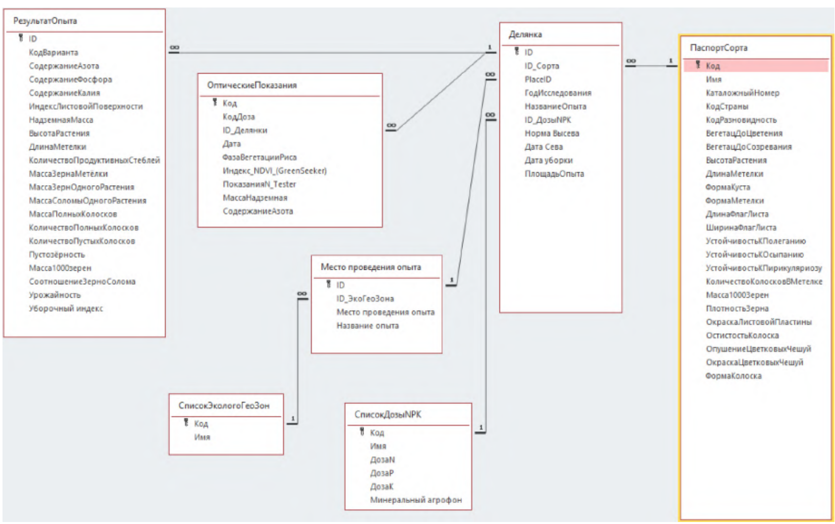


Fig. 2. Logical structure of the database

Fig. 3 shows the optical parameters of plants that are entered into the database. It includes the leaf area index, the above-ground mass of rice plants, the nitrogen content, the NDVI vegetation index and the N-tester values,

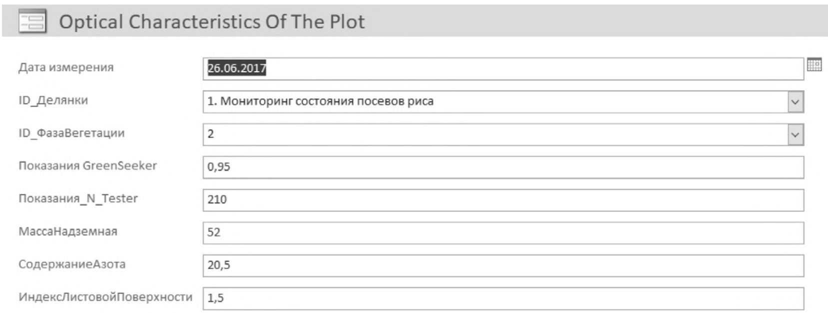
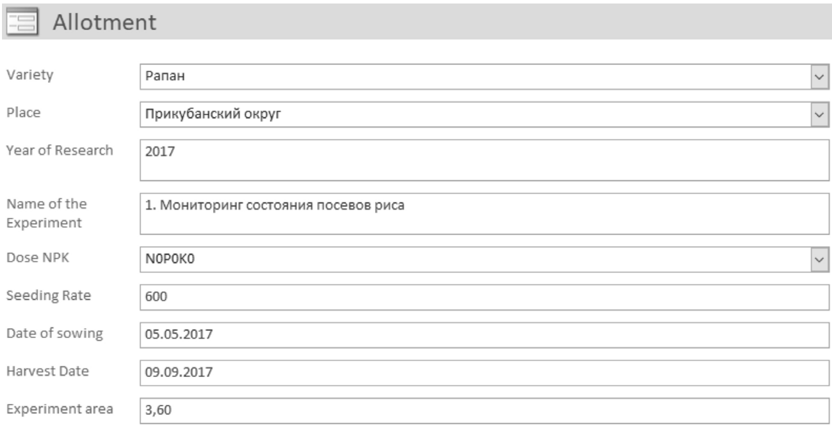


Fig. 3. Optical characteristics of plants

The task of achieving ever-higher levels of rice crop yield determines the optimal supply of nitrogen. In the $N_{24}P_{12}K_{12}$ variant, its concentration corresponds to the optimum [15]. The data are consistent with the readings of the N-tester, which characterizes the color of plant leaves in any phase of vegetation, which are associated with the ILP values and phytomass. Rice plants have different spectral reflectivity, which allows using remote sensing data to assess their condition. Precision agriculture uses indices that express the dynamics of these changes. The NDVI vegetation index we measured is an indicator of the ability of plants to reflect and absorb light waves. Chlorophyll, which is part of plant cells, reflects green waves of the light spectrum. The higher the values of the vegetation index, the higher the amount of green phytomass. NDIVI - analysis is relevant at any phase of plant development, while it is necessary to pay attention to the patterns of its values. At the beginning of the growing season and formation of the stem stand, it increases, and stops during the flowering and grain filling phase. It decreases during the full ripeness phase. In the middle of the growing season, the NDIVI index can be 0.5-0.8, which indicates good crop biomass. In our experiments, the vegetation index values varied from 0.21 to 0.79 depending on the level of mineral nutrition and is closely related to the nitrogen status. Its optimal value is in the range of 0.72-0.78 and corresponds to nitrogen values of 4.06-4.46% in the aboveground mass. These values relate to the beginning of the tillering phase and are used in diagnostics of the nitrogen status of plants.

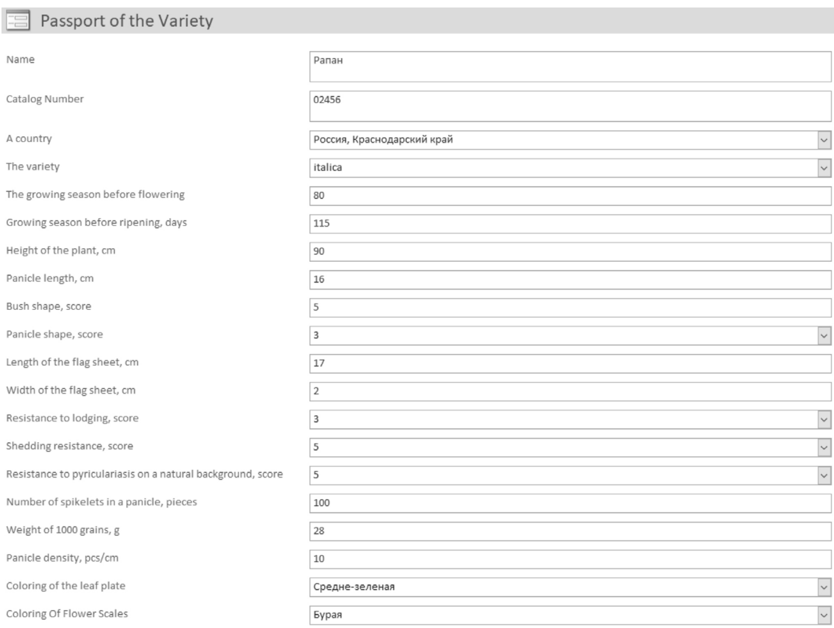
Fig. 4 shows a form about the research object. It contains fields where the main information about the research is entered: the location of the experiment, its name, variety, sowing date, sowing rate, area of the experiment, dose of mineral fertilizers.



Allotment

Variety	Рапан
Place	Прикубанский округ
Year of Research	2017
Name of the Experiment	1. Мониторинг состояния посевов риса
Dose NPK	N0P0K0
Seeding Rate	600
Date of sowing	05.05.2017
Harvest Date	09.09.2017
Experiment area	3,60

Fig. 4. Information about the research material



Passport of the Variety

Name	Рапан
Catalog Number	02456
A country	Россия, Краснодарский край
The variety	italica
The growing season before flowering	80
Growing season before ripening, days	115
Height of the plant, cm	90
Panicle length, cm	16
Bush shape, score	5
Panicle shape, score	3
Length of the flag sheet, cm	17
Width of the flag sheet, cm	2
Resistance to lodging, score	3
Shedding resistance, score	5
Resistance to pyriculariasis on a natural background, score	5
Number of spikelets in a panicle, pieces	100
Weight of 1000 grains, g	28
Panicle density, pcs/cm	10
Coloring of the leaf plate	Средне-зеленая
Coloring Of Flower Scales	Бурая

Fig. 5. Variety passport

Fig. 5 shows the form in which information on the biological characteristics of rice varieties is entered. It is of a reference nature, which allows characterizing the studied varieties by individual characteristics.

The reporting form of the database contains summary information on biological characteristics and results of monitoring the state of rice crops, presented in the form of a table. The report presents data that allow creating a mathematical model of crop productivity and developing an algorithm for providing plants with nitrogen to increase the yield of rice agrophytocenoses (Fig. 6).

Report 1

Variety	Dose NPK	NDVI	N-Tester	Plant weight	Nitrogen	LAI	Productivity	Harvesting Index
Рапан	N0P0K0	0,25	210	52	2,1	1,6	0,559	54,4
Рапан	N12P6K6	0,62	457	168	3,35	1,99	0,747	49,6
Рапан	N24P12K12	0,8	517	207	4,02	2,67	1,25	48,6
Рапан	N36P18K18	0,81	520	297	4,39	3,61	1,256	46
Визит	N0P0K0	0,24	220	58	2	1,48	0,57	52,4
Визит	N12P6K6	0,61	420	198	3,37	2,43	0,752	49,7
Визит	N24P12K12	0,79	513	195	3,88	2,73	0,999	46,3
Визит	N36P18K18	0,81	519	231	4,5	3,32	1,149	42,2
Флагман	N0P0K0	0,23	215	46	2,2	1,75	0,521	52
Флагман	N12P6K6	0,58	469	207	3,13	2,43	0,803	46,4
Флагман	N24P12K12	0,77	505	285	4,26	3,89	1,115	41,1
Флагман	N36P18K18	0,8	516	393	4,41	4,66	1,256	44,1

Note: NDVI, units; N-tester, units; plant weight, g/m^2; nitrogen content, %; LAI, m^2/m^2; yield, kg/m^2; harvesting index, %.

Fig. 6. Rice crop monitoring report

Discussion

The developed database will allow structuring large volumes of information required for analytical processing in research works. The database allows developing algorithms and identifying patterns of regulation of plant nutrition regime. Regulates the formation of productive sprouts and promotes the creation of highly productive agricultural crops. Based on the morphophysiological and optical characteristics of rice crops, based on the presented database, it is possible to determine the nitrogen supply in the tillering phase and develop an effective scheme for its application.

Conclusion

The biological and economic productivity of rice crops is largely determined by the morphophysiological characteristics of plants and is closely related to their optical characteristics formed the basis of the presented database. It is aimed at monitoring the state of rice crops and planning the harvest of future years.

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Original article

IMMUNOLOGICAL STATUS OF HIGHLY PRODUCTIVE COWS WITH COMORBID OBSTETRIC-GYNECOLOGICAL AND ORTHOPEDIC PATHOLOGY

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Abstract Аннотация

Background. Research and clinical observation confirm a significant correlation between postpartum metabolic/obstetric diseases and the development of orthopedic pathology in highly productive cows. In particular, a study supported by the Russian Science Foundation (grant No. 24-26-00172) revealed a clear relationship between the development of purulent-necrotic lesions of the hooves and the occurrence of postpartum endometritis in high-yielding cows. In this study, the following groups of animals were formed by randomization: group 1 (n=28): cows with acute purulent-catarrhal postpartum endometritis; group 2 (n=25): animals with purulent-necrotic lesions of the hooves; group 3 (n=27): cows with a comorbid course of both pathologies; and the control group (n=23): clinically healthy animals. All individuals selected for the study had their jugular venous blood collected on an empty stomach into sterile tubes for subsequent immunological analysis. It was found that the comorbid course of these pathologies is significantly more severe than each of the diseases in isolation. This is evidenced by the immunological screening we conducted. In this regard, when an animal has multiple pathologies, an individual approach is necessary, which dictates the need for a comprehensive study of the clinical course of the main, concomitant, and even previous diseases, their comprehensive diagnosis, and rational treatment.

Purpose. The purpose of the present paper is to study the immunological status of highly productive cows with comorbid obstetric-gynecological and orthopedic pathology.

Materials and methods. To assess the dynamics of the clinical manifestation of hoof diseases, an orthopedic examination was conducted on a monthly basis

throughout the year. During this examination, the following were evaluated: the degree and nature of hoof deformities; the intensity of corneal destruction; the presence of specific lesions such as pockets, delamination, and cracks; and the position of the thoracic and pelvic limbs. In cows with identified purulent-necrotic lesions during the postpartum period, a detailed obstetric and gynecological examination was additionally performed. It included a clinical examination, transrectal palpation, and ultrasound scanning, which was performed using the Scanner Falco device (8 MHz). Ultrasound was used to determine the size, echodensity, tissue homogeneity, and echogenicity of the reproductive structures. For immunological studies, blood was taken from the jugular vein of sick animals and cows from the control group (n=23) in the morning before feeding into sterile tubes. The total protein content in the blood serum of cows was determined using the biuret reaction, and the protein fractions were determined using the nephelometric method, and the A/G ratio was calculated. The amount of C-reactive protein was determined using the immunofluorescence method. The concentration of ceruloplasmin (CP) in the blood serum was determined by the standard method based on the oxidation of p-phenylenediamine with the participation of CP. The level of fibrinogen was determined spectrophotometrically, haptoglobin – by turbidimetric method. The level of circulating immune complexes (CIC) and their fractional composition were analyzed on the basis of determination of their molecular weight. The concentrations of interleukins (IL-1a and IL-8) and tumor necrosis factor-α (TNF-α) were measured by solid-phase enzyme immunoassay using commercial kits of monoclonal antibodies and reagents manufactured by Cytokin LLC, Saint Petersburg, Russia.

Results. According to the Tukey multiple comparison analysis, the most significant increase in the level of CIC was observed in the group of animals with comorbid pathology. This indicates that the combined course of endometritis and hoof diseases leads to a more severe systemic inflammatory response compared to isolated forms of the diseases. This is evidenced by the indicators of protein metabolism, the level of acute phase proteins, the cytokine profile, and the amount of circulating immune complexes in the blood samples of the experimental animals.

Conclusion. Currently, there is an urgent need for a comprehensive fundamental study of comorbidity in veterinary practice. The results of our research demonstrate that the comorbid course of orthopedic and obstetric-gynecological pathologies in high-yielding animals is characterized by a more severe clinical picture compared to isolated forms of monopathologies. This is evidenced by our immunological screening. In this regard, when an animal has multiple pathologies, an individual approach is necessary, which requires a comprehensive study of the clinical course of the main, concomitant, and even previous diseases, as well as their comprehensive

diagnosis and rational treatment. In the future, it is necessary to create a universal tool that allows veterinarians to instantly and easily assess the structure, severity, and possible consequences of concomitant diseases in animals, conduct targeted diagnostics, and then prescribe the correct set of medical measures.

Keywords: factor infections; immunological indicators; endometritis; orthopedic pathology; comorbidity; cows

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Научная статья

ИММУНОЛОГИЧЕСКИЙ СТАТУС ВЫСОКОПРОДУКТИВНЫХ КОРОВ С СОПУТСТВУЮЩЕЙ АКУШЕРСКО-ГИНЕКОЛОГИЧЕСКОЙ И ОРТОПЕДИЧЕСКОЙ ПАТОЛОГИЕЙ

В.И. Луцай, П.А. Руденко, В.Д. Сибирцев, А.М. Нефедов, А.А. Руденко

Аннотация

Обоснование. Ветеринарная практика свидетельствует о наличии клинически выраженной связи между акушерскими заболеваниями и ортопедической патологией у высокопродуктивных коров. В частности, исследование, выполненное при поддержке РНФ (грант № 24-26-00172), выявило четкую взаимосвязь между развитием гнойно-некротических поражений копыт и возникновением послеродового эндометрита у высокопродуктивных коров. На примере поголовья ЗАО «Воскресенское» Воскресенского района Московской области в настоящем исследовании были сформированы рандомизировано следующие группы животных: группа 1 (n=28): коровы с острым гнойно-катаральным послеродовым эндометритом; группа 2 (n=25): животные с гнойно-некротическими поражениями копыт; группа 3 (n=27): коровы с коморбидным течением обеих патологий; контрольная группа (n=23): клинически здоровые животные. У всех особей, отобранных в заявленное иссле-

дование, производили забор яремной венозной крови натощак в стерильные пробирки для последующего иммунологического анализа. Было установлено, что коморбидное течение этих патологий протекает значительно тяжелее, чем каждая из болезней в отдельности. Об этом свидетельствует проведенный нами иммунологический скрининг. В связи с этим при ассоциированном течении нескольких патологий у животного необходимо применять индивидуальный подход, что диктует необходимость комплексного изучения клинического течения основных, сопутствующих и даже перенесенных заболеваний, их всесторонней диагностики, а также рационального лечения.

Цель. Цель исследования - изучить иммунологический статус высокопродуктивных коров с сопутствующей акушерско-гинекологической и ортопедической патологией.

Материалы и методы. Для оценки динамики клинической манифестации заболеваний копыт в течение года ежемесячно проводили ортопедический осмотр. В ходе данного осмотра оценивали: степень и характер деформаций копыт; интенсивность разрушения рогового слоя; наличие специфических поражений: карманов, расслоений и трещин, а также положение грудных и тазовых конечностей. У коров с выявленными гнойно-некротическими поражениями в послеродовой период дополнительно выполняли детальное акушерско-гинекологическое обследование. Оно включало клинический осмотр, трансректальную пальпацию и УЗИ-сканирование, которое проводили на аппарате Scanner Falco (8 МГц). С помощью ультразвука определяли размеры, эхоплотность, однородность тканей и характер эхогенности структур репродуктивных органов.

Для иммунологических исследований кровь брали из яремной вены больных животных и коров из контрольной группы (n=23) утром перед кормлением в стерильные пробирки. Содержание общего белка в сыворотке крови коров определяли с помощью биуретовой реакции, белковых фракций - нефелометрическим методом, рассчитывали соотношение A/G. Количество С-реактивного белка определяли методом иммунофлюоресценции. Концентрацию церулоплазмина (ЦП) в сыворотке крови определяли стандартным методом, основанным на окислении п-фенилендиамина с участием ЦП. Уровень фибриногена определяли спектрофотометрически, гаптоглобина - турбидиметрическим методом. Уровень циркулирующих иммунных комплексов (ЦИК) и их фракционный состав анализировали на основе определения их молекулярной массы. Концентрации интерлейкинов (IL-1α и IL-8) и фактора некроза опухоли-α (TNF-α) измеряли методом твердофазного иммуноферментного анализа с использованием коммерческих наборов моноклональных антител и реагентов

производства (ООО «Цитокин», Санкт-Петербург, Россия).

Результаты. Согласно анализу множественных сравнений Тьюки, наиболее значимое повышение уровня ЦИК было зафиксировано в группе животных с коморбидной патологией. Это свидетельствует о том, что сочетанное течение эндометрита и заболеваний копыт приводит к более тяжелой системной воспалительной реакции по сравнению с изолированными формами болезней. Об этом свидетельствуют показатели белкового обмена, уровень белков острой фазы воспаления, цитокиновый профиль, а также количество циркулирующих иммунных комплексов в образцах крови подопытных животных.

Заключение. В настоящее время остро стоит вопрос об общем фундаментальном исследовании коморбидности в ветеринарной практике. Результаты исследования демонстрируют, что коморбидное течение ортопедической и акушерско-гинекологической патологии у высокопродуктивных животных характеризуется более тяжелой клинической картиной по сравнению с изолированными формами монопатологий. Об этом свидетельствует проведенный нами иммунологический скрининг. В связи с этим при ассоциированном течении нескольких патологий у животного необходимо применять индивидуальный подход, что диктует необходимость комплексного изучения клинического течения основных, сопутствующих и даже перенесенных заболеваний, их всесторонней диагностики, а также рационального лечения. В перспективе необходимо создание универсального инструмента, позволяющего ветеринарному врачу мгновенно и легко оценить структуру, тяжесть и возможные последствия сопутствующих заболеваний у животных, провести целенаправленную диагностику, а затем назначить правильный комплекс лечебных мероприятий.

Ключевые слова: факторные инфекции; иммунологические показатели; эндометрит; ортопедическая патология; коморбидность; коровы

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Introduction

The comorbidity of gynecological and orthopedic pathologies in dairy cattle results in substantial economic losses, stemming from diminished milk yield and the elevated expenses of diagnostic, therapeutic, and preventive veterinary measures [1-5]. The high prevalence of reproductive disorders and purulent-necrotic digital lesions necessitates the development of novel methods for their early diagnosis and management [2; 4; 6-8]. The development of various non-infectious pathologies in cows is multifactorial, stemming from stress, poor management practices, and technical errors. Key contributors include anthropogenic stress, inadequate housing, nutritional imbalances, improper dry-off periods, poor sanitation, antimicrobial misuse, endemic parasites, and mistakes in artificial insemination [1; 9-13]. In high-yielding dairy cows, systemic metabolic disorders frequently lead to the comorbid manifestation of orthopedic, obstetric, and gynecological diseases [14-19]. The prevalence of orthopedic pathology alone is a major concern, affecting 18-80% of herds. This results in a 40-50% decline in milk yield and the premature culling of up to 37% of animals, culminating in severe economic losses for producers [20-24]. The high prevalence of orthopedic pathology is furthermore associated with a significant reduction in the herd's reproductive performance. This is evidenced by impaired fertility, extended postpartum anaphrodisia, and an increased proportion of infertile cows, collectively diminishing overall reproductive efficiency [25; 26].

Existing evidence confirms etiological and pathogenetic links between reproductive and orthopedic disorders in cattle [5; 27-30]. However, the current lack of a holistic, systematic approach results in fragmented and thus less effective treatment and prevention strategies [31; 32]. Therefore, researching common triggers and shared pathological mechanisms is crucial. This will enable the development of reliable diagnostic and prognostic criteria for managing these comorbid conditions.

Consequently, this research aims to establish a foundation for developing targeted therapeutic and preventive strategies, ultimately enhancing cow health and reproductive performance. Based on this rationale, the objective of our study was to characterize the immunological profiles of cows with endometritis, orthopedic pathology, and comorbid presentation of both conditions.

Purpose. This study aims to evaluate the immunological status of high-yielding dairy cows experiencing comorbid obstetric-gynecological and orthopedic pathologies.

Materials and methods

This study was conducted within the herd of JSC Voskresenskoye (Voskresensky District, Moscow Region), which comprised 1,450 cattle, including 830 cows. The research was funded by grant No. 24-26-00172 from the Russian Science Foundation (https://rscf.ru/project/24-26-00172/). The experimental protocol was reviewed and approved by the Bioethics Commission of the Department of Veterinary Medicine at «ROSBIOTEKH», confirming adherence to international standards for the humane treatment of experimental animals, specifically the provisions of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (ETS 123, 1986). The study cohorts consisted of: high-producing cows with acute purulent-catarrhal postpartum endometritis (n=28); animals with purulent-necrotic diseases in the digits (n=25); cows with comorbid presentation of both endometritis and orthopedic pathology (n=27).

Monthly orthopedic examinations were conducted to assess the severity and type of deformities, the rate of hoof horn deterioration, and the progression of hoof diseases over a one-year period. Evaluations focused specifically on hoof conformation (presence of deformities), the integrity of the hoof horn (detecting pockets, fissures, delamination, and cracks), and the posture and alignment of both thoracic and pelvic limbs. In cows exhibiting purulent-necrotic digital lesions during the postpartum period, comprehensive obstetric and gynecological examinations were performed. These included evaluation of clinical signs, transrectal palpation, and ultrasonography of the reproductive organs using a Scanner Falco device with an 8 MHz transducer. The ultrasonographic assessment measured tissue dimensions, echo density, structural homogeneity, and the echogenic properties of both normal and pathological features.

Blood was collected from the jugular vein of sick animals and cows from the control group (n=23) in the morning before feeding in sterile tubes for immunological studies. The content of total protein in the blood serum of cats was determined by the biuret reaction, protein fractions - by the nephelometric method, the A/G ratio was calculated. The amount of C-reactive protein was determined by the immunofluorescence method. The concentration of ceruloplasmin (CP) in the blood serum was determined by the standard method based on the oxidation of p-phenylenediamine with the participation of CP. The fibrinogen level was determined spectrophotometrically, and haptoglobin - by the turbidimetric method. The total level of circulating immune complexes (CIC) and their fractional composition were determined by molecular weight. The content of interleukins (IL-1α and IL-8) and tumor necrosis factor (TNF-α) was determined using a solid-phase enzyme-linked immunosorbent assay of double antibodies using monoclonal antibody kits and reagents from Cytokine LLC (St. Petersburg, Russia).

The obtained data were subjected to statistical analysis and are presented as tables and figures. All computations were performed using STATISTICA 7.0 (StatSoft, USA) software with conventional statistical methods. Distribution normality was first assessed using ANOVA. The following parameters were calculated: 95% confidence interval (CI), arithmetic mean (Mean), standard error (SE), and standard deviation (SD). Statistical significance of differences was determined using Tukey’s test with the following notation: between control and experimental groups I–III – * p<0.05; ** p<0.01; *** p<0.001; between groups I and II – ◊ p<0.05; ◊◊ p<0.01; ◊◊◊ p<0.001; between groups I and III – ⸢ p<0.05; ⸢⸢ p<0.01; ⸢⸢⸢ p<0.001; between groups II and III – ⸙ p<0.05; ⸙⸙ p<0.01; ⸙⸙⸙ p<0.001.

Results

Clinical observations consistently reveal a clinically significant association between obstetric and orthopedic disorders in high-yielding dairy cattle. Notably, postpartum metritis demonstrates a higher incidence in cows presenting with purulent-necrotic lesions of the distal limbs, whether developed pre-partum or during the early postpartum period. Table 1 presents the protein metabolism parameters evaluated in high-productivity cows exhibiting comorbid endometritis and purulent-necrotic hoof pathology.

Table 1.

Protein metabolism indices in highly productive cows with comorbid course of endometritis and purulent-necrotic diseases in the hoof area

Index	Biometrics	Healthy cows (n=23)	Groups of sick cows			ANOVA test
			I (n=28)	II (n=25)	III (n=27)	
Total protein, g/l	M±SD	78.56±3.62	77.97±5.79	79.60±4.49	81.35±7.20	F=1.93; p<0.5
	95% CI	76.99–80.13	75.73–80.22	77.74–81.45	78.51–84.21	
Albumins, g/l	M±SD	39.09±3.17	35.03±4.92 *	33.39±6.38 ***	34.14±4.65 ***	F=6.27; p<0.001
	95% CI	37.71–40.45	33.12–36.94	30.76–36.02	32.29–35.98	
Globulins, g/l	M±SD	39.47±4.55	42.94±7.38	46.20±7.11 **	47.21±6.90 ***	F=6.79; p<0.001
	95% CI	37.51–41.44	40.08–45.81	43.27–49.14	44.48–49.95	
A\G, units	M±SD	1.00±0.17	0.86±0.28	0.76±0.25 **	0.74±0.17 ***	F=7.34; p<0.001
	95% CI	0.94–1.08	0.75–0.97	0.65–0.86	0.68–0.81	
alpha globulins, g/l	M±SD	9.69±2.06	13.29±4.13 ***	10.14±2.06 ◊◊	16.51±3.52 *** ⸢⸢⸙⸙⸙	F=26.08; p<0.001
	95% CI	8.80–10.58	11.69–14.89	9.29–10.99	15.12–17.91	
beta globulins, g/l	M±SD	11.04±2.23	7.22±1.89 ***	7.90±2.09 ***	7.03±1.79 ***	F=21.02; p<0.001
	95% CI	10.07–12.01	6.48–7.95	7.03–8.77	6.32–7.74	
gamma globulins, g/l	M±SD	18.74±6.19	22.34±6.37	28.16±7.58 ***◊	23.24±7.79	F=7.35; p<0.001
	95% CI	16.06–21.42	19.87–24.82	25.03–31.29	20.16–26.32	
alpha1 proteinase inhibitor, mg/l	M±SD	29.29±5.81	27.34±5.81	30.47±5.35	31.73±3.27 ⸢	F=3.61; p<0.05
	95% CI	26.77–31.80	25.08–29.59	28.26–32.68	30.43–33.01	
alpha2-macroglobulin, g/l	M±SD	1.12±0.09	1.15±0.18	0.89±0.23 **◊◊	0.77±0.87 *** ⸢⸢⸢	F=20.78; p<0.001
	95% CI	1.08–1.16	1.09–1.22	0.79–0.99	0.67–0.88	

Using one-way analysis of variance (ANOVA test), significant changes were found in the parameters of total protein ($F=1.93$; $p<0.5$), albumin ($F=6.27$; $p<0.001$), globulin ($F=6.79$; $p<0.001$), albumin/globulin ratio ($F=7.34$; $p<0.001$), alpha-globulins ($F=26.08$; $p<0.001$), beta-globulins ($F=21.02$; $p<0.001$), gamma-globulins ($F=7.35$; $p<0.001$), alpha1-proteinase inhibitor ($F=3.61$; $p<0.05$) and alpha2-macroglobulin ($F=20.78$; $p<0.001$). In this case, the null hypothesis that the protein metabolism indices in animals of different groups belong to the same general population can be rejected. Subsequently, Tukey's multiple comparisons analysis was performed for a detailed statistical analysis of the differences between the experimental groups of animals. Thus, it was found that the most significant changes in protein metabolism indices occur with the clinical manifestation of the comorbid course of endometritis and purulent-necrotic diseases in the hoof area in highly productive cows. At the same time, a decrease in the amount of albumins by 10.14 times ($p<0.001$); albumin/globulin ratio by 1.35 times ($p<0.001$); beta-globulins by 1.57 times ($p<0.001$) and alpha2-macroglobulins by 1.45 times ($p<0.001$), against the background of an increase in globulins by 1.19 times ($p<0.001$) and alpha-globulins by 1.70 times ($p<0.001$), when compared with the indicators of healthy animals.

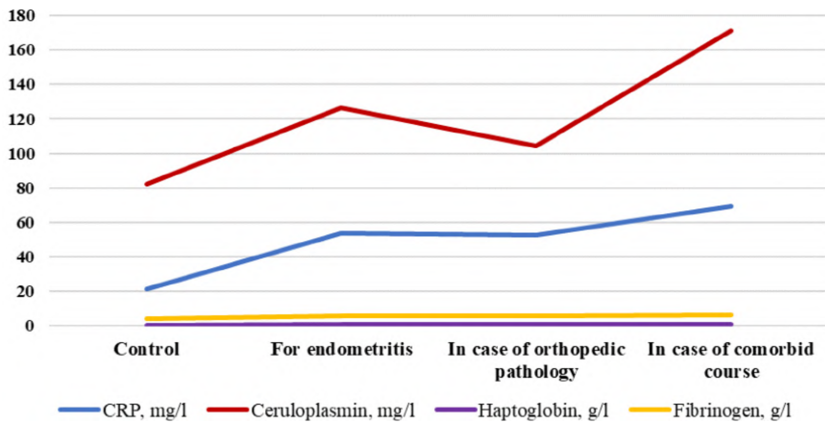

Fig. 1. Level of acute phase inflammation proteins in highly productive cows with comorbid endometritis and purulent-necrotic diseases in the hoof area

One of the main markers of the severity of the inflammatory reaction are acute phase proteins. These proteins are synthesized in the liver, and their concentration depends on the stage of the disease and the extent of damage. High correlation of the concentration of acute phase proteins in the blood with the activity of the infectious process and its stage distinguishes them favorably from such indicators as an increase in ESR or a shift in the leukocyte formula to the left. In this regard, we also determined the level of acute phase proteins of inflammation in highly productive cows with comorbid endometritis and purulent-necrotic diseases in the hoof area, which is shown in the figure.

The data in the figure indicate that during the clinical manifestation of both individual pathologies and their comorbid course, the indices of acute phase inflammation proteins in the blood serum increase significantly. Thus, in cows with endometritis, a highly reliable ($p<0.001$) increase in C-reactive protein, fibrinogen, haptoglobin and ceruloplasmin was recorded by 2.50 times, from 21.56±6.63 mg/l to 53.96±17.55 mg/l; by 1.45 times, from 4.09±0.53 g/l to 5.92±0.39 g/l; by 2.04 times from 0.51±0.10 g/l to 1.04±0.18 g/l and by 1.54 times from 82.17±5.19 mg/l to 126.32±11.84 mg/l, respectively, when compared with clinically healthy animals. It was established that with clinical manifestation of purulent-necrotic diseases in the hoof area in highly productive cows, a reliable increase ($p<0.001$) was observed in the blood serum of C-reactive protein from 21.56±6.63 mg/l to 52.44±10.38 mg/l by 58.9%; fibrinogen from 4.09±0.53 g/l to 5.96±0.63 g/l, by 32.2%; haptoglobin from 0.51±0.10 g/l to 1.01±0.23 g/l, by 49.5% and ceruloplasmin from 82.17±5.19 mg/l to 104.28±12.98 mg/l, by 21.2%. It should be noted that in cows with comorbid endometritis and orthopedic pathology, the most noticeable increase ($p<0.001$) in acute phase proteins was observed: CRP by 3.21 times, from 21.56±6.63 mg/l to 69.26±6.28 mg/l; fibrinogen by 1.57 times, from 4.09±0.53 g/l to 6.42±1.19 g/l; haptoglobin by 2.39 times, from 0.51±0.10 g/l to 1.22±0.47 g/l; CP by 2.08 times, from 82.17±5.19 mg/l to 171.22±36.53 mg/l, when compared with the indicators of healthy animals.

The level of proinflammatory cytokines in the blood serum of cows with single pathologies, as well as with comorbid course of endometritis and purulent-necrotic diseases in the hoof area is given in Table 2.

Reliable changes in the levels of IL-1alpha ($F=146.01$; $p<0.001$), IL-8 ($F=254.00$; $p<0.001$) and TNF-alpha ($F=130.41$; $p<0.001$) in the blood serum of animals from different experimental groups were established using the one-way analysis of variance (ANOVA test), which made it possible to conduct Tukey's multiple comparisons analysis to identify differences between the experimental groups. It was shown that both in case of single pathologies in cows and in case of comorbid course of two diseases, a highly reliable increase in the level of proinflammatory interleukins was recorded in the blood serum. However, the most significant deviations in the cytokine profile were revealed in animals with comorbid course of endometritis and purulent-necrotic diseases in the hooves. Thus, in the combined course of obstetric-gynecological and orthopedic pathologies, a reliable increase in the level of IL-1alpha was revealed from 19.44±1.95 pg/ml to 40.15±2.41 pg/ml, by 2.06 times ($p<0.001$); IL-8 from 13.65±1.27 pg/ml to 39.15±3.37 pg/ml, by 2.86 times ($p<0.001$); TNF-alpha from 42.04±2.95 pg/ml to 102.33±8.23 pg/ml, by 2.43 times ($p<0.001$), when compared with clinically healthy cows.

Table 2.

Cytokine profile in highly productive cows with comorbid endometritis and purulent-necrotic diseases in the hoof area

Index	Biometrics	Healthy cows (n=23)	Groups of sick cows			ANOVA test
			I (n=28)	II (n=25)	III (n=27)	
IL-1alpha, pg/ml	M±SD	19.44±1.95	33.39±3.81 ***	34.12±5.14 ***	40.15±2.41 *** ПТ⸙⸙⸙	F=146.01; p<0.001
	95% CI	18.59–20.27	31.91–34.87	31.99–36.24	39.19–41.10	
IL-8, pg/ml	M±SD	13.65±1.27	26.04±4.29 ***	29.72±3.20 ***◊◊◊	39.15±3.37 *** ПТ⸙⸙⸙	F=254.00; p<0.001
	95% CI	13.11–14.19	24.37–27.70	28.40–31.03	37.82–40.48	
TNF-alpha, pg/ml	M±SD	42.04±2.95	74.21±17.67 ***	74.68±6.58 ***	102.33±8.23 *** ПТ⸙⸙⸙	F=130.41; p<0.001
	95% CI	40.76–43.32	67.36–81.07	71.96–77.39	99.08–105.59	

The levels of circulating immune complexes in the blood serum of highly productive animals with a single manifestation of the disease, as well as with comorbid course of endometritis and purulent-necrotic diseases in the hoof area are shown in Table 3.

Tukey's multiple comparisons analysis showed that with clinical manifestation of both endometritis and orthopedic pathology in cows, a reliable increase in CIC levels is recorded in the blood, but the most significant increases are noted in the group with comorbid endometritis and purulent-necrotic diseases in the hooves. Thus, in highly productive animals with combined manifestation of endometritis and orthopedic pathology, a highly reliable ($p < 0.001$) increase in the level of CIC, general was recorded in the blood serum from 288.08 ± 26.9 un. wh. space to 583.56 ± 52.02 un. wh. space, by 2.02 times; CIC, large from 35.78 ± 5.22 un. wh. space to 56.41 ± 12.16 un. wh. space, by 1.57 times; CIC, average from 84.30±5.29 un. wh. space to 107.48±12.15 un. wh. space, by 1.27 times and CIC, small from 168.00±28.51 un. wh. space to 419.67±54.89 un. wh. space, by 2.49 times, when compared with the indicators of healthy cows.

Table 3.

Circulating immune complexes (CIC) in high-yielding cows with comorbid endometritis and purulent-necrotic diseases in the hoof area

Index	Biometrics	Healthy cows (n=23)	Groups of sick cows			ANOVA test
			I (n=28)	II (n=25)	III (n=27)	
CIC, general, un. wh. space	M±SD	288.08±26.9	398.00±28.04 ***	418.92±34.58 ***	583.56±52.02 *** ПТ⸙⸙⸙	F=273.90; p<0.001
	95% CI	27.6–299.72	387.12–428.04	404.65–433.19	562.97–604.13	
CIC, large, un. wh. space	M±SD	35.78±5.22	47.04±2.75 ***	49.84±7.65 ***	56.41±12.16 *** ПТ⸙	F=29.63; p<0.001
	95% CI	33.52–38.04	45.97–48.10	46.68–52.99	51.59–61.22	
CIC, average, un. wh. space	M±SD	84.30±5.29	90.89±11.91	101.80±11.51 ***◊◊	107.48±12.15 *** ПТ	F=29.63; p<0.001
	95% CI	82.01–86.59	86.27 – 95.51	97.05 – 106.55	102.67 – 112.29	
CIC, small, un. wh. space	M±SD	168.00±28.51	262.82±41.39 ***	267.28±36.37 ***	419.67±54.89 *** ПТ⸙⸙⸙	F=156.43; p<0.001
	95% CI	155.67–180.32	246.77–278.87	252.27–282.29	397.65–441.38	

Consequently, the clinical presentation of comorbid orthopedic and obstetric-gynecological pathology in high-yielding cows is more severe than that of either condition occurring in isolation. This is evidenced by protein metabolism indicators, the level of acute phase inflammation proteins, the cytokine profile, as well as the number of circulating immune complexes in blood samples of experimental animals.

Conclusion

Currently, the issue of a general fundamental study of comorbidity in veterinary practice is urgently needed. It has been established that the clinical manifestation of comorbid orthopedic and obstetric-gynecological pathology in highly productive animals has a more severe manifestation than in the course of individual diseases. This is evidenced by the immunological screening we conducted. Therefore, the management of animals with comorbid conditions requires an individualized approach. This necessitates a comprehensive evaluation of the clinical presentation of primary, concurrent, and previous diseases, coupled with integrated diagnostic methods and rational therapeutic strategies. In the future, it is necessary to create a universal tool that allows a veterinarian to instantly and easily assess the structure, severity and possible consequences of comorbid diseases in animals, conduct targeted diagnostics, and then prescribe the correct set of therapeutic measures.

Conflict of interest information. The authors declare that they have no conflict of interest.

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ТЯГОВЫЕ ПОКАЗАТЕЛИ ШИН РАЗЛИЧНОГО КОНСТРУКТИВНОГО ИСПОЛНЕНИЯ ДЛЯ КОМПЛЕКТАЦИИ ДВИЖИТЕЛЕЙ МОБИЛЬНЫХ ЭНЕРГЕТИЧЕСКИХ СРЕДСТВ ПЯТОГО КЛАССА ТЯГИ

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Аннотация

Обоснование. Свойства шины являются основными факторами, определяющими тяговые и агротехнологические показатели колесных мобильных энергетических средств.

Целью исследования является изучение эффективности тяговых показателей крупногабаритных шин различных конструкций для оснащения ходовой системы мобильных энергетических средств пятого класса тяги.

Материалы и методы. Тяговый КПД, как универсальный показатель эффективности эксплуатации колесной мобильной энергетической машины, в значительной степени определяется конструкцией пневматических шин её ходовой системы. Поэтому в качестве объектов исследования были использованы серийные шины 30,5R-32 и 33R-32, шины имеющие оптимизированное армирование оболочки 30,5R-32M и 33R-32M, шины экспериментального (диагонально-параллельного) конструктивного исполнения 33DP-32.

Исследования шин, предназначенных для ведущих колёс тракторов пятого класса тяги, для установления их тягово-энергетических показателей проводились экспериментальными методами путём проведения их испытаний на специально изготовленной установке «шинный тестер».

Испытания тягово-сцепных свойств шин при различных давления воздуха в них проводили на различных опорных основаниях: бетоне, стерне зерновых колосовых и поле для посева.

Подтверждение полученных результатов были получены при тяговых испытаниях трактора К-701М при комплектации его ходовой системы испытанными шинами.

В **результате** проведённых тяговых испытаний трактора пятого класса тяги (К-701М) было установлено несомненное преимущество установки на его ведущие колёса шин с параметрами внутреннего армирования, имеющими оптимальные значения, перед оснащением их шинами серийного изготовления.

Все шины при испытании на бетонном основании показали практически одинаковые тяговые показатели, но всё же шины 30,5R-32M, 33R-32M и 33DP-32 имели их значения несколько выше.

На стерне и поле для посева шины 30,5R-32M, 33R-32M и 33DP-32 по сравнению с серийными показали в основном за счёт уменьшения буксования на 5…16 % тяговый КПД выше на 0,03 и более. Следует отметить заметное преимущество шин 33R-32M и 33DP-32 по тяговым показателям на обоих агрофонах при установлении пониженного внутришинного давления, которое составляет для них соответственно на стерне 0,11 и 0,09 МПа и на поле для посева 0,09 и 0,07 МПа.

Выводы. Доказано, что трактор К-701М, на ведущие колёса которого устанавливались модернизированные и экспериментальные шины, показал более высокий (от 7 до 19 %) условный тяговый КПД по сравнению с комплектацией его ходовой системы серийными шинами.

Установлено, что серийные шины 30,5R-32 и 33R-32 при их испытании на жёстком опорном показали практически одинаковое значение тягового КПД. Наилучшие тягово-энергетические показатели на бетоне показали шины модернизированная 33R-32M и, особенно, 33DP-32, показавшая значение тягового КПД почти 0,84 за счёт незначительного буксования (3,2%).

На различных агрофонах наименьшие тяговые показатели продемонстрировала серийная шина 30,5R-32, а наивысшие – диагонально-параллельная шина 33DP-32.

Ключевые слова: мобильное энергетическое средство; движитель; пневматическое колесо; шина; сопротивление самоходу; проскальзывание; тяговая эффективность

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Original article

TRACTION CHARACTERISTICS OF TIRES OF VARIOUS DESIGNS FOR THE COMPLETE SET OF MOBILE PROPULSION DEVICES OF THE FIFTH TRACTION CLASS

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Abstract

Background. Tire properties are the main factors determining traction and agricultural technological performance of wheeled mobile energy vehicles.

Purpose. The purpose of the research is to study the traction indicator efficiency of large-sized tires of various designs for equipping the running system of mobile power equipment of the fifth traction class.

Materials and methods. Traction efficiency, as a universal indicator of the operation efficiency of a wheeled mobile energy machine, is largely determined by the pneumatic tire design of a running system. Therefore, serial tires 30.5R-32 and 33R-32, tires with optimized shell reinforcement 30.5R-32M and 33R-32M, and tires of experimental (diagonal-parallel) design 33DP-32 were used as objects of research.

The research of tires designed for tractors' driving wheels of the fifth traction class, in order to establish their traction and energy parameters, was carried out experimentally by testing them on a specially manufactured tire test bench.

Traction properties tests of tires (at various air pressures in them) were carried out on different supporting bases: concrete, stubble of grain ears, and a field for sowing.

Results' confirmation was obtained during traction tests of the K-701M tractor when its running system was equipped with tested tires.

Results. As a result of the traction tests carried out on a tractor of the fifth traction class (K-701M), the undoubted advantage of installing tires with optimal internal reinforcement parameters on its driving wheels over equipping them with mass-produced tires was established.

All tires tested on a concrete base showed almost the same traction characteristics, but still the 30.5R-32M, 33R-32M and 33DP-32 tires had slightly higher values.

On stubble and in the field for sowing, the 30.5R-32M, 33R-32M and 33DP-32 tires showed a higher traction efficiency of 0.03 or more due to a decrease in slipping by 5...16% compared to the production ones. It should be noted that the 33R-32M and 33DP-32 tires have a noticeable advantage in traction performance at both agricultural ranges when setting a reduced intraperitoneal pressure, which is 0.11 and 0.09 MPa for them, respectively, on stubble and 0.09 and 0.07 MPa in the field for sowing.

Conclusion. It is proved that the K-701M tractor, which had upgraded and experimental tires installed on the driving wheels, showed a higher (from 7 to 19%) conditional traction efficiency compared to the complete set of its chassis system with serial tires.

It was found that the serial tires 30.5R-32 and 33R-32, when tested on a rigid support, showed almost the same traction efficiency. The best traction and energy performance on concrete was shown by the upgraded 33R-32M tires and, especially, the 33DP-32, which showed a traction efficiency of almost 0.84 due to slight slipping (3.2%).

At various agricultural farms, the serial tire 30.5R-32 demonstrated the lowest traction performance, while the diagonal-parallel tire 33DP-32 demonstrated the highest traction performance.

Keywords: mobile energy vehicle; propulsion; pneumatic wheel; tire; self-propelled resistance; slippage; traction efficiency

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Введение

Важнейшей задачей работников сельского хозяйства Российской Федерации является обеспечение на основе эффективного конкурентоспособного агропромышленного производства продовольственной безопасности нашей страны и успешное интегрирование в мировой рынок сельскохозяйственной продукции. Для этого требуется на основе применения в агропромышленном комплексе (АПК) новых технологий и совершенствования мобильных энергетических средств (МЭС) добиться существенного снижения себестоимости растениеводческой продукции путём повышения качества выполнения технологических операций, а также снижения трудовых и эксплуатационных затрат за счёт значительного прироста производительности машинно-тракторных агрегатов (МТА) и уменьшения удельного расхода топлива.

Анализ развития показывает, что на ходовые системы мобильных средств, с помощью которых выполняются различные технологические операции при выращивании растениеводческой продукции, устанавливаются гусеничные или колесные движители [1-3]. В мире и России применение в сельском хозяйстве МЭС с колёсными ходовыми системами превышает 85 % вследствие их более высокой универсальности. Однако они в настоящее время по некоторым эксплуатационным показателям (энергозатраты на перемещение, уплотняющее воздействие на почву и т.д.) уступают гусеничным машинам [4-7].

Поэтому весьма актуальным является решение **проблемы** повышения тягово-энергетических показателей функционирования колёсной мобильной сельскохозяйственной техники.

Эффективность МТА можно повысить за счёт увеличения их ширины захвата и эксплуатации на повышенных скоростях, но это требует использование в составе агрегата МЭС, имеющего высокие тяговые показатели [2; 3].

Известно [8; 9], что тяговый КПД МЭС зависит главным образом от КПД движителей, так как в них происходят главные непроизводительные потери энергии при перемещении МТА, в связи с чем, технико-экономические показатели МЭС (тяговая характеристика, плавность хода, агротехнические и агротехнологические показатели и т.д.) с высокой степенью достоверности можно установить по результатам испытаний единичных пневматических колёс.

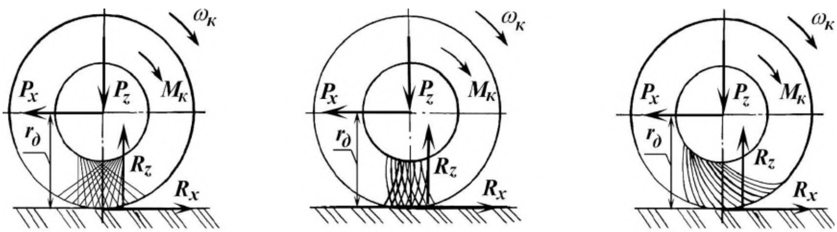
Поэтому при разработке и модернизации мобильной сельскохозяйственной техники (МСТ) необходимо обращать пристальное внимание на научные изыскания, главной задачей которых является совершенствование составных элементов ходовых систем сельскохозяйственных машин.

Подбор и комплектование ходовых систем сельскохозяйственных тракторов и зерноуборочных комбайнов шинами диагонального конструктивного исполнения в недавний исторический период производились, опираясь, в основном, на их долговечность и высокую несущую способность, что привело к возникновению проблемы переуплотнения почвы со всеми вытекающими последствиями.

Поэтому одним из путей решения вышеуказанных проблем (повышение тягово-энергетических показателей и агротехнической проходимости МСТ) является модернизация внутреннего армирования существующих диагональных и радиальных шин и разработка шин принципиально нового конструктивного исполнения для комплектования ими ходовых систем МТА [1, 7].

На основании вышеизложенного, задачей представляемого в данной статье научного исследования является сравнительная оценка тягово-энергетических показателей шин, имеющих различное конструктивное исполнение, для комплектования ходовых систем МЭС тягового класса 5.

Принципиальные схемы конструктивного исполнения шин представлены на рисунке 1.



а *б* *с*

шина конструктивного исполнения:
а – диагонального; *б* – радиального; *в* – диагонально-параллельного
Рис. 1. Принципиальные схемы конструктивного исполнения пневматических шин

В диагональных шинах (рисунок 1 *а*) волокна в оболочке расположены в обоих направлениях под углом от 15° до 45° к меридиану. Это обеспечивает оболочке очень высокую жёсткость, поэтому такие шины широко использовали для установки на колёса МСТ и транспортных средств, у которых создавались в процессе передвижения высокие вертикальные нагрузки на оси мостов. Но такие шины не гарантировали щадящее воздействие на агрофоны.

У радиальных шин (рисунок 1 *б*) волокна в оболочке расположены к меридиану под углом 0°...15°, что способствует обеспечению им гибкости, увеличению площади контакта с почвой до 20 %, чем диагональных шин таких же габаритных размеров, и росту тяговых показателей. Поэтому радиальные шины сейчас широко устанавливают на сельскохозяйственных МЭС и автомобилях.

В шинах диагонально-параллельного конструктивного исполнения, армирование которых выполнены по патенту РФ № 2677817 (рисунок 1 с), волокна в оболочках укладываются под углом к меридиану как в диагональных шинах, но в отличие располагаются параллельно в нескольких смежных слоях, поэтому зонах действия касательных сил волокна оболочки испытывают деформации растяжения, а в зоне соприкосновения их с опорным основанием – деформацию изгиба. За счёт этого обеспечивается при качении этих шин по агрофонам значительное уменьшение гистерезисных потерь и давления на почву в площади контакта колеса с почвой.

Метод исследования

При исследовании нами использовались серийные шины 30,5R-32 и 33R-32, модернизированные шины с оптимизированным внутренним армированием оболочки 30,5R-32M, 33R-32M и экспериментальные шины 33DP-32 (см. патент РФ № 2677817), некоторые характеристики которых представлены в таблице 1.

Таблица 1.

Некоторые характеристики испытываемых шин

Геометрические параметры шин		Ед. изм.	Испытываемые шины				
			30,5R-32	30,5R-32M	33R-32	33R-32M	33DP-32
Габариты	диаметр	мм	1830±4	1825±4	1924±4	1930±3	1723
	ширина	мм	768	725	829	830	1100
Рисунок протектора	высота грунтозацепов	мм	52	65	54	54	54
	шаг грунтозацепов	мм	274	276	288	290	295
	коэффициент насыщенности	-	0,318	0,328	0,300	0,300	0,300
Максимальная нагрузка		кН	51,0	51,0	44,2	44,2	68,0

Исследования тягово-энергетических показателей шин, предназначенных для ведущих колёс тракторов пятого класса тяги, проводились экспериментальными методами путём проведения их испытаний на специально изготовленной установке «шинный тестер» (см. патенты РФ №, 2107275, 2167402 и др.).

Нормальная нагрузка на испытуемое колесо устанавливалась с помощью грузов: на шинах 33R-32, 33R-32M, 33DP-32 – 40,8 кН, а на шинах 30,5R-32 и 30,5R-32M – 40,0 кН.

Испытания тягово-сцепных свойств шин при различных давления воздуха в них проводили на различных опорных основаниях: бетоне, стерне зерновых колосовых и поле для посева.

Подтверждение полученных результатов были получены при тяговых испытаниях трактора К-701М при комплектации его ходовой системы испытанными шинами.

В таблице 2 приведены характеристики сельскохозяйственных агрофонов, на которых походили испытания шин и трактора К-701М.

Таблица 2.

Характеристики сельскохозяйственных агрофонов при испытании шин и трактора К-701М

Почвенные показатели по слоям	Глубина слоя, см	Единица измерения	Сельскохозяйственный агрофон	
			стерня зерновых культур	поле под посев
Удельная плотность почвы по слоям	0 – 10	г/см^3	1.078	0.875
	10 – 20		1.167	1.186
	20 – 30		1.134	1.262
Влажность почвы по слоям	0 – 10	%	16.93	9.39
	10 – 20		19.48	19.86
	20 – 30		21.01	20.89
Высота стерневого покрова		см	15.0	–

Условия проведения испытаний шин и трактора К-701М при различной комплектации его движителей соответствовали требованиям соответствующих стандартов.

Результаты исследований

При испытаниях шин на шинном тестере мы проводили измерения следующих параметров при качения колеса на ведущем режиме: крутящий момент $M_к$ на оси колеса; горизонтальные силы соответственно на левой и правой сторонах ведущей оси колеса R_1, R_2; нагрузку по нормали R на ось колеса; массу колеса m_K, определяемую совместно с приводом, закрепленным на оси; угол наклона α рамы «шинного тестера» к горизонту; расстояние S_{on}, пройденное колесом при испытании; обороты n_K колеса; свободный кинематический радиус r_K^C колеса.

По этим данным в дальнейшем производился расчёт по широко известным зависимостям следующие тягово-энергетические показали:

– развиваемое колесом тяговое усилие P_K:

$$P_K = R_1 + R_2 \pm (R - m_K \cdot g) \cdot \alpha, \quad (1)$$

– кинематический радиус колеса $r_К$:

$$r_К = \frac{S_{оп}}{2 \cdot \pi \cdot n_К}, \qquad (2)$$

– тяговый КПД колеса:

$$\eta_К = \frac{P_К}{M_К} \cdot r_К, \qquad (3)$$

– величину буксования колеса:

$$\delta = 1 - \frac{r_К}{r_К^С}, \qquad (4)$$

– коэффициент сопротивления самопередвижения *f* колеса:

$$f = \frac{M_К}{r_К^С \cdot m_К \cdot g}. \qquad (5)$$

Модернизировать движители МСТ можно различными способами. На наш взгляд наиболее рациональными из них представляется улучшение показателей движителей путём оптимизации строения оболочек шин, а также применение шин нового (диагонально-параллельного) конструктивного исполнения в соответствии с патентом РФ № 2677817.

Параметры оптимизированного внутреннего строения шин зависят от назначения мобильного сельскохозяйственного средства. Для универсальных МЭС в результате оптимизации параметров армирования шин их движителей необходимо обеспечить достижение максимального значения тяговой мощности при допустимой радиальной деформации шин и минимизации уровня негативного воздействия на почвенное основание. Для зерноуборочных комбайнов и пропашных МЭС следует обеспечить достижение максимальной величины площади контакта шины ведущего колеса с почвой и её допустимого прогиба при максимальном тяговом КПД.

При оптимизации армирования оболочек шин нами в работе использовались симплекс-метод Данцига (для зерноуборочных комбайнов) и метод «исследование пространства параметров» (для универсальных тракторов пятого класса тяги), в результате чего были установлены параметры внутреннего строения крупногабаритных радиальных шин.

В качестве примера приводим данные внутреннего армирования радиальных шин 30,5R-32 для различных вариантов применимости:

– для зерноуборочного комбайна число слоёв брекера должно быть равно 7, число слоёв каркаса – 6, угол укладки нитей корда брекера – 62^0, угол укладки нитей корда каркаса – 15^0;

– для МЭС пятого класса тяги значения аналогичных параметров соответственно равны 4, 6, 70^0 и около 0^0.

В результате анализа тяговых показателей трактора К-701М на стерне озимого ячменя при установке на его движители шин 30,5R-32 и 30,5R-32М (таблица 3), было доказано существенное преимущество второго вариантом шин.

Таблица 3.

Тяговые показатели трактора К-701М на стерне озимого ячменя

Стандартный размер шин	Ходовая часть	Тяговое усилие на крюке, кН	Рабочая скорость, км/ч	Буксование, %	Условный коэффициент тяговой эффективности	Удельный расход топлива, г/кВт·ч
30,5R-32	2-1	78.0	5.6	27.1	0.548	407
	2-2	69.0	7.4	20.4	0.641	364
	3-2	64.0	8.2	16.6	0.658	356
	3-3	54.5	10.3	11.2	0.704	322
	2-4	49.5	11.5	9.2	0.714	319
30,5R-32М	2-1	72.5	6.7	20.8	0.605	363
	2-2	70.0	7.4	18.4	0.660	358
	3-2	65.0	8.4	14.2	0.685	336
	3-3	54.5	10.4	8.2	0.711	319
	2-4	50.0	11.0	6.2	0.716	317

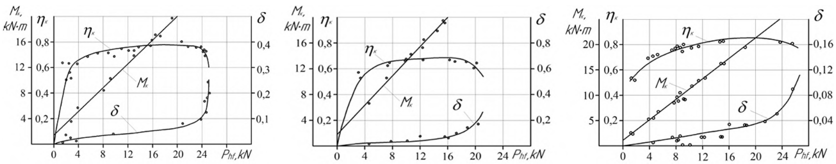
Трактор К-701М, оснащенный шинами с оптимальными параметрами, показал при контрольных сменах более высокий условный тяговый КПД по сравнению с серийной версией на 7...19 % при снижении удельного расхода топлива на единицу мощности от 3 до 9 г/кВт·ч.

При выполнении транспортных операций часовой расход топлива МТА на базе МЭС при комплектации ведущих колёс модернизированными шинами уменьшился на 13 %, несмотря на рост скорости перемещения до 0,5 км/ч.

Графические зависимости крутящего момента на оси ведущего колеса от величины тягового усилия (рисунки 2...4) для всех выбранных шин имеют практически прямолинейный характер.

В работе была сделана оценка изменения радиуса качения $r_К(P_к)$ и буксования $\delta(P_к)$ испытываемых шин на различных опорных основаниях в зависимости от величины тягового усилия.

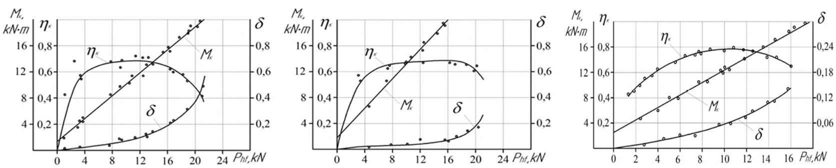
Анализом результатов испытаний установлено, что на жёстком основании для всех шин до достижения величины тягового усилия выше номинального (12,5 кН) закономерности изменения этих характеристик носят прямолинейный характер. При увеличении тягового усилия вплоть до возникновения буксования всех контактирующих элементов шины с бетоном, зависимости $r_К(P_к)$ и $\delta(P_к)$ совершают резкий изгиб.



а б в

а – шина 30,5R-32M (давление в шине 0,11 МПа); б – шина 33R-32 (давление в шине 0,11 МПа); в – шина стандартного размера 33DP-32 (давление в шине 0,13 МПа)

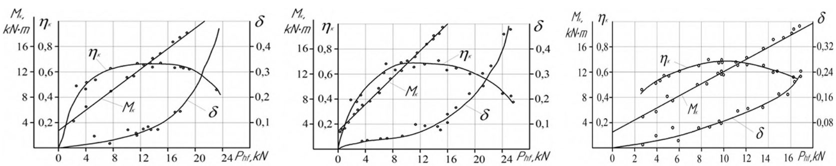
Рис. 2. Основные и тяговые характеристики испытуемых шин на бетоне



а б в

а – шина 30,5R-32M (давление в шине 0,11 МПа); б – шина 33R-32 (давление в шине 0,09 МПа); с – шина 33DP-32 (давление в шине 0,09 МПа)

Рис. 3. Основные и тяговые характеристики испытываемых шин на стерне зерновых культур



а б в

а – шина 30,5R-32M (давление в шине 0,11 МПа); б – шина 33R-32 (давление в шине 0,07 МПа); с – шины 33DP-32 (давление в шине 0,07 МПа)

Рис. 4. Основные и тяговые характеристики испытываемых шин на поле, подготовленном к посеву

Результаты испытаний шин на агрофонах показали практическое отсутствие на графиках функциональных зависимостей $r_К(P_к)$ и $\delta(P_к)$ прямолинейных участков. По сравнению с движением по бетону кинематические радиусы колёс при перемещении по агрофонам становится значительно меньше, а буксование намного выше, особенно это характерно для парового поля.

Как показали исследования, основной энергетический показатель (тяговый КПД) всех выбранных для испытания шин имеет в зоне номинального тягового усилия четко выраженное максимальное значение.

Анализом результатов испытаний шин (таблица 4) нами были установлены соответствия величин тяговых усилий P_K и буксования δ шин, полученных при максимальном значении их тягового КПД η_{max}, а также значений тягового КПД η_K шин и их буксования δ при номинальном тяговом усилии (P_K = 12,5 кН).

Установлено, что серийные шины 30,5R-32 и 33R-32 при их испытании на жёстком опорном показали практически одинаковое значение тягового КПД. Наилучшие тягово-энергетические показатели на бетоне показали шины модернизированная 33R-32M и, особенно, 33DP-32, показавшая значение тягового КПД почти 0,84 за счёт незначительного буксования (3,2%), полученное вследствие её более высокой жёсткости и в продольном и в окружном направлениях.

Анализом данных испытаний шин на основных агрофонах установлено, что по сравнению с шиной 30,5R-32 шины 30,5R-32M, 33R-32M и 33DP-32 имеют более высокие тягово-энергетические показатели: величины тяговых КПД выше на 0,03 и более при меньшем буксовании их на 5...16 %. Следует отметить заметное преимущество шин 33R-32M и 33DP-32 по тяговым показателям на обоих агрофонах при установлении пониженного внутришинного давления, которое составляет для них соответственно на стерне 0,11 и 0,09 МПа и на поле для посева 0,09 и 0,07 МПа. Этот эффект объясняется тем, что при указанных величинах давлениях p_w в оболочке шин снижаются гистерезисных потери энергии, обеспечивается более равномерное распределение давления колеса по всей площади контакта колеса с почвой, а глубина колеи – практически одинаковой по всей её ширине.

Таблица 4.

Показатели тяговой эффективности шин для оснащения тракторов пятого класса тяги на различных грунтах

Шина		30.5R32M				33R-32				33R-32M				33DP-32			
		Давление в шине, МПа															
		0,07	0,09	0,11	0,13	0,07	0,09	0,11	0,13	0,07	0,09	0,11	0,13	0,07	0,09	0,11	0,13
Стерня зерновых культур																	
Показатели при максимальном коэффициенте тяговой эффективности η_{max}	η		0,73	0,75	0,75		0,74	0,75	0,73		0,77	0,78	0,76		0,78	0,74	0,73
	Pk, kN		11,3	11,5	11,3		11,7	11,5	11,3		11,3	11,8	11,7		11,7	11,5	11,3
	δ, %		10,0	9,6	9,4		9,2	8,4	10,8		8,2	8,4	8,0		8,6	8,0	8,0
Показатели при Pk = 12,5 кН	η		0,72	0,73	0,73		0,72	0,74	0,72		0,76	0,77	0,75		0,77	0,73	0,71
	δ, %		12,8	12,0	11,8		11,2	10,5	12,0		10,2	10,2	10,4		12,0	10,0	10,6
Поле, подготовленное к посеву																	
Показатели при максимальном коэффициенте тяговой эффективности η_{max}	η	0,67	0,67	0,67		0,70	0,69	0,68		0,69	0,71	0,70		0,71	0,69	0,68	
	Pk, kN	11,1	11,0	11,0		10,8	10,5	11,0		11,2	11,3	11,0		11,4	11,2	11,3	
	δ, %	10,4	10,8	10,4		9,8	10,0	10,8		10,2	10,4	10,2		10,4	9,8	9,2	
Показатели при Pk = 12,5 кН	η	0,66	0,67	0,66		0,69	0,67	0,67		0,69	0,70	0,69		0,70	0,68	0,67	
	δ, %	12,6	13,0	12,8		11,6	12,8	13,0		11,2	12,0	11,4		11,8	11,2	10,8	

Как показали результаты экспериментальных испытаний выбранных для сравнения шин, что все они на стерне при развиваемом тяговом усилии $P_К$ = 12,5 кН и более имели максимальные величины тягового КПД, а это имеет важное значение для МЭС пятого класса тяги.

Выводы

Доказано, что трактор К-701М, на ведущие колёса которого устанавливались модернизированные и экспериментальные шины, показал более высокий (от 7 до 19 %) условный тяговый КПД по сравнению с комплектацией его ходовой системы серийными шинами.

Установлено, что серийные шины 30,5R-32 и 33R-32 при их испытании на жёстком опорном показали практически одинаковое значение тягового КПД. Наилучшие тягово-энергетические показатели на бетоне показали шины модернизированная 33R-32M и, особенно, 33DP-32, показавшая значение тягового КПД почти 0,84 за счёт незначительного буксования (3,2%). На различных агрофонах наименьшие тяговые показатели продемонстрировала серийная шина 30,5R-32. а наивысшие – диагонально-параллельная шина 33DP-32. По сравнению с шиной 30,5R-32 шины 30,5R-32M, 33R-32M и 33DP-32 имеют более высокие тягово-энергетические показатели: величины тяговых КПД выше на 0,03 и более при меньшем буксовании их на 5...16 %.

Результаты исследований показывают настоятельную необходимость оптимизации внутреннего армирования шин 30,5DP-32 и 33DP-32.

Информация о конфликте интересов. Конфликт интересов отсутствует.

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Original article

METHOD OF PROTECTION OF COASTAL LANDS OF THE KUDEPSTA RIVER IN CASE OF EMERGENCIES

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Abstract

Background. Long-term hydrological observations of the Kudepsta River formed the basis for a comprehensive study of the water body. Application of modern geoinformation technologies and statistical analysis method, large-scale field surveys of river channel processes allowed to justify the method of flood protection of the Kudepsta River coastal lands. As a result of the survey of the Kudepsta River channel section in the area of Kudepsta settlement and calculations of shoreline displacement, it was proposed to apply a flexible gabion structure to strengthen the right bank part of the river. This design demonstrates high efficiency of protective measures against erosion and waterlogging of the coastal strip. The estimation of economic efficiency of the method of bank protection is carried out, as a result the coefficient of economic efficiency is equal to 1.77, which is economically favorable. The payback period of construction will be 1 year. Practical experience in the implementation of such engineering solutions can be widely used in the implementation of bank protection works on mountain rivers in various subjects of the Russian Federation.

Purpose. Objective of the study to investigate the method of protection of the coastal lands of the Kudepsta River in case of emergency situations.

Materials and methods. The study area is located on the right bank of the Kudepsta River, its length is 358 meters. The site is located in the mouth of the Kudepsta River valley – it is a right bank section of the river, which is represented by a terrace with an overflow exposed ledge with a height of 2 to 5 meters. It is characterized by degradation associated with landslide processes occurring in the riverbed

Results. To prevent flooding of the adjacent territory and erosion of the banks of the Kudepsta River in the study area it is necessary to build a retaining wall 5.0 m high, 358 m long from gabion structures. Bottom reinforcement of the channel bottom is provided taking into account the possibility of its erosion and in order to protect the erosion funnel.

Conclusion. Based on the survey of the Kudepsta River channel section and shoreline displacement calculations, flexible gabion structures should be used to reinforce the right bank part of the river. This design demonstrates high efficiency of protective measures against erosion and waterlogging of the coastal strip. A method of coastal protection to prevent flooding of the adjacent territory and erosion of the banks of the Kudepsta River at the research site by means of a retaining wall 5.0 m high, 358 m long made of soft gabion structures is proposed.

Keywords: flood; bank stabilization; gabion structures; water flow; channel deformations; scouring

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Научная статья

СПОСОБ ЗАЩИТЫ ПРИБРЕЖНЫХ ЗЕМЕЛЬ РЕКИ КУДЕПСТА ПРИ ВОЗНИКНОВЕНИИ ЧРЕЗВЫЧАЙНЫХ СИТУАЦИЙ

Л.В. Кравченко, А.Е. Хаджиди, Д.С. Колмычек

Аннотация

Обоснование. Многолетние гидрологические наблюдения на реке Кудепста легли в основу комплексного исследования водного объекта. Применение современных геоинформационных технологий и метода статистического анализа, масштабные натурные обследования русловых процессов реки позволили обосновать способ защиты от наводнений прибрежных земель реки Кудепста. В результате обследования участка русла р. Кудепста в районе поселка Кудепста и расчетов смещения береговой линии предложено применить гибкую габионную конструкцию при укреплении правобережной части реки. Данная конструкция демонстрирует высокую результативность защитных мероприятий против размыва и подтопления береговой полосы. Выполнена оценка экономической эффективности способа берегозащиты, в результате получен коэффициент экономической эффективности равен 1,77, что является экономически выгодным. Срок окупаемости строительства составит 1 год. Практический опыт реализации подобных инженерных решений может найти широкое применение при выполнении берегозащитных работ на горных реках в различных субъектах Российской Федерации.

Цель. Цель исследования – изучить способ защиты прибрежных земель реки Кудепста при возникновения чрезвычайных ситуаций

Материалы и методы. Исследуемый участок находится на правом берегу реки Кудепста, его протяжённость 358 метров. Участок расположен в устьевой части долины реки Кудепста – это правобережный участок реки, который представлен террасой с надпойменным обнажённым уступом высотой от 2 до 5 метров. Характеризуется деградацией, связанной с оползневыми процессами, происходящими в русле реки

Результаты. Для предотвращения подтопления прилегающей территории и размыва берегов реки Кудепста на участке исследований необходимо устройство подпорной стены высотой 5,0 м, протяженностью 358 м из габионных конструкций. Низовое укрепление дна русла предусматривается с учетом возможности его размыва и из условия защиты воронки размыва.

Заключение. Исходя из обследования участка русла р. Кудепста и расчетов смещения береговой линии необходимо применение гибких габионных конструкций при укреплении правобережной части реки. Данная конструкция демонстрирует высокую результативность защитных мероприятий против размыва и подтопления береговой полосы. Предложен способ защиты прибрежных территорий для предотвращения подтопления прилегающей территории и размыва берегов реки Кудепста на участке исследований, путем устройства подпорной стены высотой 5,0 м, протяженностью 358 м из мягких габионных конструкций.

Ключевые слова: паводок; берегоукрепление; габионные конструкции; водоток; русловые деформации; размыв

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Introduction

The channel process is closely linked to sediment transport and can be seen as its external manifestation. The degree to which the channel influences the flow and the flow influences the channel depends on channel stability and flow velocities. The interaction between flow and channel produces channel forms that are most appropriate to the nature of the flow, velocities and gradients. The flow tends to smooth out all sharp breaks in the channel, which leads to a reduction in local resistance, movement and scour rate, i.e., increased channel stability. However, the dynamic equilibrium that characterizes rivers in their natural state can be disrupted by artificial changes in water and sediment flow regimes. Siltation of the river bed together with anthropogenic interference in natural water balance processes leads to a significant reduction in the channel capacity, resulting in a critical rise in water levels during the flood period.

Rational and safe management of water resources in mountain rivers requires the construction of bank protection structures, as well as the installation of automated water level control systems. The environmental aspect of flood control measures takes into account the preservation of biological diversity of riparian areas. The Kudepsta River is a mountainous river in the North Caucasus. Its source is located on the southern slopes of the Alek Range at Mount Efrem near the village of Vorontsovka. It flows into the Black Sea within the limits of the village of Kudepsta in the Khostinsky district of Sochi, a southern resort of the Krasnodar Territory. The Kudepsta River is characterized by frequent floods occurring at any time of the year, during which the adjacent floodplain is flooded. For the safe living of the inhabitants of the settlement and guests coming for vacation, it is necessary to develop protective measures to prevent flooding. Therefore, the purpose of the work is to justify the method of protection of coastal lands and settlements by means of bank reinforcement of the Kudepsa River section on the basis of studies of the right river bank erosion.

Materials and methods

The study area is located on the right bank of the Kudepsta River, its length is 358 meters. The site is located in the mouth of the Kudepsta River valley – it is a right bank section of the river, which is represented by a terrace with an overflow exposed ledge with a height of 2 to 5 meters. It is characterized by degradation associated with landslide processes occurring in the riverbed (Fig. 1).

The valley of the Kudepsta River, floodplain part, is made by alluvial-deluvial and alluvial-liman sediments. The width of the modern floodplain on the survey area is 50-60 meters In geological terms, the site of works at a studied depth of 9.0 m is composed of Quaternary sediments (QIII-IV), it takes part alluvial-deluvial and alluvial-liman deposits. According to the type of channel process of the Kudepsta River belongs to the side channel type with elements of limited meandering and mountain-doline wandering.

Fig. 1. Landslide on the right bank of the Kudepsta River

The side-bank type is widespread in mountainous-predmont rivers composed of sediments of any size and is characterized by the presence of large staggered shoals in the channel, which occupy a large part of the channel width during the low-water period. During floods the sidebanks are covered with water and the channel takes on a more rectilinear appearance; when the sidebanks dry out during low water, the river channel takes on a meandering appearance. Between side-banks there are rolls, and the river channel is located at concave banks.

Depths here are 0.2-0.3 m on the rolls, up to 1.5 m on the shoulders, current velocity is 1.0 and 0.5 m/s respectively. The bottom of the river is uneven and cluttered with boulders and karches. The left bank merges with the valley slope, the right bank is steep, up to 3-5 m high (along the right bank terrace), steep in the tops of bends, composed of pebble and gravel material with loamy filler, deformable.

The right bank of the river in the study area is steep with a height of (3.19-6.40) m, subject to deformation, the left bank is represented by an undrained slope of the valley, banks overgrown with woody and shrub vegetation.

The right bank is eroded, the bank collapses to expose the root system of woody vegetation, as a result trees and loamy sediments end up in the river channel part, partially carried away by the river water flow downstream. All this reduces channel capacity and contributes to the formation of karst and debris.

Planned deformations in the study area are mainly confined to channel bends and are observed during floods. The studies were carried out at the sites (Nos. 1-6) and are shown in Fig. 2.

Figure 2 shows that there is a constant meandering of the river flow and channel shifting in the study area. Thus, as a result of the flood emergency in 2022, the village of Kudepsta was partially flooded.

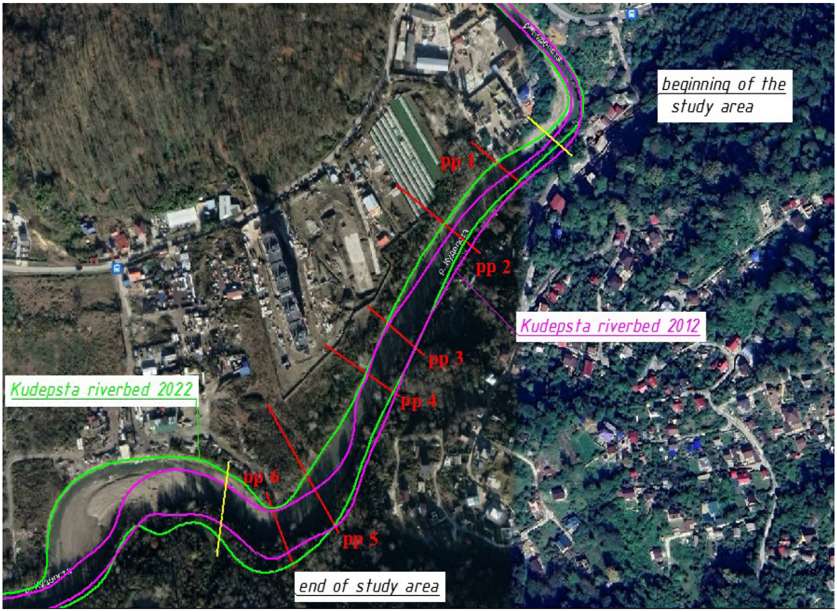

Fig. 2. Study area on the Kudepsta River with boundaries of direction and intensity of bank erosion using Google Earth Pro satellite images for 2012 and 2022.

To determine the method of bank reinforcement and technical parameters of the structure, the calculation of the shoreline displacement was performed. Displacement of the shoreline (boundary of the water body) of the river. Kudepsta is determined by the formula:

$$L_b = C_m \cdot k_{iz} \cdot T_{pr} \cdot \frac{H_{max} - H_0}{H_{pl} - H_0} \quad (1)$$

where L_b – displacement of the mean channel line or concave bank line at a given cross-section, m;

C_m – the highest rate of planned deformations, m/year;

k_{iz} – coefficient of the bend development rate;

T_{pr} – number of years of the forecast period, year;

H_{max} – the greatest depth at the design site, m;

H_{pl} – the greatest depth of the reaches of the given bend, m;

H_0 – average depth of 2 rolls adjacent to the bend, m.

Calculation data of displacement of the right bank of the Kudepsta River in the study area is given in Table 1.

Table 1.

Right shoreline displacement calculation data

Watercourse-well	Highest rate of planned deformations, Sm (m/year)	Coefficient of velocity of radiation development, k of	Number of forecasting years, Tpr (year)	The greatest depth of the shoulder of the given bend, Np (m)	Maximum depth at the pop. profile site, Hm (m)	Average depth of 2 adjacent bends, H0 (m)	Offset of concave bank centerline, Lb (m)
r. Kudepsa – pp №1	0.25	0.82	33	0.57	0.57	0.45	6.77
r. Kudepsa – pp №2	1.64	0.04	33	0.10	0.10	0.09	2.16
r. Kudepsa – pp №3	1.30	0.10	33	0.12	0.10	0.09	1.43
r. Kudepsa – pp №4	1.47	0.10	33	0.12	0.11	0.10	2.43
r. Kudepsa – pp №5	2.30	0.75	33	0.94	0.10	0.07	1.96
r. Kudepsa – pp №6 2,63 km from estuary	0.05	0.75	33	0.92	0.92	0.20	1.24

From the data in Table 1 it is clear that the value of displacement of the right bank line of the Kudepsta River at the embankment development site in Kudepsta settlement during 33 years will be (1.24 - 6.77) meters.

Results

To prevent flooding of the adjacent territory and erosion of the banks of the Kudepsta River in the study area it is necessary to build a retaining wall 5.0 m high, 358 m long from gabion structures (Fig. 2).

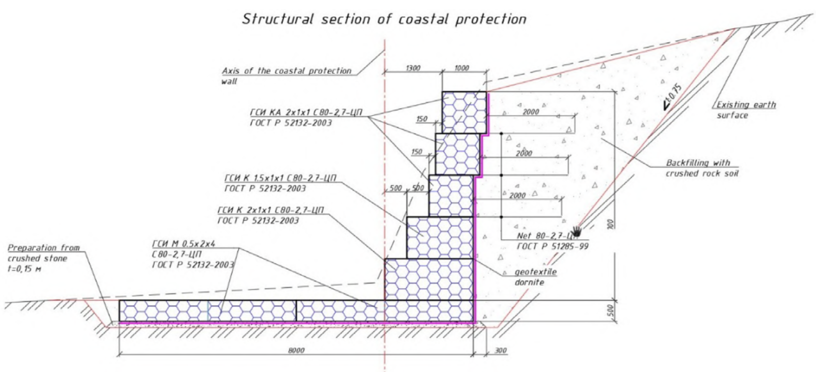

Fig. 2. Coastal protection structure design

Bottom reinforcement of the channel bottom is provided taking into account the possibility of its erosion and in order to protect the erosion funnel.

The retaining wall is installed from gabions of GSI K-2,0x1,0x1,0x1,0-C80-2,7-CP GOST 52132-2003, laid perpendicular to the wall axis on the base of mattress-tufa gabion. Then there is a row of gabions GSI K-1,5x1,0x1,0x1,0-C80-2,7-CP GOST 52132-2003, also laid perpendicular to the axis of the bank protection wall. The next three rows are box gabions with reinforcing panel GSI KA-2,0x1,0x1,0x1,0x1,0x2.0-C80-2,7-CP GOST52132-2003 (length of reinforcing panel 2 m), installed on top of each other with a 0.15 m overhang towards the bank slope with joint dressing. The “overhang” of the upper gabions over the lower ones on the back edge of the structure is 0.15 m.

Mesh size 8x10 cm made of wire with diameter d=2.7 mm, densely coated with zinc and polymer with service life up to 75 years. Laying is carried out long lengthwise on geotextile Dornit 300.

All gabion structures are connected by wire.

The 6.0 m mattress gabion extends from under the row of box gabions to the design river bottom.

The installation of geotextile is intended to prevent washout of the slope soil and backfill through the gabion structures, i.e. a back filter is installed along the contact surface.

In order to prevent scour zones at the interface of the bank protection structure with the bedrock bank, the end section of the bank protection structure is embedded in the bedrock bank. The interface is designed as a combination of a gabion wall and a rock fill made of stone with a diameter of D=0.15-0.25 meters.

The backfill behind the face of the gabion retaining wall is a gravel-sand mixture. The angle of internal friction of the gravel-sand mixture is not less than 28^{o}. Then backfilling with soil from the excavation of the gabion excavation is performed. The backfill soil is placed and compacted in layers not exceeding 0.5 meters. The standard compaction factor is 0.95.

Filling of mattresses and gabions is made of natural stone (average density of stone not less than 2.3 t/m^3, strength reduction index not less than 0.8).

Works in the riverbed are carried out only at low water levels in the river. It is forbidden to carry out works in the river bed during the fish spawning period. During the spawning period works on the shore (territory planning, procurement of construction materials and products, etc.) are carried out.

Conclusion

As a result of research on the Kudepsta River section in the area of Kudepsta settlement, it was established that the right bank of the river in the study area - steep with a height from 3.19 to 6.40 m, is subject to deformation, the left bank is represented by an undrained slope of the valley, banks overgrown with woody and shrub vegetation. The calculation method determined the amount of displacement of the right bank line of the Kudepsta River at the site of embankment development in the settlement of Kudepsta during 33 years, which will be from 1.24 to 6.77 meters.

Based on the survey of the Kudepsta River channel section and shoreline displacement calculations, flexible gabion structures should be used to reinforce the right bank part of the river. This design demonstrates high efficiency of protective measures against erosion and waterlogging of the coastal strip. A method of coastal protection to prevent flooding of the adjacent territory and erosion of the banks of the Kudepsta River at the research site by means of a retaining wall 5.0 m high, 358 m long made of soft gabion structures is proposed.

To assess the economic efficiency of the bank protection method, the prevented damage (losses, damages, costs) minus operating costs for maintenance and servicing of the facility (net profit) to the capital investment providing this result was calculated. The economic effect of preventing damage from flooding is 296.29 million rubles. The cost of bank reinforcement construction is 160.68 million rubles. The coefficient of economic efficiency is 1.77, which is economically favorable. The payback period of construction will be 1 year.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

THE IMPACT OF TOTAL CAPITAL ON THE FINANCIAL STABILITY AND SOLVENCY OF AGRICULTURAL ENTERPRISES

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Abstract

Background. The study provides definitions of "capital", "total capital", "financial stability", "solvency", and analyzes the influence of the composition and structure of total capital on the financial stability and solvency of agricultural formations. The study was based on general scientific methods of cognition. The study examined the history of the development of the definition of "capital" and its components, systematized the risks that have a negative impact on the solvency and financial stability of agricultural enterprises. The article defines the components of the total capital of agricultural enterprises, examines their relationship, as well as the relationship between financial stability and solvency, selects indicators that most fully characterize the level of financial stability and solvency of economic entities, analyzes the impact of total capital on the financial stability and solvency of agricultural enterprises. The study formulates the main problems that have a negative impact on the composition and structure of total capital and, as a consequence, on the financial stability and solvency of agricultural enterprises, and suggests directions for optimizing the composition and structure of total capital that can have a positive impact on the level of financial stability and solvency of agricultural businesses.

Purpose. The purpose of this study is to examine the impact of total capital on the financial stability and solvency of agricultural enterprises.

Materials and methods. The study was based on the following methods of knowledge: static, dialectical, logical, comparative, and also used the methods of modeling, formalization, synthesis, induction, deduction, analysis, grouping, observation, absolute, relative, average values.

The empirical basis of the study was the main forms of accounting statements of agricultural businesses operating in the southern regions of the Rostov region, as well as official statistics.

The scientific and methodological basis of the study was the legislatively enshrined principles of drawing up accounting and statistical reports, methods of analyzing financial stability and solvency, articles of domestic and foreign accounting in scientific publications, materials of scientific and practical conferences, monographs.

Results. Optimal interaction of the components of the total capital ensures effective management of an agricultural enterprise in modern business conditions and has a direct impact on its financial stability and solvency.

The study showed that all enterprises where equity capital occupies a predominant share in the financial capital are more financially stable than those that carry out statutory activities at the expense of borrowed sources of financing.

The share of debt coverage of agricultural enterprises depends to a greater extent on the amount of financial capital in the structure of total capital, that is, the larger the share of equity capital in the total capital, the greater the likelihood of timely coverage of debt obligations to counterparties. The probability of repaying current debt is higher for those enterprises that have a large share of borrowed capital in the total.

The lowest level of total solvency is observed at an enterprise with a large share of borrowed capital.

Thus, the ratio of financial capital components in the total capital affects the level of financial stability and solvency of agricultural enterprises. Physical capital as part of total capital has an indirect impact on the financial stability and solvency of agricultural enterprises.

Conclusion. Different forms of ownership and sizes of the enterprises under study do not have a significant impact on the composition and structure of their total capital. This fact has a negative impact on the level of their financial stability and solvency, which suggests the need to develop measures to optimize the composition and structure of the capital of enterprises, taking into account the conditions for implementing their statutory activities.

Keywords: total capital; financial stability; solvency; physical capital; financial capital; agricultural enterprises

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Научная статья

ВЛИЯНИЕ СОВОКУПНОГО КАПИТАЛА НА ФИНАНСОВУЮ УСТОЙЧИВОСТЬ И ПЛАТЕЖЕСПОСОБНОСТЬ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ПРЕДПРИЯТИЙ

И.Н. Ефременко, О.В. Буткова

Аннотация

Обоснование. В исследовании даны определения дефиниций «капитал», «совокупный капитал», «финансовая устойчивость», «платежеспособность», проанализировано влияние состава и структуры совокупного капитала на финансовую устойчивость и платежеспособность сельскохозяйственных формирований. Проведенное исследование базировалось на общенаучных методах познания. В ходе исследования была рассмотрена история развития дефиниции «капитал» и его составляющих, систематизированы риски, оказывающие негативное влияние на платежеспособность и финансовую устойчивость предприятий аграрного бизнеса. В статье определены составляющие совокупного капитала предприятий АПК, исследована их взаимосвязь, а также взаимосвязь финансовой устойчивости и платежеспособности, проведен отбор показателей, наиболее полно характеризующих уровень финансовой устойчивости и платежеспособности экономических субъектов, проведен анализ влияния совокупного капитала на финансовую устойчивость и платежеспособность предприятий аграрного бизнеса. В исследовании сформулированы основные проблемы, оказывающие негативное влияние на состав и структуру совокупного капитала и, как следствие, на финансовую устойчивость и платежеспособность сельскохозяйственных предприятий, предложены направления оптимизации состава и структуры совокупного капитала, которые могут оказать положительное воздействие на уровень финансовой устойчивости и платежеспособности предприятий аграрного бизнеса.

Цель. Целью данного исследования является изучение влияния совокупного капитала на финансовую устойчивость и платежеспособность сельскохозяйственных предприятий.

Материалы и методы. Исследование базировалось на следующих методах познаний: статическом, диалектическом, логическом, сравнительном, а также использовались методы моделирования, формализации, синтеза, ин-

дукции, дедукции, анализа, группировки, наблюдения, абсолютных, относительных, средних величин.

Эмпирической базой проведенного исследования послужили основные формы бухгалтерской отчетности предприятий аграрного бизнеса, функционирующих в южных районах Ростовской области, а также официальные статистические данные.

Научно-методологической основой исследования послужили законодательно закрепленные принципы составления бухгалтерской и статистической отчетности, методики анализа финансовой устойчивости и платежеспособности, статьи отечественных и зарубежных учетных в научных изданиях, материалы научно-практических конференций, монографии.

Результаты. Оптимальное взаимодействие составляющих совокупного капитала обеспечивает эффективное управление аграрным предприятием в современных условиях хозяйствования и оказывает непосредственное влияние на его финансовую устойчивость и платежеспособность.

Проведенное исследование показало, что все предприятия, где преобладающую долю в финансовом капитале занимает собственный капитал, более финансово устойчивы, чем те, которые осуществляют уставную деятельность за счет заемных источников финансирования. Доля покрытия долгов сельскохозяйственных предприятий в большей степени зависит от величины финансового капитала в структуре совокупного каптала, то есть чем большую долю занимает собственный капитал в совокупном капитале, тем больше вероятности своевременного покрытия долговых обязательств перед контрагентами. Вероятность погашения текущей задолженности выше у тех предприятий, у которых велика доля заемного капитала в составе совокупного. Самый низкий уровень общей платежеспособности наблюдается на предприятии, где имеет место большая доля заемного капитала.

Таким образом, на уровень финансовой устойчивости и платежеспособности аграрных предприятий оказывает соотношение составляющих финансового капитала в составе совокупного капитала. Физический капитал в составе совокупного капитала оказывает опосредованное влияние на финансовую устойчивость и платежеспособность аграрных предприятий.

Заключение. Различные формы собственности и размеры исследуемых предприятий не оказывают существенного влияния на состав и структуру их совокупного капитала. Данный факт оказывает негативное влияние на уровень их финансовой устойчивости и платежеспособности, что предполагает необходимость разработки мероприятий по оптимизации состава и структуры капитала предприятий с учетом условий осуществления их уставной деятельности.

Ключевые слова: совокупный капитал; финансовая устойчивость; платежеспособность; физический капитал; финансовый капитал; сельскохозяйственные предприятия

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Introduction

Modern economic conditions, caused by economic and political reasons, force enterprises of all forms of ownership to solve the problem of ensuring uninterrupted financing of statutory activities.

In the current economic conditions, characterized by a high level of instability [1] and uncertainty [2], these are agrarian formations that are in a special position, on whose activities the food security of the state depends. The emerging changes, taking into account modern target settings for the positive evolution of agribusiness [3], leads to an urgent need for constant monitoring of the financial condition of agricultural formations, since it reflects the level of efficiency of the use of the property at their disposal.

The most important indicators characterizing the effectiveness of the statutory activities of agricultural business enterprises are indicators of financial stability and solvency.

The financial stability of an enterprise is its ability to effectively manage its own financial resources.

Solvency characterizes the ability of an enterprise to pay off its obligations at any given moment in time. A good level of solvency gives an economic entity an advantage in attracting and further using investments and borrowed funds to expand production.

Recently, the problem of increasing the level of financial stability and solvency has become quite acute for most agricultural formations, since the adoption of effective management decisions requires the management of the latter to clearly understand the degree of influence of the main factors on their value [4].

Economic science considers financial stability as a starting point for the growth of the well-being of any economic entity, indicating the degree of its competitiveness.

The financial stability of an agricultural business formation depends both on the degree of efficiency of its economic resources and on the ratio of the components of the enterprise's total capital that form its level of solvency, with the ratio of the components of financial capital being of primary importance.

With optimal synchronization of cash flows and outflows, the enterprise will be able to repay its obligations in a timely manner, its profit will grow, which will lead to an improvement in the level of its financial condition. However, such synchronization is possible for an enterprise only under conditions of sufficient financial resources for the implementation of the statutory activities of the economic entity.

Consequently, both the solvency and financial stability of a business entity depend on the optimal provision of resources and their effective use in the implementation of its statutory activities.

In order to effectively conduct statutory activities, agricultural enterprises need timely identification of problems with financial stability and solvency in order to mitigate their negative impact on the activities of the enterprise and promptly eliminate all possible risks that have a negative impact on its solvency and financial stability. (Table 1).

Table 1.

Risks that have a negative impact on the financial stability and solvency of agricultural businesses*

Probability of the effect	Degree of influence on financial stability		
	Low	Average	High
Low	Reduced profitability means loss of reputation	Reduction in sales volumes is a breach of contract	Reduction of qualified personnel, production, profits – high competition
Average	Reduction of profits – inflationary processes	Additional costs – changes in legislation, competitors, inflation	Loss of purchasing power of counterparties – decrease in demand for products
High	Financial losses – new technologies, force majeure circumstances	Reduction of production – use of outdated equipment	Exchange rate fluctuations, rising accounts receivable, loss of liquidity

*compiled by the authors

As a result of many years of research, scientists have proven that there is a close relationship between the definitions of “financial stability” and “solvency” (Fig. 1).

Any economic entity that separately carries out its statutory activities has a total capital, which is a combination of physical, financial, human, informational and natural capital in their interrelationship and interdependence (Fig. 2).

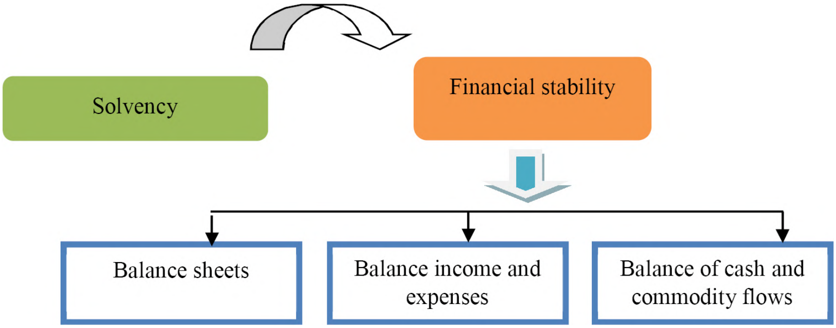

Fig. 1. The relationship between financial stability and solvency

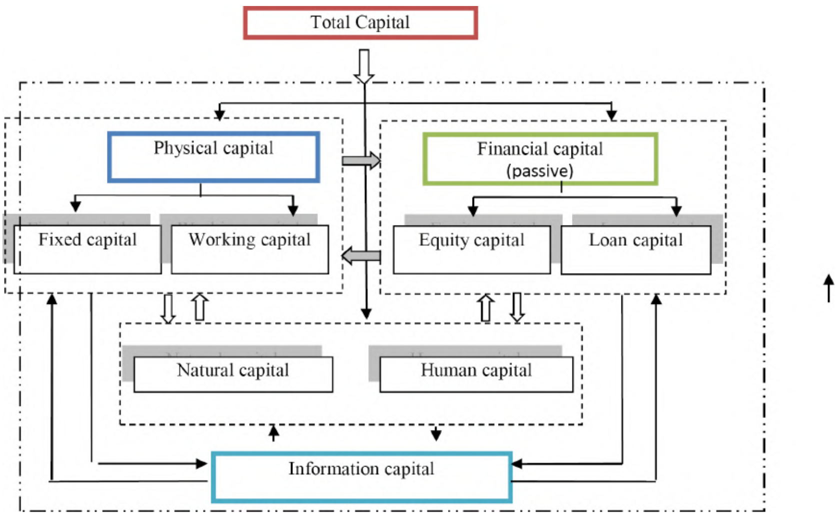

Fig. 2. The relationship of the components of the total capital.

At the same time, the ratio of physical and financial capital in the structure of total capital is of primary importance for studying financial stability and solvency; therefore, agricultural enterprises need to clearly understand how to manage this ratio to obtain the maximum economic effect [5].

When implementing the statutory activities of agricultural business enterprises, each component of their total capital performs a specific function and influences the level of their solvency and financial stability [6] and their relationship, which certainly requires further scientific research.

Purpose

The purpose of this study is to examine the impact of total capital on the financial stability and solvency of agricultural enterprises.

Materials and methods

The study was based on the following methods of knowledge: static, dialectical, logical, comparative, and also used the methods of modeling, formalization, synthesis, induction, deduction, analysis, grouping, observation, absolute, relative, average values.

The empirical basis of the study was the main forms of accounting statements of agricultural businesses operating in the southern regions of the Rostov region, as well as official statistics.

The scientific and methodological basis of the study was the legislatively enshrined principles of drawing up accounting and statistical reports, methods of analyzing financial stability and solvency, articles of domestic and foreign accounting in scientific publications, materials of scientific and practical conferences, monographs.

Table 2.

The system of indicators of financial stability and solvency of agricultural enterprises used in the study*

Indicators	Components	
	numerator	denominator
Indicators of financial stability		
Financial autonomy	Equity capital	Balance sheet total
Covering debts with equity capital		Loan capital
Financial dependency	Loan capital	Balance currency
Current debt ratio	Short-term financial liabilities	
Financial leverage	Loan capital	Equity capital
Indicators of solvemcy		
Overall solvemcy	Assets	Loan capital
Solvency for current liabilities	Liabilities	Average monthly revenue

*compiled by authors

The methodology for calculating financial stability and solvency in domestic practice does not differ from foreign analogues. At the same time, a large number of various analytical indicators used to analyze the efficiency of economic entities [7] have a negative impact on the quality of their analytical work and consequently on the development of management decisions aimed at improving the efficiency of the economic entity [8]. Therefore, a sample of optimal indicators of solvency and financial stability was conducted (Table 2).

Increasing financial stability and solvency means strengthening the financial position of an agricultural enterprise.

Results

Optimal interaction of the components of the total capital ensures effective management of an agricultural enterprise in modern business conditions and has a direct impact on its financial stability and solvency.

The study of the definition of "capital" and its components has been going on for more than six centuries, but it is so complex and multifaceted that today there is an ongoing discussion about its conceptual apparatus and the degree of its influence on the efficiency of enterprises [9; 10]. It should be noted that even today the correlation of the enterprise capital with its financial component is not appreciated at its true value. Despite certain differences in the interpretation of total capital and its components, all researchers associate them with some resources capable of generating income.

The composition and structure of the total capital of agribusiness enterprises, as well as the relationship of its constituent components, affect the financial stability and solvency of economic entities [12; 13].

Table 3.

Criteria for selecting enterprises for the study [14]

Criterion	Agrarian formations of the Rostov region				
	1	2	3	4	5
Administrative unit of the Rostov region	Zernograd	Salsk	Kagalnik	Egorlyk	Kagalnik
Organizational and legal form	Joint-stock company	Limited Liability Company	Limited Liability Company	Limited Liability Company	Agricultural production cooperative
Size of an enterprise	Large	Medium	Large	Medium	Large
Size of production	Growing	Decreasing	Growing	Growing	Decreasing
Specialization	Crop production	Crop production	Crop production	Crop production	Crop production

The analysis of the impact of total capital on solvency and financial stability was carried out on the basis of data from the accounting statements of agricultural business enterprises located in the southern regions of the Rostov region. The criteria for selecting enterprises selected for the research work are presented in Table 3.

Processing of statistical and accounting (financial) reporting data within the framework of existing accounting and analytical systems of each enterprise under study made it possible to create a database for further analysis of financial stability and solvency (Table 4).

Table 4.

Database for analyzing the impact of total capital on the financial stability and solvency of agricultural enterprises*

Indicator	Year	Agrarian enterprises of the Rostov region				
		1	2	3	4	5
Total capital, thousand rubles.	2021	510233	271630	1504709	2204790	1996949
	2022	630760	348486	1839612	2077315	2270383
	2023	690126	884981	1966062	2529470	2341551
Fixed capital, thousand rubles.	2021	248784	132410	596147	1204190	751089
	2022	268669	122388	893896	1263650	897723
	2023	280389	639492	1011600	1419500	904681
Working capital, thousand rubles.	2021	261449	139220	908562	1000600	1245860
	2022	362091	226098	945716	813665	1372660
	2023	409737	245489	954462	1109970	1436870
Own capital, thousand rubles.	2021	374089	43535	968522	1641380	1917720
	2022	531534	86128	1123280	1970530	2200130
	2023	577415	65605	1364520	2370720	2259440
Loan capital, thousand rubles.	2021	75631	228095	536188	563411	79226
	2022	59035	262358	716330	106780	70253
	2023	83745	828376	601540	109651	82113
Share of fixed capital / working capital in the structure of total capital, %	2021	48.8/51.2	48.7/51.3	39.6/60.4	54.6/45.4	37.6/62.4
	2022	42.6/57.4	35.1/64.9	48.6/51.4	60.8/39.2	39.5/60.5
	2023	40.6/59.4	72.3/27.7	51.5/48.5	56.1/43.9	38.6/61.4
The share of own / loan capital in the structure of total capital, %	2021	73.3/26.7	16.0/87.0	64.4/35.6	74.4/25.6	96.0/4.0
	2022	84.3/15.7	24.7/75.3	61.1/38.9	94.9/5.1	96.9/3.1
	2023	83.7/16.3	7.4/92.6	69.4/30.6	93.7/6.3	96.5/3.5
Profit, thousand rubles.	2021	78903	-19071	391635	151792	180767
	2022	175890	122593	363153	330370	165580
	2023	90873	-7105	614657	402150	68966

* compiled by the authors based on the accounting and financial statements of the enterprises selected for the study

The analysis of the data presented in Table 4 showed some changes occurred in the structure of the total capital during the study period.

So, the current assets occupied a larger share in the structure of physical capital in 2021 and 2022 at all enterprises except 4 of them. In 2023, several enterprises – 2 and 3 – radically changed the structure of physical capital in the composition of total capital in favor of the predominance of non-current assets in it.

In the structure of financial capital, its own sources of financing occupy the largest share at enterprises 1, 3, 4, 5 during the study period, while enterprise 2 carriying out its activities at the expense of loan sources. Moreover, it was Company 2 in 2021 and 2023 according to the results of the activity that received a loss.

Further analysis was carried out by analytical methods using determined factor models of financial stability and solvency indicators (Table 2). The results of the analysis are presented in Table 5.

Analysis of Table 5 allows us to draw a number of the following conclusions:

1. All enterprises (1, 3, 4, 5), where the main share in financial capital belongs to equity capital, are more financially stable than those that carry out statutory activities at the expense of borrowed sources of financing
2. The share of debt coverage of the enterprises under study depends to a greater extent on the size of its financial capital in the structure of total capital. Thus, the greater share occupies its own capital in the total capital, the greater the likelihood of timely covering of debt obligations to counterparties.
3. The probability of repaying current debt is higher for those enterprises in which borrowed capital accounts for the largest share of total capital.
4. The lowest level of general solvency is observed at Enterprise 2 that owns a large share of loan capital.

Summarizing the results of the conducted study, we note that the level of solvency and financial stability of agricultural business enterprises is influenced mainly by the ratio of the components of financial capital in the composition of total capital, while the composition and structure of their physical capital has an indirect effect on the studied indicators.

Therefore, in order to maximize the indicators of solvency and financial stability, enterprises carrying out statutory activities in the sphere of agricultural business need to find reserves for the growth of financial capital and optimize its structure.

Table 5.

Financial stability and solvency of agricultural enterprises with the existing composition and structure of their total capital*

Indicator	Year	Agrarian enterprises of the Rostov region				
		1	2	3	4	5
Indicators of financial stability						
Financial autonomy	2021	0.75	0.16	0.64	0.74	0.96
	2022	0.84	0.25	0.61	0.95	0.97
	2023	0.84	0.07	0.69	0.94	0.96
Financial dependency	2021	0.15	0.84	0.36	0.26	0.04
	2022	0.16	0.75	0.39	0.05	0.03
	2023	0.16	0.934	0.31	0.06	0.04
Current debt ratio	2021	0.12	0.30	0.13	0.26	0.04
	2022	0.13	1.60	0.07	0.05	0.03
	2023	0.19	0.73	0.13	0.04	0.04
Covering debts with equity capital	2021	4.95	0.19	1.81	2.91	24.21
	2022	9.00	0.33	1.57	18.45	31.32
	2023	6.89	0.08	2.27	21.62	27.52
Financial leverage	2021	0.20	5.24	0.55	0.34	0.04
	2022	0.11	3.05	0.64	0.05	0.03
	2023	0.15	12.63	0.44	0.05	0.04
Indicators of solvency						
Overall solvency	2021	6.75	1.19	2.81	3.91	25.21
	2022	10.68	1.33	2.57	19.45	32.32
	2023	8.24	1.07	3.27	23.07	28.52
Solvency for current liabilities	2021	0.15	0.67	0.72	2.12	0.09
	2022	0.12	0.87	0.68	0.18	0.07
	2023	0.15	2.02	0.55	0.11	0.09

*compiled by authors on the basis of accounting financial reporting of enterprises selected for research

The results of the conducted study showed that the most important reserve for the growth of financial capital as part of the total capital for agricultural enterprises is the growth of their profits, mainly due to compliance with the timing of agrotechnical measures in accordance with technological maps, seeding rates of agricultural crops, the use of scientifically based crop rotations and the latest methods of land cultivation [15].

In the course of the study, there have been calculated the reserves of growth in the amount of profit of agrarian enterprises presented in Table 6.

Table 6.

Profit growth reserves for pilot enterprises in 2023, thousand rubles [14]

Reserve for increasing in the amount of profit	Agrarian formations of the Rostov region				
	1	2	3	4	5
By increasing in the volume of product sales	+21547.1	+24773.4	+19812.5	+8622.0	+29894.2
By reducing the cost of production	+645.2	+22.5	+542.1	+48.6	+896.9
Total	+22192.3	+24795.9	+20354.6	+8670.6	+30791.1

According to Table 6, all enterprises under study have a reserve of increase in the amount of profit. Therefore, they can increase their financial stability and solvency (Table 7).

Table 7.

Reserves for increasing the Financial stability and solvency of agricultural enterprises under study, % *

Factor	Value	Agrarian formations of the Rostov region				
		1	2	3	4	5
Indicators of financial stability						
Financial autonomy	actual	0.84	0.07	0.69	0.94	0.96
	including reserves	0.84	0.10	0.70	0.94	0.97
Financial dependency	actual	0.16	0.93	0.31	0.06	0.04
	including reserves	0.16	0.90	0.30	0.06	0.03
Current debt ratio	actual	0.19	0.73	0.13	0.04	0.04
	including reserves	0.18	0.71	0.13	0.04	0.03
Covering debts with equity capital	actual	6.89	0.08	2.27	21.62	27.52
	including reserves	7.16	0.11	2.30	21.70	27.89
Financial leverage	actual	0.15	12.63	0.44	0.05	0.03
	including reserves	0.14	9.16	0.43	0.05	0.04
Indicators of solvency						
Overall solvency	actual	8.24	1.07	3.27	23.07	28.52
	including reserves	8.51	1.10	3.30	23.15	28.89

* compiled by the authors based on the conducted research

The conducted research allowed us to identify the main problems that have a negative impact on the composition of the total capital of agricultural formations and their structure, which in turn affected the level of their financial stability and solvency.

Conclusion

Different forms of ownership and sizes of the enterprises under study do not have a significant impact on the composition and structure of their total capital. This fact has a negative impact on the level of their financial stability and solvency, which suggests the need to develop measures to optimize the composition and structure of the capital of enterprises, taking into account the conditions for implementing their statutory activities [16].

To optimize the composition and structure of the total capital of agrarian enterprises, one should:

1. Form a planning system in stages: to draw up the enterprise's budget, to develop a system of indicators of the efficiency of the enterprise, depending on the goals of the latter, to carry out financial planning, to develop a marketing strategy aimed at increasing the competitiveness of enterprises operating in the field of agribusiness [17], to organize the financial management service, to carry out various situations and conduct a scenario analysis.
2. Optimize the composition and structure of total capital, paying special attention to financial capital, namely the ratio of own and borrowed sources of financing.
3. Achieve an increase in crop yields: use alternative methods of soil cultivation, develop and use optimal crop rotations, draw up technological maps of agrotechnical measures and strictly adhere to them, which will subsequently allow agricultural businesses to increase profits.
4. Develop and use a profit distribution mechanism that will allow agricultural formations to optimize the ratio of their own and foreign sources of financing, thereby improving the structure of financial capital, as well as improve the structure of physical capital by acquiring both current and non-current assets.

The proposed enterprises will allow agricultural enterprises to receive additional profits, adjust the composition and structure of total capital, improve solvency and financial stability.

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Original article

IRRIGATION OF SLOPE LANDS BY SUBSURFACE IRRIGATION METHOD USING A SIMULATOR OF HORIZONTAL WELLS

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Abstract

Background. To evaluate the effect of different irrigation parameters, a model of a sloping slope was developed for experiments, and different irrigation regimes were investigated using a horizontal well simulator. To consider the process of subsurface irrigation were modeled sloping slopes of sand-soil on the laboratory installation of the author's design, implemented at the Department of Hydraulics and Agricultural Water Supply of Kuban State Agricultural University. Based on the analysis of the results of the experiments, a graph showing the trajectory of irrigation water movement when modeling subsurface irrigation using a simulator of horizontal well was obtained for the first time. The obtained results showed that the main flow of irrigation water in the process of its movement has the trajectory of a downward curve, originating directly from the simulator of horizontal well, then passing at an angle the whole considered area of the slope, and ending at its lower boundary.

Purpose. Purpose of the study to investigate the effectiveness of subsurface irrigation on sloping slope models using a horizontal well simulator.

Materials and methods. Measurement of the indicators of slope angle and soil moisture level were carried out in laboratory conditions, experiments using a simulator of horizontal wells; the method of mathematical modeling was used for the analysis of wetting processes; statistical methods were used for the processing of experimental data. This work is based on the analysis of methods and techniques of irrigation on sloping soil surfaces. To consider the process of subsurface irrigation were modeled sloping slopes of sand-soil on the laboratory installation of the author's design, implemented at the Department of Hydraulics and Agricultural Water Supply of Kuban State Agricultural University. Horizontal well simulators in the form of U-shaped tubes consisting of two vertical parts and one perforated horizontal part were placed in the sand-soil of the author's laboratory installation. A multifactorial experiment was conducted on the experimental laboratory installation to study the technical feasibility of quality irrigation of crops grown on sloping slopes with the help of simulators of horizontal wells equidistantly located down the slope.

Results. The data obtained during the laboratory experiment were processed, and on the basis of their analysis the graphs of dependences of water penetration distances on its volumes at angles of inclination to the plane of 10-30 degrees were plotted.

Conclusion. Based on the analysis of the results of the experiments, for the first time a graph showing the trajectory of irrigation water movement when modeling subsurface irrigation using a simulator of a horizontal well was obtained, which demonstrated the movement of the main flow of irrigation water, which is the trajectory of a downward curve originating directly from the simulator of a horizontal well, then passing at an angle through the whole slope area under consideration, and ending at its lower boundary.

Keywords: subsurface irrigation; simulator of horizontal wells; U-shaped tube; visual inspection; video endoscope

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Научная статья

ОРОШЕНИЕ СКЛОНОВЫХ ЗЕМЕЛЬ СПОСОБОМ ПОДПОЧВЕННОГО ПОЛИВА С ИСПОЛЬЗОВАНИЕМ ИМИТАТОРА ГОРИЗОНТАЛЬНЫХ СКВАЖИН

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Аннотация

Обоснование. Для оценки влияния различных параметров полива была разработана модель наклонного склона для экспериментов, исследованы различные режимы полива с использованием имитатора горизонтальных скважин. Для рассмотрения процесса подпочвенного полива были смоделированы наклонные склоны пескогрунта на лабораторной установке авторской конструкции, реализованные на кафедре гидравлики и сельскохозяйственного водоснабжения Кубанского ГАУ. Полученные результаты показали, что основной поток поливочной воды в процессе своего движения имеет траекторию ниспадающей кривой, берущей свое начало непосредственно от имитатора горизонтальной скважины, далее проходящей под некоторым углом весь рассматриваемый участок наклонного склона, и заканчивающейся у нижней его границы.

Цель. Цель исследования изучить эффективность подпочвенного полива на моделях наклонных склонов с использованием имитатора горизонтальных скважин.

Материалы и методы. Измерение показателей эффективности угла наклона и уровня увлажненности почвы проводились в лабораторных условиях, эксперименты с использованием имитатора горизонтальных скважин; для анализа процессов увлажнения использовался метод математического моделирования; для обработки экспериментальных данных – статистические методы. Данная работа основана на анализе методов и способах полива на наклонных поверхностях почвогрунта. Для рассмотрения процесса подпочвенного полива были смоделированы наклонные склоны пескогрунта на лабораторной установке авторской конструкции, реализованные на кафедре гидравлики и сельскохозяйственного водоснабжения Кубанского ГАУ. В пескогрунт авторской лабораторной установки были помещены имитаторы горизонтальных скважин в виде П-образных трубок, состоящие из двух вертикальных частей и одной перфорированной горизонтальной. На опытной лабораторной установке был проведен многофакторный эксперимент по изучению технической возможности осуществления качественного полива сельскохозяйственных культур, выращиваемых на наклонных склонах, при помощи имитаторов горизонтальных скважин, эквидистантно расположенных вниз по склону.

Результаты. Полученные в ходе лабораторного эксперимента данные были обработаны, на основании их анализа были простроены графики зависимостей расстояний проникновения воды от ее объемов при углах наклона к плоскости 10-30 градусов.

Заключение. На основании анализа результатов проведенных экспериментов впервые получен график, отображающий траекторию движения поливочной воды при моделировании подпочвенного полива при помощи имитатора горизонтальной скважины, продемонстрировавший движение основного потока поливочной воды, представляющего собой траекторию ниспадающей кривой, берущей свое начало непосредственно от имитатора горизонтальной

скважины, далее проходящей под некоторым углом весь рассматриваемый участок наклонного склона, и заканчивающейся у нижней его границы.

Ключевые слова: подпочвенный полив; имитатор горизонтальных скважин; П-образная трубка, визуальный осмотр; видеоэндоскоп

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Introduction

Cultivation of agricultural structures is largely determined by the timeliness and sufficiency of irrigation water volumes delivered to the fields. If the first, the timeliness of irrigation, is solved mainly by organizational and logistical methods, then the second condition, i.e., provision of necessary volumes of irrigation water, often has problems associated with both its physical deficit, including due to changes in climatic conditions, and with the complexity of water delivery to agricultural lands located at sufficiently large distances from water supply sources [1-5].

This becomes especially important for the conditions of growing agricultural products on sloping slopes, the percentage of which is used in agriculture in Krasnodar Krai (and not only) is quite high.

Materials and methods

It should be noted that the organization of supply and distribution of irrigation water at the top of the slope is a complex technical task, in addition, it is necessary to develop a set of measures for its retention and uniform distribution over the entire area of the slope.

Currently, there is a significant number of studies devoted to the study and development of irrigation technologies on sloping surfaces, but the problem remains relevant and requires further study and solution [6-12].

In order to solve the problem of developing the technology of subsurface irrigation of agricultural structures grown on sloping slopes, as well as to identify and take into account as many factors influencing this process as possible, a multifactor laboratory experiment was designed to study different variants of application of this technology on the laboratory unit of the author’s design and implementation.

The main factors influencing the technological process of subsurface irrigation were determined, as well as the functional values obtained as a result of the experiment (Table 1).

Table 1.

Plan for a multivariate laboratory experiment

Rock type Tilt angle	$К_1$ (sandy soil)		
α_1	L_1	L_2	L_3
	V_1	V_2	V_3
	l_1	l_2	l_3
	t_1	t_2	t_3
	φ_1	φ_2	φ_3
α_2	L_1	L_2	L_3
	V_1	V_2	V_3
	l_1	l_2	l_3
	t_1	t_2	t_3
	φ_1	φ_2	φ_3
α_3	L_1	L_2	L_3
	V_1	V_2	V_3
	l_1	l_2	l_3
	t_1	t_2	t_3
	φ_1	φ_2	φ_3

where $\alpha_{1\text{-}3}$ – tilt angles; $К_{1\text{-}3}$ – permeability coefficients; $L_{1\text{-}3}$ – borehole depth, cm; $V_{1\text{-}3}$ – water volume, ml; $l_{1\text{-}3}$ – liquid penetration distance, cm; $\varphi_{1\text{-}3}$ – measured moisture content within the rock type under study, %; $t_{1\text{-}3}$ – time measurement for determining the moisture content indicator inside the soil, min.

The experiment was prepared and conducted at the Department of Hydraulics and Agricultural Water Supply of Kuban State Agricultural University using a laboratory unit of its own design and execution, scale 1:100. In the process of its realization, works were carried out on the production of a working model of the slope, allowing to change the values of the angles of its inclination to the horizon. In addition, on the slope itself were placed at different depths simulators of horizontal wells, which made it possible to model different variants of subsurface irrigation, according to the given methodology in Table 1.

The 3000 cm long experimental setup was divided into three parts in order to set different tilt angles as shown in Figure 1. Each part of the model was separated from the other by waterproof plates made of PVC material. The modeled tilt angle to the plane was made of PVC plates having struts along the entire length of the arrangement inside each model. On top of the slope plate, 10 cm high sand-soil was poured on top of the slope plate. Then inside the sand-soil was laid U-shaped tube to a depth of 2 cm, consisting of two vertical and 1 horizontal perforated tube. And the horizontal tube has a perforation on the side of 45 degrees. The spacing of the U-shaped tube was carried out for technical reasons, and to prevent hydraulic fracturing and flow of drilling mud on the surface of the sand-soil. In order to determine the fluid movement inside the sand-soil, an observation well for the whole depth of the sand-soil was laid inside at a distance of 5 cm from the U-tube. For the convenience of monitoring the movement of liquid inside the sand-soil, the observation wells were marked with a series of 1-cm-long marks.

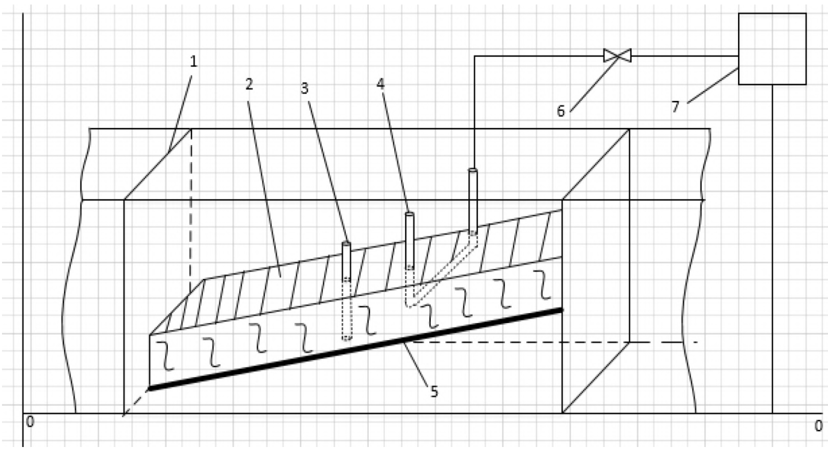

Fig. 1. Schematic diagram of the experimental laboratory setup
1 – Waterproof PVC plate; 2 – Sandy soil; 3 – Observation well; 4 – U-shaped tube; 5 – PVC plate for creating a slope; 6 – Crane; 7 – Measuring container

After placing the above mentioned, equipment in the laboratory setup, the experiment was carried out from the existing measuring tank filled with water up to 1000 ml. After opening the rotary tap, water from the measuring tank started to flow into one vertical tube of the U-tube system.

Measurements of sand-soil moisture indices were carried out with the help of a tare moisture meter. Measurement of sand-soil moisture was carried out with the help of a calibrated probe sensor, the error of which did not exceed 5%. At the time of the experiment, the movement of liquid was observed using a moisture meter and a video endoscope in the observation well. The time of each experiment was measured using a stopwatch, the time of which was synchronized with the NTP server MSK-IX.

Results

According to the above described, methodology and algorithm of the experiment, experiments with the P-tube placement at a depth of 4 cm and 6 cm were carried out. The results of experiments with the U-shaped tube at a depth of 2 cm, 4 and 6 cm are presented in Table 2.

Table 2.

Experimental results

Tilt angle, degree	Liquid volume, ml	Distance of observation well location from the U-tube, cm	Depth of U-tube placement 2 cm		
			Humidity, %	Fluid passage distance, cm	Depth of water penetration into the observation well, cm
10	200	5 cm	5.3	4.5	5.5
	400		5.7	5	
	600		7.5	6	
20	200		4.4	5.3	3
	400		6.2	6.7	
	600		8.8	9	
30	200		4.8	5	5
	400		7	6.2	
	600		9	7.3	
Tilt angle, degree	Liquid volume, ml	Distance of observation well location from the U-tube, cm	Depth of U-tube placement 4 cm		
			Humidity, %	Fluid passage distance, cm	Depth of water penetration into the observation well, cm
10	200	5 cm	7	3.7	6.5
	400		13.2	6	
	600		14.1	7.5	
20	200		7.5	4.5	7.5
	400		12.9	6.4	
	600		14.1	7.5	
30	200		5.3	4.3	6.5
	400		9	5	
	600		11.5	6.6	
Tilt angle, degree	Liquid volume, ml	Distance of observation well location from the U-tube, cm	Depth of U-tube placement 6 cm		
			Humidity, %	Fluid passage distance, cm	Depth of water penetration into the observation well, cm
10	200	5 cm	9.5	4.5	7
	400		13.7	6.5	
	600		15.3	6.5	
20	200		9.4	4	8
	400		10.4	4.5	
	600		13.7	6.3	
30	200		7.1	4.6	7.5
	400		8.9	7	
	600		12.8	7.5	

Based on the data given in Table 2, a graph of dependencies of water penetration distances on its volume at angles of inclination to the plane of 10-30 degrees was plotted. Thus, on the example of laying a U-shaped tube at a depth of 2 cm, we will build a 3D model in the programming language Python, as well as calculate the error in Python [11]. Figure 3 shows the graph of water penetration distance dependencies on its volume at angles of inclination to the plane of 10-30 degrees at a depth of 2 cm of the P-shaped tube.

At the end of the experiments, an evaluation of the obtained metrics was performed:

– Root-mean-square error MSE:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2, \tag{1}$$

where y_i – true value; $\hat{y}_i$ – predicted value; n – number of data points. The closer the MSE is to zero, the better the model.

– Root-mean-square error MAE:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \tag{2}$$

The smaller the MAE, the more accurate the model.

– Determination coefficient R^2:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2}, \tag{3}$$

where $\tilde{y}_i$ – average of the true values.

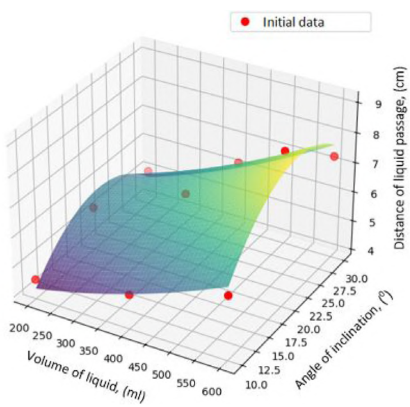

Fig. 3. Graph of dependences of water penetration distance on its volumes at angles of inclination to the plane of 10-30 degrees at the depth of U-tube embedment by 2 cm

Value of R^2 is characterized by the following conditions:

1) $R^2 = 1$ (model perfectly predict the data);

2) $R^2 = 0$ (model predicts no better than the mean value);

3) $R^2 < 0$ (model is worse than the prediction of the mean).

An algorithm implemented in Python was developed to determine the values of the metrics and the results obtained are shown in Table 3.

Table 3.

Metrics values

№	Metrics	Values
	Root-mean-square error MSE	0,1284
	Root-mean-square error MAE	0,3062
	Determination coefficient R^2	0,9265

Conclusion

Based on the analysis of the results of the experiments, a graph showing the trajectory of irrigation water movement when modeling subsurface irrigation using a simulator of horizontal well was obtained for the first time. The obtained results showed that the main flow of irrigation water in the process of its movement has the trajectory of a downward curve, originating directly from the simulator of horizontal well, then passing at an angle the whole considered area of the slope, and ending at its lower boundary.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

DIGITAL MODELING IN THE STUDY OF AGRICULTURAL LAND DEGRADATION PROCESSES

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Abstract

Background. This article discusses the problem of soil degradation from flooding and waterlogging. The analysis of the influence of these factors on the quality of land resources and agricultural productivity is given. As a solution, it is proposed to use digital surface modeling and other methods aimed at preventing erosion and improving soil condition. The article may be useful for scientists and specialists in the field of land reclamation and agronomy

Purpose. Objective of the study to explore numerical modeling in the study of agricultural land degradation processes.

Materials and methods. The research was conducted in the Dinsky district of the Krasnodar Territory, which belongs to the steppe zone. This area is characterized by significant humidification (from moderate to severe), relatively warm winters, short spring, hot summers, and long warm autumn. The annual rainfall in recent decades has increased to 643 mm, including 370 mm for the warm period (April – October) and 273 mm for the cold period (November – March).

Results. A feature of the territory has been determined, which is weak slopes and depressions of the terrain, in which even small obstacles to surface and ground runoff in wet years can lead to waterlogging of soils. Closed relief depressions (saucers) were formed due to subsidence of soils under the influence of natural moisture. Due to the high porosity and significant carbonate content, loess-like rocks of the irrigation site are predisposed to subsidence phenomena that occur during irrigation or during waterlogging of rocks. The territory is in the initial stage of degradation caused by flooding and waterlogging of the land. Land degradation is caused by natural and anthropogenic factors, where anthropogenic factors are more strongly influenced.

Conclusion. For intensive use of the studied territory (which is represented by meadow-chernozem leached weakly developed soils) in agricultural production, it is necessary to: carry out reclamation work on drainage (reducing the level of high water) by installing tubular periodic drainage in irrigation fields with the withdrawal of excess water into drainage channels that are located parallel to the irrigation fields; construction of absorption wells in the centers of low-lying areas of fields with upstream and outlet through drainage pipes into drainage channels that are located parallel to irrigation fields; to improve water permeability and aeration, eliminate the plow sole and reduce the density of the humus horizon of meadow-chernozem leached weakly silted soils, use chisels or deep dredges once every 2-3 years; change the composition of crop rotation by increasing the proportion of legumes crops; application of organic matter to the fields in the amount of 8-10 t/ha for 5 years.

Keywords: land degradation; digital terrain models; flooding; waterlogging

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Научная статья

ЦИФРОВОЕ МОДЕЛИРОВАНИЕ В ИССЛЕДОВАНИИ ПРОЦЕССОВ ДЕГРАДАЦИИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЕЛЬ

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Аннотация

Обоснование. В статье рассматривается проблема деградации почв от наводнений и заболачивания. Приводится анализ влияния этих факторов на качество земельных ресурсов и продуктивность сельского хозяйства. В качестве решения предлагается использовать цифровое моделирование поверхности и другие методы, направленные на предотвращение эрозии и улучшение состояния почв. Статья может быть полезна для ученых и специалистов в области мелиорации и агрономии.

Цель. Цель исследования изучить цифровое моделирование в исследовании процессов деградации сельскохозяйственных земель

Материалы и методы. Исследования проводились в Динском районе Краснодарского края, который относится к степной зоне. Для этой территории характерно значительное увлажнение (от умеренного до сильного), относительно теплая зима, короткая весна, жаркое лето и продолжительная теплая осень. Годовое количество осадков за последние десятилетия увеличилось до 643 мм, из них 370 мм приходится на теплый период (апрель - октябрь) и 273 мм - на холодный (ноябрь - март).

Результаты. Определена особенность территории – слабые уклоны и понижения рельефа, при которых даже небольшие препятствия для поверхностного и подземного стока во влажные годы могут привести к заболачиванию почв. Замкнутые понижения рельефа (блюдца) образовались в результате проседания почв под воздействием естественного увлажнения. Из-за высокой пористости и значительного содержания карбонатов лессовидные породы участка орошения предрасположены к просадочным явлениям, возникающим при орошении или при подтоплении пород. Территория находится в начальной стадии деградации, вызванной затоплением и заболачиванием земель. Деградация земель происходит под воздействием природных и антропогенных факторов, причем антропогенные факторы оказывают более сильное влияние.

Заключение. Для интенсивного использования исследуемой территории (которая представлена лугово-черноземными выщелоченными слаборазвитыми почвами) в сельскохозяйственном производстве необходимо: провести мелиоративные работы по осушению (снижению уровня высоких вод) путем устройства трубчатого периодического дренажа на полях орошения с отводом избыточной воды в дренажные каналы, расположенные параллельно полям орошения; строительства поглотительных колодцев в центрах низменных участков полей с подъемом и отводом через дренажные трубы в дренажные каналы, расположенные параллельно полям орошения; для улучшения водопроницаемости и аэрации, ликвидации плужной подошвы и снижения плотности гумусового горизонта лугово-черноземных выщелоченных слабозаиленных почв использовать долота или глубокие землечерпалки 1 раз в 2-3 года; изменить состав севооборота за счет увеличения доли бобовых культур; внесение органического вещества на поля в количестве 8-10 т/га в течение 5 лет.

Ключевые слова: деградация земель; цифровые модели местности; наводнения; заболачивание

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Introduction

One of the main causes of degradation of agricultural lands in the south of the Russian Federation is the processes of flooding and waterlogging of lands. These phenomena are important factors that have a detrimental effect on cultivated crops, affecting the quality and quantity of the crop. The consequences of waterlogging and flooding are: soaking of crops, their diseases, oppression or complete death; the inability to carry out most types of agricultural work in optimal agronomic terms; the inability to cultivate certain types of crops (winter crops, perennial plantations and grasses); degradation of waterlogged soils (loss of structure, multiple decrease in water and air permeability, compaction, gluing, etc.), accompanied by a significant decrease in their potential and actual fertility [1; 2]. Waterlogging and flooding of lands is a phenomenon summing up the effects of natural and anthropogenic factors. Agro-landscapes are very sensitive to external influences, which leads to the exit of landscape systems from equilibrium after a certain time of man-made impact. An example of such a process development is the emergence of hydromorphic complexes among initially automorphic soils.

Due to the fact that engineering topographic surveys, which make it possible to assess the qualitative condition of agricultural lands, are financially costly, digital modeling comes to the rescue, which serves as the main tool, in particular, for studying the development of erosion, and also allows predicting its further development [3].

Topography is a soil-forming factor and, therefore, affects the characteristics of the soil that determine the use, management, conservation and degradation of this resource. In the case of erosion, the relief is a factor affecting the transfer and accumulation of soil by water, depending on the features of the relief. The influence of relief on erosion is associated with variables such as the length and steepness of the slope, the shape and uniformity of the slope.

Land degradation from the effects of flooding and waterlogging is a process of deterioration in the quality of land resources, which leads to a decrease in productivity and a general decline in the ecosystems of agricultural production. The *purpose* of this study is to study the effectiveness of digital modeling of the surface of agricultural fields to prevent soil degradation.

Materials and methods

The research was conducted in the Dinsky district of the Krasnodar Territory, which belongs to the steppe zone. This area is characterized by significant humidification (from moderate to severe), relatively warm winters, short spring, hot summers, and long warm autumn. The annual rainfall in recent decades has increased to 643 mm, including 370 mm for the warm period (April – October) and 273 mm for the cold period (November – March). The increase in precipitation is to some extent associated with the creation of the Krasnodar reservoir. Evaporation of water from the reservoir surface contributes to an increase in climate humidity and an increase in precipitation. The increase in precipitation during the cold season was 63 mm.

The soils of the study site are represented by leached low–humus heavy-duty light-clay chernozems on loess-like clays and meadow - chernozem leached weakly layered low-humus heavy-duty light-clay on modified loess-like clays. Meadow-chernozem leached weakly silted soils lie in the bottoms of shallow depressions. They were formed on modified loess-like clays. The morphological structure of the profile of these soils is similar to the structure of chernozems, but their periodic waterlogging contributed to the appearance of hydromorphic signs in the form of ochre spots, compaction and deterioration of the structural condition of the horizon to a depth of 1 m deep from the earth's surface. The water permeability of these soils decreases to 0.001-0.0001 m/day, they become practically waterproof, this factor is the main problem of flooding and waterlogging of the studied agricultural lands. Taking into account the anthropogenic impact, which is expressed in the planting of forest belts across the direction of prevailing winds, subsurface and surface runoff, as a result of deflationary processes, dust deposits accumulate, in which or next to which rises form, blocking the runoff, which contributes to the development of waterlogging along dry gullies and the formation of puddles. The formation of a closed depression is accelerated if a field road is laid along the forest belt. Since the direction of runoff and the direction of deflationary winds coincide (from east to west), flow blocking is observed everywhere in this area.

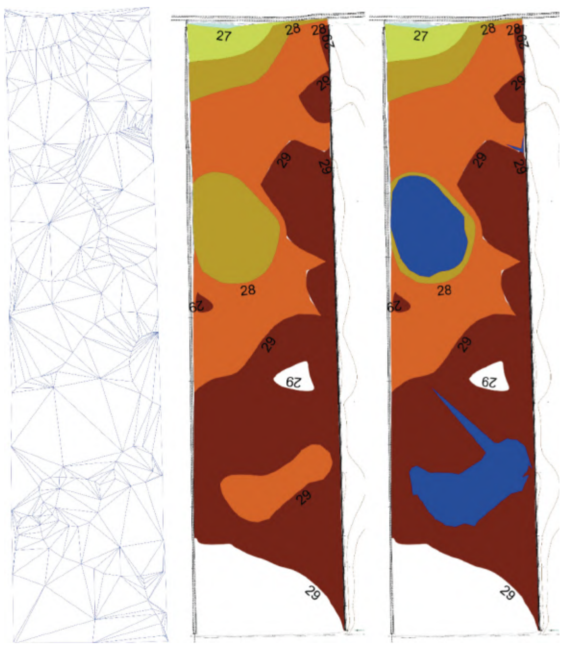
Also, the development of land degradation is influenced by methods of tillage with agricultural implements leading to the formation of foci of local waterlogging – plowing across the direction of natural runoff, plowing of beams, passages of heavy agricultural machinery, etc.

All this confirms the need to pay special attention to measures to regulate the nutrient and water regime of irrigated soils in the reclamation system. It is necessary to note two important circumstances that determine the special importance of the nutrient regime of irrigated soils:

– firstly, high crop yields on irrigation leads to accelerated removal of food elements from products;

– secondly, increased soil moisture causes higher mobility of mineral nutrition elements and their leaching into the underlying layers, and microbiological activity under optimal humidity conditions leads to accelerated mineralization of humus. The reaction of the soil medium is neutral (pH 6.6 – 7.2).

Crop rotation, cover culture and resource-saving tillage are traditional farming methods aimed at improving soil conditions. These methods reduce soil erosion and promote nutrient cycling. Their effectiveness depends on factors such as crop selection, application of cover crops and optimal tillage methods. In addition, the implementation of these methods by farmers may be difficult due to lack of awareness and potential resistance to change. The development of technologies, in particular digital surface modeling (DSM), has made it possible to create reliable tools and methods to solve this problem, such as geographic information systems (GIS) [4; 5]. The analysis of surface changes over time allows for detailed and comprehensive mapping and monitoring of land degradation processes. The overlap of various spatial data, such as topography, vegetation cover and human activity, makes it possible to identify areas subject to degradation in GIS [6].



a) b) c)

Fig. 1. a – triangulation of the surface, b – digital model digital model of the relief of the studied area, c – hydrodynamic model of flooding of the area of the studied area

Digital surface modeling is the most important tool for modern analysis and visualization, allowing you to create detailed representations of real surfaces in digital format. While traditional modeling methods required the creation of physical prototypes, computer algorithms are also used to capture and manipulate geometric surface data. By integrating climate data, it is possible to predict future changes in the land surface according to various scenarios, which allows us to obtain valuable information about the potential consequences of climate change and develop adaptation strategies [7; 8]. Modeling the effects of precipitation or temperature changes in various climatic scenarios can exacerbate soil degradation processes, and in the future it becomes possible to develop strategies to mitigate such consequences, for example, to introduce methods of sustainable land use or identify zones to prevent soil erosion through reclamation [9].

To analyze the spatial variability of the relief, which is the main parameter for evaluating geomorphometric variables, the profile characteristic of the landscape unit was determined. One field of the studied crop rotation was selected as a landscape unit.

The process of modeling a digital surface model was performed using the IndoorCAD program. Before starting the modeling process, it is necessary to collect the necessary data. IndoorCAD relies on accurate measurements, these data can be obtained using laser scanning or total station survey. IndoorCAD supports various file formats, including DXF and DWG, which are widely used in engineering applications.

The import of the collected data into the IndoorCAD program should be carried out with the condition that the coordinate system and units of measurement correspond to the collected data. Accurate geographic reference is necessary to align the model with any external data sources or geospatial information. The workflow in the project is organized by creating the necessary layers. Specific model elements, relief points, triangulation lines (Fig. 1, a), isolines, and isocontures are assigned. This arrangement of layers helps simplify the modeling process and makes it easier to make changes later.

It is necessary to make sure that all dimensions, heights and details accurately reflect the real space. All inconsistencies and errors that may have occurred in the process are eliminated, and edges are shifted during triangulation if necessary to display the slopes more correctly. The study was conducted in two stages:

– Creation of a digital terrain model. Using a 1:1000 scale topographic survey and a specialized IndorCAD Topo/Road 2023 software package to create a digital terrain model (which includes processing and analyzing terrain data to create a three-dimensional terrain model).

– Creation of a hydrodynamic model: Software tools for modeling phenomena are used to create a hydrodynamic model of flooding of the area. Take into account the terrain and other parameters that may affect the spread of water and flooding.

The digital model (Fig. 1, b) reflects the peculiarity of the relief with the predominance of closed contours of surfaces, the isocontures are highlighted in different colors with a step of 0.5 m marks. Thus, altitude information about the relief, data on the drainage system are reflected, which will help to build hydrographic maps and other parameters that may affect.

The modeling process takes into account various factors that can affect the spread of water and flooding, such as the speed and direction of flow, surface and underground runoff, soil properties, etc. The blue contours represent the most negative flooding scenario (Fig. 1, c).

The actual flood data used, hydrological markers, as well as other parameters, confirm the accuracy and reliability of the model, since the calculated flood contours coincide with the locations of confirmed flood sites at the moment.

Results and conclusions

The modeling process takes into account various factors that can affect the spread of water and flooding, such as the speed and direction of flow, surface and underground runoff, soil properties, etc. The blue contours shown in Figure 2 represent the most negative flooding scenario. The results of hydrodynamic modeling of the surface during flooding of the studied field revealed 2 flooding locations with depths of 0.1 – 0.4 m, the corresponding flooding areas are 546.0 m2 and 127879.2 m2. The actual data on flooding used, hydrological markers, as well as other parameters, confirm the accuracy and reliability of the model, since the calculated contours of flooding coincide with the locations of confirmed flood sites at the moment, confirmed by a route survey.

A feature of the territory has been determined, which is weak slopes and depressions of the terrain, in which even small obstacles to surface and ground runoff in wet years can lead to waterlogging of soils. Closed relief depressions (saucers) were formed due to subsidence of soils under the influence of natural moisture. The shape of the saucers is very diverse (rounded, elongated, dumbbell-shaped, amoeboid, etc.). The number of saucers will increase over time, and the area of existing ones will noticeably increase. The soil–forming rocks are represented by loess–like clays, which contain 60.9 – 66.4% physical clay, 35.7 - 40.1% silt, 48.0 - 69.0% dust and sand 3.4 – 17.4%. Due to the high porosity and significant carbonate content, loess-like rocks of the irrigation site are predisposed to subsidence phenomena that occur during irrigation or during waterlogging of rocks. The territory is in the initial stage of degradation caused by flooding and waterlogging of the land. Land degradation is caused by natural and anthropogenic factors, where anthropogenic factors are more strongly influenced.

For intensive use of the studied territory (which is represented by meadow-chernozem leached weakly developed soils) in agricultural production, it is necessary to: carry out reclamation work on drainage (reducing the level of high water) by installing tubular periodic drainage in irrigation fields with the withdrawal of excess water into drainage channels that are located parallel to the irrigation fields; construction of absorption wells in the centers of low-lying areas of fields with upstream and outlet through drainage pipes into drainage channels that are located parallel to irrigation fields; to improve water permeability and aeration, eliminate the plow sole and reduce the density of the humus horizon of meadow-chernozem leached weakly silted soils, use chisels or deep dredges once every 2-3 years; change the composition of crop rotation by increasing the proportion of legumes crops; application of organic matter to the fields in the amount of 8-10 t/ha for 5 years. One of the main measures is the drainage of surface and soil water in relief depressions. To do this, you need a drainage device at a depth of 1.0-1.1 m in the form of a perforated pipe with a slope towards the main drainage channel. The pipe into the trench is filled with coarse-grained to a depth of 0.6 m. The thickness of the layer is due to the filtering ability of the soil (table), which has a high filtration coefficient in the upper vegetation layer and will allow excess water to be removed from this layer. An additional mandatory measure is capital planning on the areas of waterlogged lands where drainage is arranged. Capital planning must be carried out with a bias towards drainage channels, which are collectors for all excess water in the area of the reclamation system

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

IMMUNOMODULATORY FEED ADDITIVES FOR FARM ANIMALS AND FISH

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Abstract

Background. Modern applied biotechnology is focused on the development and implementation of fundamentally new multifunctional feed additives in a complex form. Currently, new approaches to the maintenance of farm animals and aquaculture objects under the influence of environmental factors are being sought, based on the use of biologically active additives. Intensive antibiotic therapy has become one of the reasons for the disruption of normal bacteriocenosis and a decrease in the immunobiological reactivity of animals and fish, the emergence of resistant strains of pathogens, which reduces the therapeutic effect of antibacterial drugs. The use of antibiotics leads to the accumulation of microorganisms with complex antibiotic resistance in the environment, their entry into natural water bodies is almost impossible. One of the promising ways to solve these problems is the use of feed additives with immunomodulatory action. The article examines existing feed additives with biological activity, provides generalized literature data on the use of biological additives in animal husbandry and aquaculture.

Purpose. The objective of the present study is to investigate impact of immunomodulatory feed additives on farm animals and fish.

Materials and methods. Feeds play a crucial role in the diet of farm animals and fish, as they must contain all the necessary nutrients, vitamins and minerals to ensure healthy growth and development of animals and aquaculture objects. Such preparations as probiotics (including symbiotics and metabiotics), prebiotics, and synbiotics, which are actively used in feed production, meet these requirements. In 1995, Gibson and Robertfroy introduced the concepts that should be classified as prebiotics and found that these components should be: 1) a selective component that promotes the metabolic activity or growth of one or more beneficial bacteria; 2) capable of altering the microbiota towards a healthy state; 3) capable of exerting a systemic or luminal beneficial effect on the host organism; 4) not absorbed and not hydrolyzed in the upper part of the stomach.

Results. Current research shows the positive impact of prebiotic use on performance, including improved weight gain, improved feed conversion and reduced disease. Prebiotics promote the growth of beneficial microorganisms such as bifidobacteria and lactobacilli in the intestines of animals. This reduces the concentration of pathogens such as salmonella and coliform bacteria, which reduces the risk of disease and improves the overall health of animals and fish. Research confirms the possibility of reducing the use of antibiotics in feed through the use of prebiotics, which is important in the context of the problem of antibiotic resistance. Prebiotics can be used to improve the environmental sustainability of livestock and aquaculture, as they help to reduce the release of harmful substances into the environment.

Conclusion. Numerous scientific studies confirm the beneficial effects of immunomodulatory additives on the health of animals, poultry and aquaculture objects, especially in terms of protection against pathogens, stimulation of the immune response and increased productivity. Prebiotics can be used as an alternative or enhance the effect of probiotics. The use of a combination of these components, demonstrating a synergistic effect, can be even more effective in stimulating the intestinal microbiota and protecting animal health. One promising area of research is the use of wheat grain heap as an immunomodulatory additive, which has high prebiotic properties.

In the future, it is necessary to pay attention to studies of the thermal treatment of grain in the production of feed and feed additives. It should be emphasized that the use of feed additives such as probiotics, prebiotics and synbiotics is safe, does not have a negative impact on the natural environment and reduces the demand for antibiotic-based growth promoters. However, the mechanisms of action of probiotic organisms, prebiotics, and their combinations in synbiotics require further research. In the technology of compound feed production, plant raw materials, including wheat, are subjected to the extrusion process in order to increase the nutritional value, during which, during heat treatment, pathogenic microorganisms are killed. Presumably, wheat grain of early ripeness phases may lose its beneficial properties during heat treatment (extrusion). In this regard, it is advisable to conduct research on the effect of grain processing on its prebiotic properties.

Keywords: probiotic; prebiotic; symbiotic; compound feed; grain

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Научная статья

ИММУНОМОДУЛИРУЮЩИЕ КОРМОВЫЕ ДОБАВКИ ДЛЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЖИВОТНЫХ И РЫБ

Д.В. Рудой, Е.Н. Пономарева, Д.С. Мангасарян, Т.А. Мальцева

Аннотация

Обоснование. Современная прикладная биотехнология ориентирована на разработку и внедрение принципиально новых многофункциональных кормовых добавок в комплексной форме. В настоящее время ведется поиск новых подходов к содержанию сельскохозяйственных животных и объектов аквакультуры в условиях воздействия факторов окружающей среды, основанных на использовании биологически активных добавок. Интенсивная антибиотикотерапия стала одной из причин нарушения нормального бактериоценоза и снижения иммунобиологической реактивности животных и рыб, появления устойчивых штаммов патогенных микроорганизмов, что снижает терапевтический эффект антибактериальных препаратов. Применение антибиотиков приводит к накоплению в окружающей среде микроорганизмов с комплексной антибиотикорезистентностью, их попадание в природные водоемы практически невозможно. Одним из перспективных путей решения этих проблем является использование кормовых добавок с иммуномодулирующим действием. В статье рассмотрены существующие кормовые добавки с биологической активностью, приведены обобщенные литературные данные по использованию биологических добавок в животноводстве и аквакультуре.

Цель. Цель исследования – изучить влияние иммуномодулирующих кормовых добавок на сельскохозяйственных животных и рыб.

Материалы и методы. Корма играют важнейшую роль в рационе сельскохозяйственных животных и рыб, поскольку должны содержать все необходимые питательные вещества, витамины и минералы для обеспечения здорового роста и развития животных и объектов аквакультуры. Этим требованиям отвечают такие препараты, как пробиотики (включая синбиотики и метабиотики), пребиотики и синбиотики, которые активно используются в кормопроизводстве. В 1995 году Гибсон и Роберфруа представили понятия, которые следует относить к пребиотикам, и пришли к выводу, что эти компоненты должны быть: 1) селективным компонентом, способствующим метаболической актив-

ности или росту одной или нескольких полезных бактерий; 2) способным изменять микробиоту в сторону здорового состояния; 3) способным оказывать системное или люминальное благоприятное воздействие на организм хозяина; 4) не всасывается и не гидролизуется в верхнем отделе желудка.

Результаты. Современные исследования показывают положительное влияние применения пребиотиков на продуктивность, в том числе на увеличение веса, повышение конверсии корма и снижение заболеваемости. Пребиотики способствуют росту полезных микроорганизмов, таких как бифидобактерии и лактобактерии, в кишечнике животных. Это снижает концентрацию патогенных микроорганизмов, таких как сальмонелла и колиформные бактерии, что уменьшает риск заболеваний и улучшает общее состояние здоровья животных и рыб. Исследования подтверждают возможность снижения использования антибиотиков в кормах за счет применения пребиотиков, что важно в контексте проблемы устойчивости к антибиотикам. Пребиотики можно использовать для повышения экологической устойчивости животноводства и аквакультуры, поскольку они помогают сократить выброс вредных веществ в окружающую среду.

Заключение. Многочисленные научные исследования подтверждают благотворное влияние иммуномодулирующих добавок на здоровье животных, птицы и объектов аквакультуры, особенно в плане защиты от патогенов, стимуляции иммунного ответа и повышения продуктивности. Пребиотики могут использоваться в качестве альтернативы или усиливать действие пробиотиков. Использование комбинации этих компонентов, демонстрирующей синергетический эффект, может быть еще более эффективным в стимулировании кишечной микробиоты и защите здоровья животных. Одним из перспективных направлений исследований является использование в качестве иммуномодулирующей добавки зернового вороха пшеницы, который обладает высокими пребиотическими свойствами. В дальнейшем необходимо уделить внимание исследованиям термической обработки зерна при производстве кормов и кормовых добавок. Следует подчеркнуть, что использование таких кормовых добавок, как пробиотики, пребиотики и синбиотики, является безопасным, не оказывает негативного влияния на окружающую среду и снижает потребность в стимуляторах роста на основе антибиотиков. Однако механизмы действия пробиотических организмов, пребиотиков и их комбинаций в синбиотиках требуют дальнейшего изучения. В технологии производства комбикормов растительное сырье, в том числе пшеница, для повышения питательной ценности подвергается процессу экструзии, в ходе которого при термической обработке уничтожаются патогенные микроорганизмы. Предположительно, зерно пше-

ницы ранних фаз спелости может потерять свои полезные свойства в процессе тепловой обработки (экструзии). В связи с этим целесообразно провести исследование влияния обработки зерна на его пребиотические свойства.

Ключевые слова: пробиотики; пребиотики; синбиотики; комбикорм; зерно

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Introduction

The agribusiness is a dynamically developing sector with significant potential in relation to the strategy of ensuring food security of any country. However, technological problems arise on the way to a stable increase in production volumes in the country and providing the population with high-quality, diverse and affordable agricultural products. First of all, these include:

– diseases of cultivated objects that reduce productivity and marketability of goods;

– lack of effective systems for monitoring and rapid diagnostics of pathogens;

– environmental issues related to the quality of the environment for growing aquatic organisms;

– lack of sufficient assortment and high cost of specialized domestically produced compound feeds, etc.

The problem of ensuring food security for the population is becoming increasingly important. One of the important aspects in this matter is providing livestock with high-quality and balanced compound feed. The global volume of compound feed products is growing every year. Compared to 2023, global production of compound feed increased by 1% and amounted to 1187.7 million tons (FAO Cereal Supply and Demand Brief, 2024) (Fig. 1) [1]. This is primarily due to the increase in the world's population and the increase in demand for animal and plant products. Along with the increase in the volume of feed production, their prices are also rising [2]. In this regard, increasing the volume of feed raw materials is an urgent task.

Feeds play a crucial role in the diet of farm animals and fish, as they must contain all the necessary nutrients, vitamins and minerals to ensure healthy growth and development of animals and aquaculture objects. Such preparations as probiotics (including symbiotics and metabiotics), prebiotics, and synbiotics, which are actively used in feed production, meet these requirements. In 1995, Gibson and Robertfroy introduced the concepts that should be classified as prebiotics and found that these components should be:

1) a selective component that promotes the metabolic activity or growth of one or more beneficial bacteria;

2) capable of altering the microbiota towards a healthy state;

3) capable of exerting a systemic or luminal beneficial effect on the host organism;

4) not absorbed and not hydrolyzed in the upper part of the stomach [3].

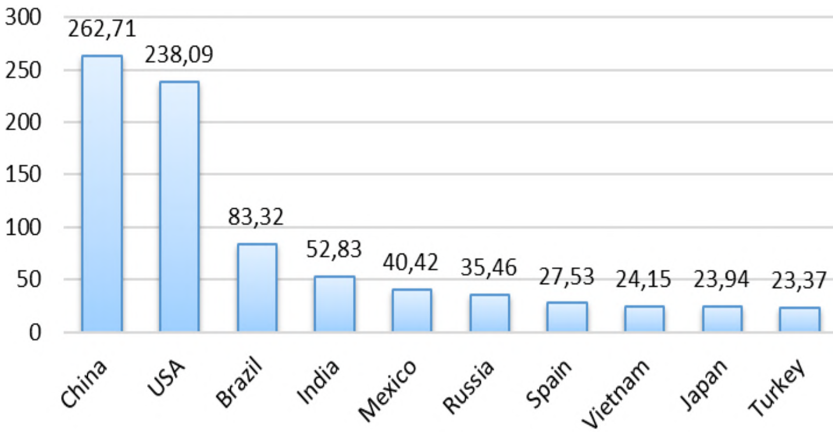

Fig. 1. TOP 10 countries by feed production volume, million tons

Currently, immunotropic drugs of different groups are offered for practical animal husbandry, and there is a need for their extensive industrial testing. For this purpose, a review of existing additives and their impact on the body of animals, birds and aquaculture objects has been conducted.

The use of prebiotic additives in agriculture helps to normalize the microbiocenosis of the organism of farm animals and fish, as well as their resistance to pathogenic microflora, which ultimately affects the increase in productivity and quality of goods.

Prebiotics are carbohydrates that are not broken down in the upper gastrointestinal tract, and other products that are a source of nutrition for normal intestinal microflora. Prebiotics include fructose- and galactose-oligosaccharides, inulin, lactulose, lactiol, dietary fiber, etc. [4].

Prebiotics are insoluble food ingredients that help stimulate the growth and activity of beneficial microorganisms in the intestines of animals and fish. These feed additives play an important role in regulating the microbiota and metabolism of animals and fish, which affects their health and productivity.

Current research shows the positive impact of prebiotic use on performance, including improved weight gain, improved feed conversion and reduced disease. Prebiotics promote the growth of beneficial microorganisms such as bifidobacteria and lactobacilli in the intestines of animals. This reduces the concentration of pathogens such as salmonella and coliform bacteria, which reduces the risk of disease and improves the overall health of animals and fish. Research confirms the possibility of reducing the use of antibiotics in feed through the use of prebiotics, which is important in the context of the problem of antibiotic resistance. Prebiotics can be used to improve the environmental sustainability of livestock and aquaculture, as they help to reduce the release of harmful substances into the environment.

Purpose. The objective of the present study is to investigate impact of immunomodulatory feed additives on farm animals and fish.

Materials and methods

For a substance to be classified as a prebiotic, a detailed specification of its parameters – including origin, purity, and structural characteristics – is an essential prerequisite. Regulatory acceptance mandates adherence to global safety protocols, requiring not only a recognized safety status but also a thorough assessment of its toxicological profile, dosage efficacy, and the absence of adulterants. A fundamental requirement is its confirmed role in promoting the ecological equilibrium of the gut microbiome [5].

As delineated by Wang [6], the classification of a nutritional component as a prebiotic is contingent upon satisfying five key criteria (Fig. 2, 3):

1. Resilience to gastric acidity, hydrolysis by mammalian enzymes, and gastrointestinal absorption.
2. Serving as a selective substrate for colonic microbiota fermentation.
3. Eliciting a beneficial physiological effect on the host's well-being.
4. Selectively enriching for populations of health-promoting bacteria.
5. Maintaining chemical stability throughout industrial processing and storage.

The fundamental criteria for prebiotic compounds begin with their resilience to enzymatic digestion and absorption in the upper gastrointestinal tract. This indigestibility ensures their intact passage to the colon, where they serve as substrates for selective fermentation by beneficial commensal bacteria–constituting the second criterion. The subsequent fermentation metabolites, notably short-chain fatty acids, mediate the third criterion by inducing beneficial shifts in host metabolism and enhancing immunomodulatory functions. Furthermore, a definitive prebiotic must demonstrate a selective stimulation of probiotic bacterial growth (criterion four) and retain stability through food processing technologies to remain bioavailable within the gut lumen (criterion five).

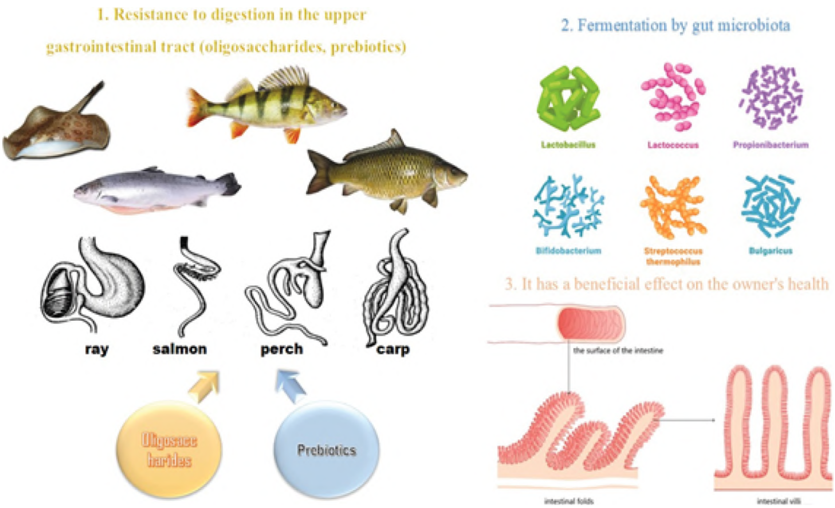

Fig. 2. The main criteria for classifying feed components as prebiotics

Fig. 3. The main criteria for classifying feed components as prebiotics (continued)

The technological process of feed production involves an extrusion process, as a result of which the digestibility of feed and its organoleptic properties are increased. In addition, pathogenic microorganisms die during heat treatment, which ensures the safety of compound feeds. The extrusion process takes place at temperatures from 120 to 200 °C, so it is important to select such probiotics that will be resistant to high temperatures [7].

Results

Research on feed additives and poultry health

Most studies related to poultry microbiota and/or prebiotic potential have focused mainly on the cecum microbiota. The cecum is the most densely populated and microbiologically diverse region of the poultry gastrointestinal tract, with a digestion time of 12 to 24 hours and a major site for bacterial anaerobic fermentation and pathogen colonization [8]. Lignin from sugarcane bagasse has been found to have potential as an animal feed additive when added to feed rations. It promotes the growth of bifidobacteria, a well-known beneficial bacteria, inhabiting the gut microbiota, whose activity, among other things, inhibits the growth of pathogenic bacteria (e.g. Enterobacteriaceae), which is an important factor for animal husbandry.

The study showed that the inclusion of lignin in broiler diets improved the population of lactobacilli and bifidobacteria in the cecum. This indicates that the inclusion of lignin in poultry feed can potentially promote the growth of bifidobacteria in the cecum of broilers, thus acting as a prebiotic ingredient in poultry nutrition.

Another study determined the effect of plant feed supplement and prebiotic on plant protein diet in broiler chickens. A total of 90 chickens (Cobb-500) were weighed and randomly assigned to three treatment groups supplemented with either plant feed supplement or prebiotic and raised for 28 days [9]. The results showed that significant increase in body weight of broiler chickens was observed in both plant feed supplement and prebiotic groups compared to the control group at 4 weeks of age. No significant differences were found in body weight gain between treatment groups at weekly intervals throughout the experimental period. However, significant differences were evident in cumulative weight gain at 3 and 4 weeks of age. The addition of plant protein with a plant feed additive or a prebiotic showed a positive effect of the additive on feed efficiency throughout the entire experimental period compared to the control diet without additives. The authors of the article recommended the use of plant protein as an important source of protein in broiler diets [10].

On the other hand, studies [11] by scientists from the Institute of Animal Reproduction and Food Research of the Polish Academy of Sciences showed that fructooligosaccharides (organophosphorus compounds) administered to commercial male turkeys for 8 weeks did not affect the productivity of the animals. The organophosphorus compounds used were assessed in terms of their effectiveness in terms of productivity and physiological response of the digestive tract. Particular attention was paid to the metabolism of the cecum. The following levels were used in the diet: 0.5, 1 and 2%. After 8 weeks of experimental feeding, diet intake, body weight and feed efficiency were the same in all examined groups. The pH of the ileum and cecum contents was reduced as a result of dietary procedures, especially when using 2% dietary organophosphorus compounds. The experimental treatment did not statistically affect the activity of bacterial enzymes; However, after taking the organophosphorus compounds preparation, a slight beneficial decrease in the activity of β-glucosidase and β-glucuronidase was observed. Addition of organophosphorus compounds to the diet did not affect the growth and productivity of animals.

Another example of a beneficial effect on the intestinal microflora of broilers is a study by scientists from the Institute of Bacteriology and Mycology, Veterinary Faculty of the University of Leipzig [13]. The team conducted a field trial to evaluate the effect of a fructan-containing syrup (0.5%) diluted in drinking water on bacterial activity levels, endotoxin values, as well as body weight and relative organ weights. Fructan resulted in a significant reduction in total aerobes, Enterobacteriaceae and C. perfringens counts, as well as in lower blood endotoxin levels compared to control birds. An increase in body weight as a result of consumption was observed on day 35 of the study period ($P < 0.05$). These results indicate that drinking water containing fructan has a beneficial effect on growth performance, reduces bacterial endotoxin levels and suppresses potential pathogens in the intestine of broilers.

Sims M.D. and co-authors [14] fed crossbred male turkeys to 18 weeks of age for a subsequent comparison of growth promoters. Four dietary treatments were used in the study: negative control (CON), bacitracin methylene disalicylate (BMD) at 55 mg/kg up to 6 weeks and 27.5 mg/kg thereafter, mannan oligosaccharide (MOS) at 0.1% up to 6 weeks and 0.05% thereafter, and BMD and MOS at the concentrations listed above.

Research on feed additives on pig health

Various feed additives are used in studies of the effects of prebiotics on the gastrointestinal microbiota and overall health of pigs.

M.R. Smiricky-Tjardes and co-authors evaluated the effect of galactooligosaccharides (GALOS) supplementation in pig diets on nutrient digestibility, ileal and fecal bacterial populations, and ileal short-chain fatty acid (SCFA) production and determined their effect on ileal enzymatic performance in vitro. The galactooligosaccharides used in this study were prebiotics that increased in vivo beneficial bacteria and SCFA concentrations both in vivo and in vitro. Pigs were fed 35 g/kg TOS for 6 weeks. A significant increase in fecal bifidobacteria and lactobacilli was found compared to the control group.

Studies of feed additives on the health status of aquaculture objects. In addition to the production of animal feed, there is also a need to increase the volume of food fish products, which in turn requires an increase in the growth of feed production for aquaculture facilities. The growth of aquaculture is hampered by a growing number of problems, primarily infectious diseases and improper or irrational fish nutrition. Therefore, it is essential to develop new prevention strategies to minimize infectious diseases and pharmaceutical interventions. Nutritional problems and health of fish can be improved by regulating their gut microbiota. Microbiomes can play a critical role in fish physiology, especially in digestion, by metabolizing largely indigestible components of feed for the host or synthesizing essential micronutrients. In addition to their nutritional role, microbiomes are considered the first line of defense against pathogens [17].

Scientists from the Don State Technical University, together with the Astrakhan State Technical University, the Southern Scientific Center of the Russian Academy of Sciences, and the Agricultural Research Center "Donskoy", conducted research on the effect of feed with probiotics B-1895 and Subtilis-S on the growth and physiological state of sterlet producers [24-26]. Experiments with B-1895 and Subtilis-S based on Bacillus subtilis on sterlet producers grown in a recirculating aquaculture system revealed their positive effect on the studied fish. Compared to the control, the body weight gain in the first experimental group ("B-1895") was 13.3% higher, and in the second group ("Subtilis-S") - by 53.3%. At the same time, an improvement in the physiological state of the experimental fish was recorded, expressed in stabilization and moderate reduction of physiological and biochemical parameters of the blood, in contrast to the control group of fish, in which they either remained unchanged or remained unchanged. increased slightly. In the protein system, the most positive changes were noted in the second group of experimental fish with the greatest weight gain. From the obtained results of the conducted studies, it follows that the most positive effect of the studied probiotics in feeding fish was provided by the drug "Subtilis-S".

The researchers tested a new prebiotic mixture (Selectovit) consisting of

1,3/1,6-beta-glucans, mannan oligosaccharides, nucleic acids, nucleotides, mediumchain fatty acids and single-chain fatty acids at different inclusion levels (0.0; 0.5; 1.0; 2.0 g/kg) in the diet of Atlantic salmon (Salmo salar). Using experimental feed trials and microbiome profiling with 16 S rRNA, the effects of the prebiotic mixture on fish growth and the microbial community in both the gastrointestinal tract and skin were assessed. Overall, the supplementation did not significantly affect growth. However, the prebiotic could significantly affect the number of microorganisms in the distal gut and skin. Several potentially beneficial bacteria, such as Bacillus and Mycoplasma spp. were significantly more numerous in the prebiotic-fed groups compared to the control. In contrast, putative pathogenic bacteria were less numerous in salmon fed the prebiotic mixture. The supplement caused more changes in the skin than in the intestine. In fish, there is increasing evidence of very complex interactions between microorganisms in the digestive system and the external mucosa, as well as with the immune system. Further research in this area may lead to the development of new bacterial biomarkers and new non-invasive strategies for monitoring the health of the fish digestive system [18].

Manufacturers of herbal supplements: Delacon Biotechnik, Biomin Phytogenics, Phytobiotics Futterzusatzstoffe, Pancosma, EW Nutrition, Dostofarm, Nutriad International, Ropapharm International, Himalaya Drug Company, Tanin Sevnica and others [22].

Conclusion

Numerous scientific studies confirm the beneficial effects of immunomodulatory additives on the health of animals, poultry and aquaculture objects, especially in terms of protection against pathogens, stimulation of the immune response and increased productivity. Prebiotics can be used as an alternative or enhance the effect of probiotics. The use of a combination of these components, demonstrating a synergistic effect, can be even more effective in stimulating the intestinal microbiota and protecting animal health. One promising area of research is the use of wheat grain heap as an immunomodulatory additive, which has high prebiotic properties. In the future, it is necessary to pay attention to studies of the thermal treatment of grain in the production of feed and feed additives. It should be emphasized that the use of feed additives such as probiotics, prebiotics and synbiotics is safe, does not have a negative impact on the natural environment and reduces the demand for antibiotic-based growth promoters. However, the mechanisms of action of probiotic organisms, prebiotics, and their combinations in synbiotics require further research. In the technology of compound feed production, plant raw materials, including wheat, are subjected to the extrusion process in order to increase the nutritional value, during which, during heat treatment, pathogenic microorganisms are killed. Presumably, wheat grain of early ripeness phases may lose its beneficial properties during heat treatment (extrusion). In this regard, it is advisable to conduct research on the effect of grain processing on its prebiotic properties.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

THE EFFECT OF A PROBIOTIC BASED ON BACILLUS AMYLOLIQUEFACIENS VKPM B-11475 ON THE COMPOSITION OF INTRAMUSCULAR FAT AND THE AMINO ACID COMPOSITION OF GOAT MEAT PROTEIN WAS STUDIED

G.V. Molyanova, M.M. Orlov

Abstract

Background. The article presents the results of an experimental study evaluating the effect of the probiotic strain Bacillus amyloliquefaciens VKPM B-11475, used in dosages of 4×10^9 and 4×10^7 CFU, on the metabolic profile of Zaanen goats, with an emphasis on the modulation of the composition of volatile fatty acids in intramuscular fat and the amino acid spectrum of muscle protein in the age periods of 8 months and 4 of the year. It was found that probiotic intervention induced a statistically significant modification of lipid metabolism, expressed in an increase in the proportion of saturated fatty acids by 5.22-7.23% (8 months) and 1.62% (4 years), monounsaturated – by 1.14-2.95% and 0.4-2.26%, polyunsaturated – by 0.67-1.53% and 0.46–0.81%, as well as an increase in the level of linoleic acid by 0.83-1.13% and 0.05-0.24%, with a concomitant decrease in the concentration of linolenic acid by 0.19-0.49% and 0.04-0.17%, respectively. The data obtained highlight the potential of B. amyloliquefaciens as a functional additive for targeted correction of the nutritional status of productive animals.

Purpose. To study the effect of the probiotic *Bacillus amyloliquefaciens* on the amino acid composition of goat meat

Materials and methods. A probiotic based on *Bacillus amyloliquefaciens* VKPM B-11475 (*B. amyloliquefaciens*) was produced in the research laboratory of the individual entrepreneur and head of the farm “Tsirulev Evgeny Pavlovich”. The preparation is a light-brown liquid with an average concentration of 4×10^9 CFU. An experimental study was conducted at the goat milk production and processing farm of Semkina O.V. in the Privolzhsky District, Samara Region. Kids were selected as matched pairs, 10 animals per group, at 2 months of age. Three groups of animals, 10 animals each, were created for the experiment. The control group included young kids on a basic feeding ration. Goats in the first experimental group received a probiotic at a dose of 4×10^9, while those in the second experimental group received 4×107 30 minutes before feeding, one capsule per head once daily for one month, administered using a bolus dispenser. Animals were slaughtered at the age of 8 months. A similar experiment was conducted with animals aged 4 years; they were also given the probiotic annually for 2 months. The experiment examined the effect of the probiotic on the fatty acid composition of intramuscular fat (studied using FT-MIR spectroscopy) and the amino acid composition of meat protein (studied using the method described in GOST 34132-2017, method for amino acid analysis).

Results. A significant quality indicator is not only the fat content but also the fatty acid composition of its lipid fraction. Animal fats contain essential polyunsaturated fatty acids, such as linoleic and linolenic acids, which play a vital role in metabolic processes. Like essential amino acids, they are not synthesized in the body, or are synthesized to a limited extent. A prolonged lack of polyunsaturated acids in the diet leads to growth retardation, necrotic skin lesions, and changes in capillary permeability.

Conclusion. The use of a probiotic based on *Bacillus amyloliquefaciens* VKPM B-11475 in raising Saanen goats demonstrates a positive effect on the lipid and amino acid composition of meat. In the short term (8 months), an increase in the proportion of saturated fatty acids by 5.22-7.23%, monounsaturated fatty acids by 1.14-2.95%, and polyunsaturated fatty acids by 0.67-1.53% was observed, including an increase in linoleic acid content by 0.83-1.13%, while linolenic acid decreased by 0.19–0.49%. In the long-term experiment (4 years), the changes persist, but are more pronounced: an increase in saturated fatty acids by 1.62%, monounsaturated by 0.4-2.26%, polyunsaturated by 0.46-0.81% and linoleic acid by 0.05-0.24%, as well as a decrease in the content of linolenic acid by 0.04-0.17%.

Keywords: B. amyloliquefaciens preparation; volatile fatty acids; amino acids; Zaanen goat breed; muscle tissue

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Научная статья

ВЛИЯНИЕ ПРОБИОТИКА НА ОСНОВЕ BACILLUS AMYLOLIQUEFACIENS ВКПМ В-11475 НА СОСТАВ ВНУТРИМЫШЕЧНОГО ЖИРА И АМИНОКИСЛОТНЫЙ СОСТАВ БЕЛКА КОЗЛЯТИНЫ

Г.В. Молянова, М.М. Орлов

Аннотация

Обоснование. В статье представлены результаты экспериментального исследования по оценке влияния пробиотического штамма *Bacillus amyloliquefaciens* ВКПМ В-11475, применяемого в дозировках 4×10^9 и 4×10^7 КОЕ, на метаболический профиль зааненских коз, с акцентом на модуляцию состава летучих жирных кислот во внутримышечном жире и аминокислотный спектр мышечного белка в возрастные периоды от 8 месяцев до 4 лет. Было установлено, что применение пробиотика вызвало достоверные изменения показателей липидного обмена: увеличение насыщенных жирных кислот на 5,22-7,23% (8 месяцев) и 1,62% (4 года), мононенасыщенных – на 1,14-2,95% и 0,4-2,26%, полиненасыщенных – на 0,67-1,53% и 0,46-0,81%, а также повышение уровня линолевой кислоты на 0,83-1,13% и 0,05-0,24%, с сопутствующим снижением концентрации линоленовой кислоты на 0,19-0,49% и 0,04-0,17% соответственно. Полученные данные подчеркивают потенциал *B. amyloliquefaciens* в качестве функциональной добавки для целенаправленной коррекции пищевого статуса продуктивных животных.

Цель. Изучить влияние пробиотика *Bacillus amyloliquefaciens* на жирнокислотный и аминокислотный состав мяса коз.

Материалы и методы. В научно-исследовательской лаборатории индивидуального предпринимателя, главы крестьянского хозяйства «Цирулев Евгений Павлович» был произведен пробиотик на основе *Bacillus amyloliquefaciens* ВКПМ В-11475 (B. amyloliquefaciens). Препарат представляет собой жидкость светло–коричневого цвета, средняя концентрация составляет 4×10^9 КОЕ (КОЕ - колониеобразующая единица). Научно-производственный опыт проводился на ферме по производству и переработке козьего молока фермерского хозяйства «Семкина О.В.» Приволжского района Самарской области. Козлята были отобраны по принципу пар-аналогов по 10 голов в группе в возрасте 2 месяцев. Для проведения эксперимента были созданы три группы животных по 10 голов в каждой. В контрольную группу вошли козлята-молодняк с базовым рационом кормления. Козы I опытной группы принимали пробиотик в дозе 4×10^9, II опытной группы - 4×10^7 за 30 минут до кормления по 1 капсуле на голову 1 раз в день в течение месяца с использованием болюсного дозатора. Убой животных проводили в возрасте 8 месяцев. Аналогичным образом был проведен эксперимент с животными в возрасте 4 лет, им также назначали пробиотик в течение 2 месяцев ежегодно. В ходе эксперимента изучалось влияние исследуемого пробиотика на состав жирных кислот во внутримышечном жире (изучалось с помощью FT-MIR спектроскопии), а также на аминокислотный состав мясного белка (изучалось методом, описанным в ГОСТ 34132-2017).

Результаты. Значимым показателем качества является не только содержание жира, но и жирнокислотный состав его липидной фракции. В составе животных жиров присутствуют незаменимые полиненасыщенные жирные кислоты, играющие важную роль в обменных процессах: линолевая и линоленовая. Подобно незаменимым аминокислотам, они в организме не синтезируются или синтезируются ограниченно. Длительное отсутствие в рационе полиненасыщенных кислот приводит к прекращению роста, некротическим поражениям кожи, изменениям проницаемости капилляров.

Заключение. Использование пробиотика на основе *Bacillus amyloliquefaciens* ВКПМ В-11475 при выращивании зааненских коз демонстрирует положительное влияние на липидный и аминокислотный состав мяса. В краткосрочной перспективе (8 месяцев) наблюдается увеличение доли насыщенных на 5,22–7,23%, мононенасыщенных на 1,14-2,95% и полиненасыщенных на 0,67-1,53% жирных кислот, в том числе увеличение содержания линолевой кислоты на 0,83-1,13%, при этом линоленовая кислота снижается на 0,19-0,49%. В долгосрочном эксперименте (4 года) изменения сохраняются, но более выражены: увеличение насыщенных жирных кислот на 1,62%, мононасыщенных на 0,4-2,26%, полинасыщенных на 0,46-0,81% и линолевой кислоты на 0,05-0,24%, а также по мере снижения содержания линоленовой кислоты на 0,04-0,17%.

Ключевые слова: B. amyloliquefaciens; летучие жирные кислоты; аминокислоты; козы зааненской породы; мышечная ткань

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Introduction

Agriculture, acting as a system-forming sector of the economy, plays a critically important role in ensuring global food security, socio-economic development and maintaining ecological balance. In the context of population growth, projected to reach 9 billion people by 2050, and the intensification of climate change, the agricultural sector faces the need not only to increase food production, but also to radically improve its quality, nutritional value and accessibility. The economic importance of the industry is reflected in the creation of employment opportunities, especially in developing countries, stimulating related sectors (processing, logistics, trade) and improving the standard of living of rural communities. At the same time, modern agriculture is being transformed towards sustainable and high-tech practices that minimize the ecological footprint, promote biodiversity conservation and ecosystem restoration, which underlines its key role in achieving sustainable development goals and adapting to anthropogenic challenges [1].

Goat breeding, being a strategically important branch of the agro-industrial complex of Russia and other countries, demonstrates a high adaptive potential in the face of various climatic and economic challenges. The actualization of the sector is driven by the growing consumer demand for natural and organic products, where goat's milk and meat occupy a niche of functional nutrition due to their unique biochemical properties. Comparative analysis shows the superiority of goat's milk over cow's milk in terms of calcium (13-15% higher) and B vitamins (B2 by 18-20%, B12 by 8-10%), as well as the presence of an alternative form of casein, which reduces the risk of allergic reactions by 40-60% in sensitized individuals. These characteristics correspond to the trend of conscious consumption, stimulating farmers to introduce resource-saving technologies and form new market niches, which ultimately contributes to the diversification of agriculture and strengthening food security [2; 3].

In addition, goat breeding has a lower negative impact on the environment compared to cattle. Goats are less demanding of resources and can successfully graze on less fertile lands, making them ideal for sustainable agriculture. This attracts the attention of not only consumers, but also public and private investors interested in supporting environmentally friendly industries. In general, the growing interest in natural and organic products creates favorable conditions for the development of goat breeding and contributes to the formation of a new culture of consumption focused on health and a sustainable future [4].

In the article by T.L. Krasovskaya, S.I. Novopashina (2012), the goats were fed, in addition to the main diet, the feed additive Humival at a dosage of 50 mg dv/ kg. There was a 40% reduction in the number of sick animals. Increase the safety of young animals by 10%. Bactericidal activity increased by 3.55%, lysozyme activity by 4.74% [5].

Under the influence of the LactoMin supplement (at a dosage of 50 g /head / day), the average daily milk yield increased by 11.7%, protein by 0.08%, fat content by 0.15%. Under the action of the LactuVet additive (at a dosage of 50 g / head / day), there was an increase in indicators compared to the control: average daily milk yield by 8.5%, protein by 0.02%, and fat content by 0.07% [6]. Feed additive “Plantarum” in a dosage of 0.8 ml / kg of body weight per day. There was an increase in such indicators as: productivity by 3.27%, protein mass fraction by 3.33%; fat mass fraction by 3.22% [7]. When sapropel feed additive was introduced into the main diet (0.6 g / kg of live weight + hongurin 0.20 g / kg of live weight + Kempendyai salt 10 g), there was an increase in live weight in 6 months by 4.38%, in 8 months by 6.69%, in 10 months by 6.88%, in 12 months. by 7.78%. Absolute growth increased by 18.12%, profitability by 8.51% [4]. Additives “YODDAR-ZN” (100 mg per 1 kg of concentrated feed) and DAFS-25 (1.6 mg per 1 kg) increase the index of albumins (by 0.45 and 1.21%), phosphorus (by 8.53 and 20.12%, respectively). Reduction of globulins (by 0.51 and 1.21%), creatinine (by 13.43 and 17.21%, respectively [8]. Algavet feed additive (in a dosage of 40 ml per animal) provides an increase in productivity (by 24.55%), fat mass fraction (by 0.26%), protein mass fraction (by 0.28%), SOMO (by 0.27%), density (by 0.09%), milk caloric content (by 8.10%) [9]. The Plantarum feed additive (at a dosage of 0.8 mg/kg) provides an increase in such indicators as: absolute increase (by 3.12%), average daily increase (by 2.80%), live weight (by 18.2%), relative increase (decreased by 0.6%) [10]. The use of a feed additive from ginger seeds (ginger estrudate) led to an increase in the mass fraction of fat (by 0.43%), mass fraction of protein (by 0.10%), SOMO (by 0.02%), average daily milk yield (by 17.52%) [11]. Under the influence of the feed additive Zhomstevia (5 g / kg of live weight) There was an increase in productivity (by 19.20%), acidity (by 0.69%), density (by 0.09%), fat mass fraction (by 0.28%), protein mass fraction (by 0.24%), SOMO (by 0.26%), casein (by 0.33%). The content of whey proteins decreased by 0.09% [12]. The probiotic drug Celobacterin (at a dosage of 1 g of the drug per 1 kg of feed) provides a 33% increase in milk yield, and a 32% reduction in the cost of dry matter for milk synthesis [13]. The introduction of 150 g + sodium acetate into the main diet of soy meal (at a dosage of 90 g per head per day) led to an increase in the average daily milk yield (by 14.67%), fat (by 6.25%), protein (by 18.99%), lactose (by 12.35%) [14].

In the study of I.F. Gorlov, A.A. Korotkova et al. (2013), in addition to the basic diet, the goats of the II experimental group were fed the feed additive "YODDAR-ZN" (100 mg per 1 kg of concentrated feed), and the III experimental group, in addition to O.R., were fed the selenium-organic drug DAFS-25 (1.6 mg per 1 kg). There was an increase in such indicators as milk yield by 10.87% (II experimental group) and 14.78% (III experimental group); fat mass fraction by 0.21 and 0.78%; protein mass fraction by 0.05 and 0.10%; live weight by 3.06 and 3.85%; lactation coefficient by 7.57 and 10.53%; lactation constancy coefficient 3.43 and 3.95%. Erythrocyte count by 0.71 and 1.17%; leukocytes (decreased) by 2.5% (experimental group III), and (increased) by 5.69% (experimental group II); hemoglobin by 1.25 and 2.5%; total protein by 5.46 and 7.33%; glucose by 2.56 and 4.27%; calcium 0.75 and 1.35%; urea 11.34 and 6.58% respectively [15].

Under the influence of feed additives Lactovet-1 (at a dosage of 0.5% by weight of concentrates) and Cumelact -1 (at the same dosage), erythrocyte counts increase (by 4.98 and 9.53%), hemoglobin (by 2.17 and 3.41%), total protein (by 4.69 and 7.59%), albumins (by 2.18 and 32.83%), urea (by 8.88 and 19.28%), glucose (by 8.98 and 11.23 %), calcium (by 8.64 and 20.57 %), phosphorus (by 4.45 and 19.74%), bilirubin (by 2.03%) (when using Cumelact-1, the indicator was equal to the control group). ALT (by 2.80 and 11.92%), AST (by 0.46 and 1.20%), lysozyme activity (by 12.32 and 14.63%). The number of phagocytic neutrophils increased by 4.26 and 5.72%, the phagocytic index by 0.44 and 0.79%. Milk yield increased by 5.41 and 6.49%, fat by 0.28 and 0.30%. Titrated acidity increased by 0.29 and 0.82%, respectively. The following indicators decreased: leukocytes by 2.00 and 0.72%, globulins by 0.92 and 2.17%, creatinine by 10.40 and 16.93%, respectively [16].

The drug "Em Kurunga" (in a dosage of 0.01 g of concentrate per 1 kg of live weight) provides an increase in body weight by 12.1%, and a change in the physique index in terms of: legginess by 3.5%, elongation (decrease) by 8.6%, downness by 13%, overgrowth (decrease) by 0.6%, massiveness by 3%, bony by 1.1%, big-headed by 2%, broad-browed (decrease) by 6.6% [17].

Materials and methods

A probiotic based on *Bacillus amyloliquefaciens* VKPM B-11475 (*B. amyloliquefaciens*) was produced in the research laboratory of an individual entrepreneur, the head of a Peasant (Farmer) Farms "Tsirulev Evgeny Pavlovich" [18]. The preparation is a light-brown liquid with an average concentration of 4×10^9 CFU.

A scientific and production experiment was carried out at the goat milk production and processing farm of Semkina O.V. of the Privolzhsky district of the Samara region. The goats were selected according to the principle of pairs of analogues of 10 heads in a group of 2 months of age. To conduct the experiment, three groups of animals were created, including 10 heads each [18]. The control group included baby goats with a basic feeding diet. The goats of the experimental group I took probiotic at a dose of 4×10^9, experimental group II 4×10^7 30 minutes before feeding, 1 capsule per head 1 time per day for a month using a bolus dispenser. The slaughter of animals was carried out at the age of 8 months. Similarly, an experiment was conducted with animals aged 4 years, they were also prescribed a probiotic for 2 months annually.

During the experiment, the effect of the probiotic under study on the composition of fatty acids in intramuscular fat (studied using FT-MIR spectroscopy), as well as on the amino acid composition of meat protein (studied by the method described in GOST 34132-2017).

The digital data obtained in the experiments were subjected to statistical processing using the Microsoft Office Excel 2010 computer application and analyzed in accordance with the norms of variation statistics. Statistical reliability was determined by the Student's criterion.

Results

A significant indicator of quality is not only the fat content, but also the fatty acid composition of its lipid fraction. The composition of animal fats contains essential polyunsaturated fatty acids that play an important role in metabolic processes: linoleic and linolenic. Like essential amino acids, they are not synthesized in the body or are synthesized in a limited way. Prolonged absence of polyunsaturated acids in the diet leads to cessation of growth, necrotic skin lesions, changes in capillary permeability. The results of the study of the content of fatty acid are presented in Tables 1-2, amino acid composition in tables 3-4.

Table 1.

Fatty acid composition of intramuscular fat in 8-month-old goats, %

Indicator	Groups of animals		
	Control group	First experimental group	Second test
Saturated fatty acids	50.47±1.258	57.70±1.437***	55.69±1.387***
Monounsaturated fatty acids	42.89±1.065	45.84±1.142***	44.03±1.093***
Polyunsaturated fatty acids	4.65±0.113	3.12±0.078***	3.98±0.097***
Linoleic acid	2.89±0.072	4.02±0.096***	3.72±0.087***
Linolenic acid	1.08±0.027	0.59±0.012***	0.89±0.018***

Here and further note: *** – p≤0.001 – relative to the control data.

Analysis of the data presented in Table 1 demonstrates that changes in the diet of goats (experimental groups) had a statistically significant ($p<0.001$) effect on the profile of fatty acids in intramuscular fat compared with the control group. There is a marked tendency to increase the proportion of saturated fatty acids (from 50.47% in the control to 57.70% and 55.69% in the first and second experimental groups, respectively) and monounsaturated (from 42.89% to 45.84% and 44.03%), while the content of polyunsaturated fatty acids decreased significantly (from 4.65% to 3.12% and 3.98%). It is noteworthy that, contrary to this general trend, the level of linoleic acid increased (from 2.89% to 4.02% and 3.72%), while the content of linolenic acid, on the contrary, showed the sharpest decrease (by 1.8 and 1.2 times – from 1.08% to 0.59% and 0.89%), indicating a complex and multidirectional the influence of experimental factors on the metabolism of various classes of PUFA. From the point of view of physiology and biochemistry, the observed changes are probably due to the modification of lipid metabolism in the rumen of animals under the influence of a new diet. A sharp decrease in the level of linolenic acid (C18:3 n-3) and a general decrease in the proportion of PUFA (polyunsaturated fatty acids) with a simultaneous increase in SFA (saturated fatty acids) and MUFA (monounsaturated fatty acids) indicates an increased biohydrogenation process in the rumen, during which microorganisms saturate the free double bonds of fatty acids supplied with feed, converting polyunsaturated acids into monounsaturated (for example, into oleic acid) and further in saturated (primarily stearin C18:0). The paradoxical increase in linoleic acid (C18:2 n-6) despite a general decrease in PUFA may be explained by an initially linoleic-acid–rich diet and ruminal metabolic pathways (e.g., partial biohydrogenation to conjugated linoleic acid) that could cause transient accumulation in tissues.

Table 2.

Fatty acid composition of intramuscular fat in 4-year-old goats

Indicator	Groups of animals		
	Control group	First experimental group	Second experimental group
Saturated fatty acids	64.68±1.613	63.06±1.572**	63.96±1.587**
Monounsaturated fatty acids	32.70±0.815	34.96±0.871***	33.10±1.822
Polyunsaturated fatty acids	3.31±0.267	3.77±0.093	4.12±0.116**
Linoleic acid	1.79±0.081	2.03±0.049***	1.84±0.048
Linolenic acid	1.36±0.031	1.19±0.026***	1.32±0.031

The data for the 4-year period revealed significant but less contrasting changes in the fatty acid profile compared to the 8-month experiment. The content of saturated fatty acids in the experimental groups (63.06% and 63.96%) decreased significantly ($p<0.01$) compared with the control (64.68%), while the proportion of monounsaturated acids increased significantly only in the first experimental group (34.96% versus 32.70% in the control, $p<0.001$). There is a tendency to increase polyunsaturated fatty acids, which reached statistical significance in the second experimental group (4.12% vs. 3.31%, $p<0.01$). The content of linoleic acid significantly increased only in the first group (2.03% vs. 1.79%, $p<0.001$), and the level of linolenic acid, on the contrary, significantly decreased in the same group (1.19% vs. 1.36%, $p<0.001$), which indicates a long-term adaptation of metabolism and possible compensatory regulation of biochemical pathways, leveling the initial effect of a change in diet. From a physiological and biochemical point of view, the changes observed over 4 years indicate a long-term adaptation of the rumen microbiome and lipid metabolism of animals to the experimental diet. A decrease in the proportion of saturated fatty acids (NLCs) and an increase in monounsaturated (MNFA) and polyunsaturated (PUFA) acids compared to earlier results suggests partial compensation and increased efficiency of assimilation of dietary lipids, possibly due to an adaptive shift in the rumen microbial population towards communities with less intensive biohydrogenation activity. This adaptation leads to a higher bypass of unsaturated fatty acids from the rumen for deposition in tissues. The stabilization of linolenic acid levels in the second near control values group (1.32% vs 1.36%) against the background of its reduction in the first group indicates a complex regulation of omega-3 acid metabolism, which may depend on the exact composition of the diet and individual characteristics of animals, including the activity of tissue desaturases, elongases and specific peroxisomal β-oxidizing enzymes.

According to the data, dietary modification in goats led to selective but statistically significant changes in the content of some essential amino acids in muscle protein after 8 months of the experiment. There was a significant increase in the concentration of lysine (from 6.1 g/100 g of protein in the control to 6.6 and 6.3 in the first and second experimental groups, respectively, $p < 0.001$), isoleucine (from 3.3 to 3.7, $p < 0.001$ and 3.4, $p < 0.01$) and the amount of phenylalanine and tyrosine (from 5.4 to 5.8, $p < 0.05$ and 5.7, $p < 0.001$).

At the same time, the levels of histidine, leucine, methionine with cysteine, threonine, tryptophan, and valine remained statistically unchanged, indicating a targeted effect of diet on the metabolism of specific amino acids without disrupting the overall amino acid balance of the protein matrix.

Table 3.

Amino acid composition of essential amino acids of goat meat proteins 8 months, %

Amino acid	Amino acid content, g/100 protein		
	Control group	First experimental group	Second experimental group
Histidine	2.5±0.061	2.6±0.065	2.6±0.063
Isoleucine	3.3±0.079	3.7±0.087***	3.4±0.081**
Leucine	6.7±0.162	6.9±0.169	6.8±0.164
Lysine	6.1±0.149	6.6±0.163***	6.3±0.153***
Methionine+cysteine	2.8±0.064	2.9±0.068	2.9±0.068
Phenylalanine+ tyrosine	5.4±0.132	5.8±0.139*	5.7±0.137***
Threonine	2.5±0.061	2.6±0.062	2.5±0.056
Tryptophan	0.087±0.001	0.091±0.001	0.089±0.001
Valin	4.6±0.112	4.8±0.117	4.7±0.112

A significant quality indicator is not only fat content but also the fatty acid composition of its lipid fraction. The observed increase in the content of specific essential amino acids (lysine, isoleucine, phenylalanine, and tyrosine) while maintaining the overall amino acid balance indicates a selective effect of diet composition on metabolic pathways. It is likely that experimental feed additives contained an increased number of precursors of these amino acids or stimulated the activity of key enzymes of their synthesis in the rumen microbiota, such as aminotransferases and dehydrogenases. At the same time, the absence of changes in the concentration of other essential amino acids indicates a high degree of metabolic homeostasis and regulatory compensation provided by the mechanisms of feedback inhibition of biosynthetic pathways, which prevents imbalance and maintains the stability of the muscle tissue proteome.

After four years, the amino acid composition showed a stable and statistically significant improvement in the profile of essential amino acids in the experimental groups compared with the control. In the first experimental group, there was a significant increase in all key amino acids: histidine (2.4±0.04 vs 2.0±0.02, $p<0.001$), isoleucine (3.5±0.07 vs 3.1±0.02, $p<0.001$), leucine (6.6±0.01 vs 6.2±0.04, $p<0.001$), lysine (6.4±0.09 vs 6.1±0.05, $p<0.01$), methionine+cysteine (2.7±0.05 vs 2.5±0.07, $p<0.01$), phenylalanine+tyrosine (5.6±0.03 vs 5.0±0.08, $p<0.001$) and valine (4.6±0.07 vs 4.1±0.06, $p<0.001$). In the second experimental group, the changes were less pronounced, but also significant: histidine (2.2±0.05, $p<0.01$), isoleucine (3.4±0.07, $p<0.01$), leucine (6.6±0.08, $p<0.001$), lysine (6.2±0.06, $p<0.05$), phenylalanine+tyrosine (5.2±0.05, $p\leq0.01$) and valine (4.3±0.05, $p\leq0.001$).

Table 4.

Amino acid composition of essential amino acids of goat meat proteins 4 years old. %

Amino acid	Amino acid content. g/100 protein		
	Control group	First experimental group	Second experimental group
Histidine	2.0±0.02	2.4±0.04***	2.2±0.05**
Isoleucine	3.1±0.02	3.5±0.07***	3.4±0.07**
Leucine	6.2±0.04	6.6±0.01***	6.6±0.08***
Lysine	6.1±0.05	6.4±0.09**	6.2±0.06*
Methionine+ cysteine	2.5±0.07	2.7±0.05**	2.6±0.03
Phenylalanine+ tyrosine	5.0±0.08	5.6±0.03***	5.2±0.05**
Threonine	2.4±0.08	2.5±0.06	2.4±0.03
Tryptophan	0.083±0.001	0.088±0.001	0.085±0.001
Valin	4.1±0.06	4.6±0.07***	4.3±0.05***

The content of threonine and tryptophan remained unchanged in both groups, which indicates a long-term positive effect of the experimental diet on the protein composition of meat while maintaining metabolic balance. Long-term use of experimental diets for 4 years led to a significant improvement in the amino acid composition of goat meat, which indicates a deep metabolic adaptation of animals. There was a statistically significant increase in the content of histidine (from 2.0 to 2.4 and 2.2 g/100 g of protein), isoleucine (from 3.1 to 3.5 and 3.4), leucine (from 6.2 to 6.6 in both groups), lysine (from 6.1 to 6.4 and 6.2), methionine with cysteine (from 2.5 to 2.7) and valine (from 4.1 to 4.6 and 4.3) while maintaining unchanged levels of threonine and tryptophan. These changes are explained by the optimization of the synthetic activity of the scar microflora and improved utilization of nutrients, while the stability of individual amino acids indicates the preservation of metabolic homeostasis due to the mechanisms of enzymatic regulation.

Conclusion

The use of a probiotic based on *Bacillus amyloliquefaciens* VKPM B-11475 in the cultivation of Saanen goats demonstrates a positive effect on the lipid and amino acid profile of meat. In the short term (8 months), there is an increase in the proportion of saturated (by 5.22–7.23%), monounsaturated (by 1.14–2.95%) and polyunsaturated (by 0.67–1.53%) fatty acids, including an increase in linoleic acid (by 0.83–1.13%), while linolenic acid decreases (by 0.19-0.49%). In the long–term experiment (4 years), the changes persist, but are more pronounced: an increase in NLC (by 1.62%), MNFA (by 0.4–2.26%), PUFA (by 0.46–0.81%) and linoleic acid (by 0.05-0.24%), as well as a decrease in linolenic acid (by 0.04–0.17%). The amino acid composition of the protein improves significantly: after 8 months, there is an increase in all essential amino acids, including isoleucine (by 3.03–12.12%), lysine (by 3.17–8.19%) and valine (by 2.17–4.34%), and after 4 years the effect increases for histidine (by 10-20%), isoleucine (by 9.67–12.9%) and valine (by 4.87–12.19%), which confirms the stability of the metabolic changes induced by the probiotic.

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Original article

STUDY OF THE EFFECT OF UV IRRADIATION OF SEED-BEARING WHEAT ON ENZYME ACTIVITY DURING GERMINATION

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Abstract

Background. In this article, the study is devoted to the influence of UV irradiation on the activity of enzymes (amylase, catalase and peroxidase) in germinating seeds of winter wheat variety Rostovchanka 5. The aim of the study was to select the optimal modes of UV irradiation to stimulate germination. The results of the study indicate that short-term UV irradiation (3-5 minutes) can effectively stimulate enzyme activity in germinating winter wheat seeds, which can potentially increase germination and germination energy. These results may be useful for the development of innovative environmentally safe methods of pre-sowing seed stimulation. In this article, the study is devoted to the influence of UV irradiation on the activity of enzymes (amylase, catalase and peroxidase) in germinating seeds of winter wheat variety Rostovchanka 5. The aim of the study is to select the optimal modes of UV irradiation to stimulate germination.

Purpose. The aim of the study was to select the optimal modes of UV irradiation to stimulate germination

Materials and methods. In 2022-2024, research was conducted on wheat seeds of the Rostovchanka 5 variety bred in the Rostov region

Irradiation of seeds with UV rays after soaking in distilled water accelerates germination by 20%. The laboratory conducted experiments with repetition of 100 grains, moistening them every day with a tray of water in the thermostat.

Results. The results of the study indicate that short-term UV irradiation (3-5 minutes) can effectively stimulate enzyme activity in germinating winter wheat seeds, which can potentially increase germination and germination energy.

Conclusion. A mercury-quartz lamp for irradiation of winter soft wheat seeds was used for the study. The activity of enzymes (amylase, catalase, peroxidase) depending on irradiation time was determined.

The study showed that the use of UV irradiation to irradiate seeds improves their germination, activates biochemical processes and promotes plant growth. This demonstrates the importance of using UV irradiation in agriculture.

Keywords: wheat; UV rays; lamp BNPO 2-30-001U3,5; enzymes

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Научная статья

ИССЛЕДОВАНИЕ ВЛИЯНИЯ УФ-ОБЛУЧЕНИЯ СЕМЯНОЗИМОЙ ПШЕНИЦЫ НА АКТИВНОСТЬ ФЕРМЕНТОВ ПРИ ПРОРАСТАНИИ

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Аннотация

Обоснование. В данной статье исследование посвящено изучению влияния УФ-излучения на активность ферментов (амилазы, каталазы и пероксидазы) в прорастающих семенах озимой пшеницы сорта Ростовчанка 5. Цель исследования – выбор оптимальных режимов УФ-облучения для стимуляции прорастания.

Результаты исследования указывают на то, что кратковременное УФ-облучение (3-5 минут) может эффективно стимулировать активность ферментов в прорастающих семенах озимой пшеницы, что потенциально может повысить всхожесть и энергию прорастания. Данные результаты могут быть полезны для разработки инновационных экологически безопасных приемов предпосевной стимуляции семян.

Цель. Цель исследования – выбор оптимальных режимов УФ-облучения для стимуляции прорастания

Материалы и методы. В 2022-2024 годах проводились исследования на семенах пшеницы сорта Ростовчанка 5, выведенного в Ростовской области.

Облучение семян УФ лучами после замачивания в дистиллированной воде ускоряет прорастание на 20%. В лаборатории проводили эксперименты с повторением по 100 зерен, увлажняя их каждый день с помощью поддона с водой в термостате.

Результаты. Результаты исследования указывают на то, что кратковременное УФ-облучение (3-5 минут) может эффективно стимулировать активность ферментов в прорастающих семенах озимой пшеницы, что потенциально может повысить всхожесть и энергию прорастания.

Заключение. Для изучения была использована ртутно-кварцевая лампа для облучения семян озимой мягкой пшеницы. Определена активность ферментов (амилаза, каталаза, пероксидаза) в зависимости от времени облучения.

Исследование показало, что использование УФ-излучения для облучения семян улучшает их прорастание, активирует биохимические процессы и способствует росту растений. Это демонстрирует важность применения УФ-облучения в сельском хозяйстве.

Ключевые слова: пшеница; УФ лучи; лампа БНПО 2-30-001У3,5; ферменты

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Introduction

Wheat is the main crop in the Rostov region. The use of innovative environmentally safe methods of seed treatment increases the efficiency and competitiveness of agriculture.

Various stimulation methods can accelerate biochemical processes, growth and formation. Seed germination is related to the activity of enzymes that are activated by swelling. This enzyme activity that promotes germination is a response to stress from ultraviolet radiation.

Amylase breaks down starch into maltose, which is then converted to glucose. Catalase converts hydrogen peroxide to water, and peroxidase, in conjunction with catalase, protects cells from hydrogen peroxide accumulation, preventing exposure to pathogens and stressors. The response to stress may vary with duration and plant species. Investigation of the effect of UV light on enzymes in wheat seeds and search for optimal conditions to accelerate germination. Study of the effect of different duration of UV irradiation on enzyme activity in germinating wheat seeds. Study of optimal irradiation conditions for improving seed germination.

Materials and methods

In 2022-2024, research was conducted on wheat seeds of the Rostovchanka 5 variety bred in the Rostov region. This semi-dwarf variety has a mass of 1000 grains from 35 to 44 grams. The yield is 49.7 c/ha, a medium-early variety with a vegetation period of 228 to 286 days. Rostovchanka 5 is resistant to lodging, diseases and drought, has excellent baking characteristics.

Irradiation of seeds with UV rays after soaking in distilled water accelerates germination by 20%. The laboratory conducted experiments with repetition of 100 grains, moistening them every day with a tray of water in the thermostat.

The seeds were irradiated with UV light at an intensity of 30 W/m^2 for different time intervals to stimulate enzyme activity.

A method with NaCl addition and incubation with starch was used to measure amylase activity. The amount of hydrolyzed starch was measured in milligrams per milliliter of enzyme extract.

Gasometric method was used to measure the activity of catalase. Total peroxidase activity was determined using the Boyarkin method, which is based on the oxidation of benzidine by hydrogen peroxide with the participation of peroxidase.

Results

Successful germination requires that seeds swell and germinate under optimal environmental conditions. The germination process involves four stages: swelling, germination, seedling growth using external nutrition and transition to an autotrophic type of nutrition. Water plays a key role by penetrating the seed, moisturizing and activating enzyme systems.

Amylase is essential for the breakdown of starch in seeds during germination. The highest amylase activity during wheat germination is usually reached after 3-5 days.

In the experiment, the effect of UV irradiation on amylase activity in winter wheat seeds was investigated. It was found that the peak of enzyme activity occurs on the fourth and fifth day of germination, after which it begins to decrease. On the first day of germination there is an increase in amylase activity in all groups of the experiment.

Amylase showed high activity at the beginning of seed germination. After 3 minutes treatment, the activity increased by 19%, and after 5 minutes it increased by 23.5%.

Maximum amylase activity was reached on the fourth day of germination, exceeding the control values by 58.6% and 64.1% in samples with UV irradiation of 3 and 5 minutes duration.

After irradiating the seeds with UV irradiation for three or five minutes, the level of amylase activity increased, which promotes rapid germination of the embryo and increases growth vigor.

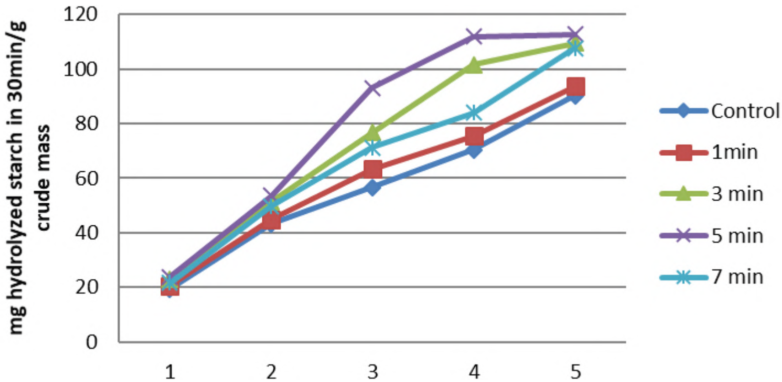

Fig. 1. Amylase activity in winter wheat seeds increased after UV irradiation

Catalase in seeds prevents the formation of hydrogen peroxide, having optimum activity at pH 6.5. In the oxidized state, it catalyzes the oxidation of alcohols and aldehydes, acting as a peroxidase. The activity of catalase increases during intense respiration of germinating seeds.

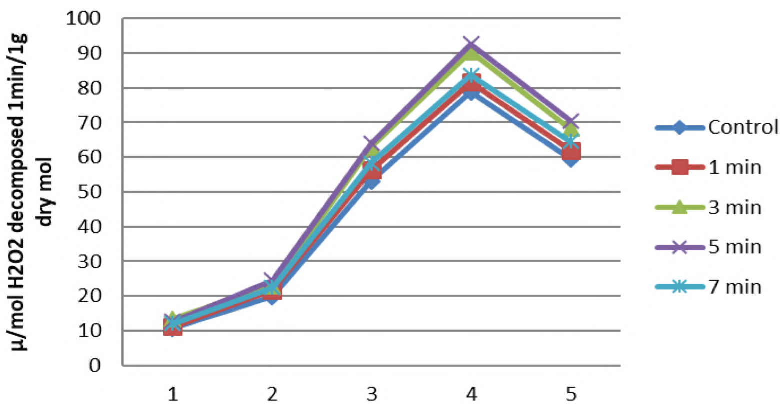

Fig. 2. Catalase enzyme shows activity in germinating winter wheat seeds

The study showed that UV irradiation increases the activity of catalase in germinating seeds of winter wheat variety Rostovchanka 5. The maximum activity is reached after 4 days and gradually decreases.

Irradiation with ultraviolet light increased catalase activity in wheat seedlings. The maximum effect was achieved in five-minute treatment.

After five days, catalase activity decreases in both control group and all the experiment variants, but the short period of irradiation helps to improve catalase activity, which may contribute to more efficient respiration and seed survival during germination.

When seeds are germinated in a thermostat at 20°C, catalase activation occurs unevenly, as shown by the experimental curve. When seeds are moistened, catalase is activated. Activation begins on the first to second day, increases on the second and third day, peaks on the fourth day, and then decreases.

Studies have shown that irradiation of wheat seeds with ultraviolet radiation increases catalase activity and enhances synthesis processes in seedlings).

Peroxidase helps plants to be resilient and plays an important role in their development. $_2O_2$ peroxidase is an important component of the plant defense system against oxidative stress due to its ability to catalyze the oxidation of various compounds and prevent lipid oxidation.

Peroxidase activity increases during seed awakening, which is associated with respiration. Experiments show that peroxidase plays an important role in cellular metabolism and can act at different levels of acidity.

UV-irradiated wheat seeds showed an increase in peroxidase activity during germination. Differences were found in the level of enzyme activity under different conditions and with time.

Peroxidase activity increased gradually during the first seven days in all groups of the experiment and reached a peak by the eighth day. The activity was highest in the groups with three and five-minute exposure to irradiation.

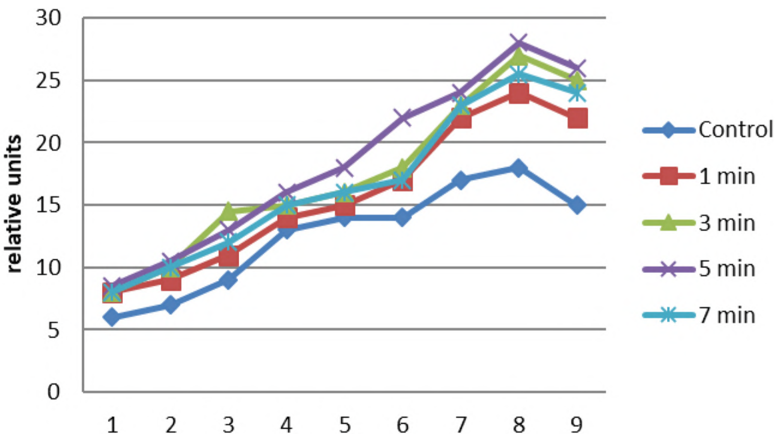

Fig. 3. Peroxidase activity in germinating winter wheat seeds was studied

Figure 3 shows how peroxidase activity in winter wheat seeds changes during nine days of germination. An increase in peroxidase activity is observed during seed germination when seeds are soaked at 20°C.

The study confirmed that the level of peroxidase activity in seeds increases significantly at the beginning of germination, reaches a maximum on the eighth day and then decreases by the ninth day.

Eight days after seed planting, peroxidase enzyme activity increased by 50% at three-minute irradiation and 55% at five-minute irradiation, exceeding the control level. The peak activity was reached at longer irradiation.

Studies have shown that prolonged irradiation makes seeds more sensitive to UV rays, while short irradiation induces less vivid responses.

Fresh evidence shows that stress affects the metabolism of organisms, causing changes. Moderate stress can stimulate adaptation and improve the resilience of living systems.

Under stress, an organism goes through several stages: stimulation, inhibition, plateauing, and activation or suppression. Stress-resistant entities also go through these changes, but with a delay and at higher exposures. Understanding stress responses helps to optimize conditions for growth and development of living systems.

Conclusion

The use of BNPO 2-30-001U3.5 lamps for enzyme activation accelerates seed germination and germination, which makes it an environmentally safe method of seed stimulation in agriculture.

A mercury-quartz lamp for irradiation of winter soft wheat seeds was used for the study. The activity of enzymes (amylase, catalase, peroxidase) depending on irradiation time was determined.

The study showed that the use of UV irradiation to irradiate seeds improves their germination, activates biochemical processes and promotes plant growth. This demonstrates the importance of using UV irradiation in agriculture.

New electrophysical methods of seed stimulation can increase yields by 10-20%, so it is necessary to establish installations with electro-optical transducers for seed treatment before sowing in agriculture.

Conflict of interest information. The authors declare that they have no conflict of interest.

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ВКЛАД АВТОРОВ

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Original article

ALTERNATIVE METHODS OF DISEASE PREVENTION AND TREATMENT IN AQUACULTURE

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Abstract

Background. In recent years, the use of antibiotics in aquaculture has raised increasing concern due to the development of microorganism resistance to antibacterial drugs and the negative impact on the ecosystem. Therefore, search for alternative methods for treating and preventing fish diseases has become an urgent task. Promising alternatives for the prevention and treatment of aquaculture species include the use of probiotics, prebiotics, synbiotics, postbiotics, phytobiotics, bacteriophages, and quorum sensing (QS) inhibition mechanisms. The state of the microflora of aquatic organisms is crucial for enhancing the organism's resistance to infectious diseases. Thus, using agents that can positively influence the microbiota, exert antimicrobial effects, and modulate the immune system is essential for the effective development of the aquaculture industry. This article discusses some of the main fish diseases, the likelihood of which increases with the intensification of aquaculture. Bacteria of the genus *Aeromonas* are often the cause of diseases and financial losses in the industry. The work provides an overview of alternative methods for preventing and treating fish diseases that can reduce the use of antibacterial drugs, including the application of vaccines, probiotics, prebiotics, and bacteriocins.

Purpose. To investigate alternative methods of treatment and prevention of fish diseases.

Materials and methods. In the study, a method of collecting, analyzing, and systematizing of published scientific sources was used. The collection of literary information was carried out using reference databases such as Science Direct, Research Gate, Google Scholar, National Library of Medicine, Wiley Online Library, and others. To search for suitable scientific publications, keywords such as «aquaculture», «diseases», «bacterial fish diseases», «probiotics», «prebiotics», «synbiotics», «bacteriocins», «phytobiotics», and «quorum sensing» were used individually or in various combinations. The search period was limited to scientific works published between 2014 and 2024.

Results. As alternative methods, vaccination, quorum sensing inhibition, bacteriophages, as well as probiotics, prebiotics, phytobiotics, and others can be used. The state of the fish microbiome has an important impact on the likelihood of developing of infectious processes. For example, it has been reported that fish with a healthy microbiome more effectively controlled and suppressed the colonization and dissemination of bacteria of the genus *Aeromonas* than fish with a disrupted microbiota. Currently, probiotic microorganisms are most commonly used as agents that can influence the microflora and correct the microbial balance [36]. Probiotics are most commonly represented with bacteria, including species from cultures *Bacillus* sp., *Lactococcus* sp., *Micrococcus* sp., *Carnobacterium* sp., *Enterococcus* sp., *Lactobacillus* sp., *Streptococcus* and *Weissella* sp. Some strains of yeast and algae may be used too. Probiotics are most commonly represented with a group of lactic acid bacteria, as among all microorganisms with registered probiotic properties, they are considered to have a higher safety profile. They can produce antimicrobial substances and positively influence the immune system of the macroorganism. Probiotics used in aquaculture must undergo a special assessment to determine their potential for application, taking into account the specifics of the industry. The main spectrum of action of probiotic microorganisms in the intestines of aquatic organisms lies in their anti-adhesive effect against pathogenic strains, the production of antimicrobial substances (including bacteriocins and defensins), competition with pathogenic flora, enhancement of the host's resistance properties, alteration of the intestinal pH level, and activation of the immune system.

Conclusion. Thus, despite the intensification of aquaculture and the increased likelihood of infectious diseases in aquaculture species, the worsening issue of antibiotic resistance and the irrational use of antibacterial drugs necessitate the development and implementation of alternative methods for controlling fish diseases.

Keywords: aquaculture; diseases; bacterial diseases of fish; probiotics; prebiotics; bacteriocins

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Научная статья

АЛЬТЕРНАТИВНЫЕ МЕТОДЫ ПРОФИЛАКТИКИ И ЛЕЧЕНИЯ ЗАБОЛЕВАНИЙ В АКВАКУЛЬТУРЕ

Б.Ч. Месхи, Д.А. Джедиров, Д.В. Рудой, В.Н. Шевченко, Л.С. Головко, А.В. Ольшевская, М.Ю. Одабашян, А.С. Пруцков, С.В. Теплякова

Аннотация

Обоснование. В последние годы использование антибиотиков в аквакультуре вызывает все большее беспокойство из-за развития устойчивости микроорганизмов к антибактериальным препаратам и негативного воздействия на экосистему. Поэтому исследование альтернативных методов лечения и профилактики рыбных заболеваний стало актуальной задачей. Перспективными альтернативами для профилактики и лечения видов аквакультуры являются использование пробиотиков, пребиотиков, синбиотиков, постбиотиков, фитобиотиков, бактериофагов и механизмов ингибирования кворум-сенсинга (QS). Состояние микрофлоры водных организмов имеет решающее значение для повышения устойчивости организма к инфекционным заболеваниям. Таким образом, использование агентов, которые могут положительно влиять на микробиоту, оказывать антимикробное действие и модулировать иммунную систему, является важным для эффективного развития аквакультуры. В данной статье рассматриваются некоторые основные заболевания рыб, вероятность которых увеличивается с интенсификацией аквакультуры. Бактерии рода *Aeromonas* часто являются причиной заболеваний и финансовых потерь в отрасли. Работа предоставляет обзор альтернативных методов профилактики и лечения рыбных заболеваний, которые могут снизить использование антибактериальных препаратов, включая применение вакцин, пробиотиков, пребиотиков и бактериоцинов.

Цель. Исследовать альтернативные методы лечения и профилактики рыбных заболеваний.

Материалы и методы. В исследовании использовался метод сбора, анализа и систематизации опубликованных научных источников. Сбор литературной информации осуществлялся с использованием реферативных баз данных Science direct, Research Gate, Google academy, National Library of Medicine, ScienceDirect, онлайн-библиотека Wiley и др. Для поиска подходящих научных публикаций использовали ключевые слова «аквакультура», «заболевания», «бактериальные заболевания рыб», «пробиотики», «пребиотики», «синбиотики», «бактериоцины», «фитобиотики», «чувство кворума» по отдельности или в различных комбинациях. Период поиска ограничивался научными работами, опубликованными в период 2014-2024 гг.

Результаты. В качестве альтернативных средств можно использовать вакцинацию, подавление чувства кворума, бактериофаги, а также пробиотики, пребиотики, фитобиотиков и др. Состояние микробиома рыбы имеет важное значение на вероятность развитие инфекционного процесса. Так, например, сообщается, что у рыб со здоровым микробиомом более эффективно контролировалась и подавлялась колонизация и диссеминация бактерий рода *Aeromonas*, чем у рыб с нарушением микробиоты. На данный момент в качестве средств, которые могут влиять на микрофлору и корректировать микробный баланс, чаще всего применяются пробиотические микроорганизмы. В качестве пробиотиков чаще всего используют бактерии, включая бактерии рода *Bacillus* sp., *Lactococcus* sp., *Micrococcus* sp., *Carnobacterium* sp., *Enterococcus* sp., *Lactobacillus* sp., *Streptococcus* и *Weissella* sp., также могут использоваться некоторые штаммы дрожжей, водорослей. Чаще всего в качестве пробиотиков используется группа молочнокислых бактерий, так как среди всех микроорганизмов с зарегистрированными пробиотическими свойствами, считается, что у них более высокий профиль безопасности, они могут продуцировать антимикробные вещества и положительно влиять на иммунную систему макроорганизма. Пробиотики, применяемые в аквакультуре, должны проходить специальную оценку для определения их потенциала применения с учетом специфики отрасли. Основной спектр действия пробиотических микроорганизмов в кишечнике гидробионтов заключается в антиадгезивном эффекте в отношение патогенных штаммов, продукции антимикробных веществ (в том числе бактериоцинов и дефензинов), конкурирование с патогенной флорой, повышение резистентных свойств макроорганизма, изменение уровня pH кишечника и активация иммунной системы.

Заключение. Несмотря на интенсификацию аквакультуры и повышение вероятности развития инфекционных заболеваний у товарных объектов аквакультуры, усугубление проблемы антибиотикорезистентности и нерационального применения антибактериальных лекарственных средств диктуют необходимость разработки и внедрения альтернативных методов контроля развития болезней рыб.

Ключевые слова: аквакультура; болезни; бактериальные болезни рыб; пробиотики; пребиотики; бактериоцины

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Introduction

In recent years, aquaculture in the Russian Federation and around the world has shown significant growth in production volumes. Raising fish in artificial conditions allows to supply population with accessible animal protein. By 2017, more than 112 million tons of aquaculture products were produced, of which 80 million tons – fish and shellfish, and 32 million tons – seaweeds. The number of cultivated species increased from 300 species of plants and animals in 1997 to 425 species in 2017 [1].

The production intensification inevitably leads to an increase in cases of fish diseases. To solve this problem, farmers often use antibiotics. Irrational use of antibacterial therapy results in the selection and preservation of resistant strains of pathogenic bacteria. According to available information, up to 700,000 people die each year from infections caused by resistant bacteria, and by 2050, this number may rise up to 10,000,000 deaths per year [2]. This problem requires the development of new strategies to ensure biological safety in agriculture and other areas.

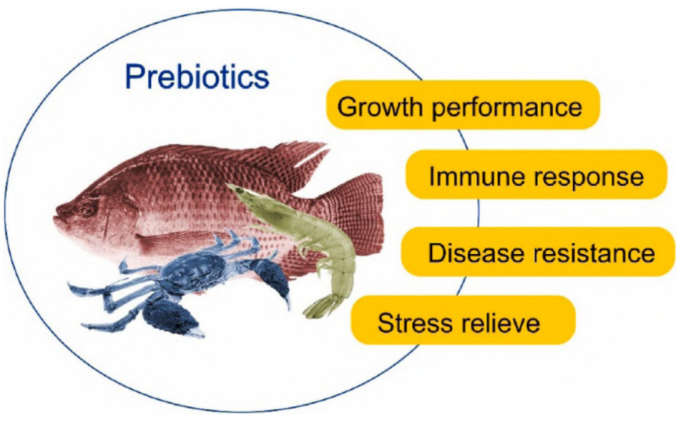

Fig. 1. Probiotic effect in aquaculture
Source: https://doi.org/10.1111/are.15846 [10]

In aquaculture, diseases of various etiologies are registered: bacterial [3], viral [4], parasitic [5], fungal [6]. The diversity of pathogens requires the selection of effective methods of prevention and treatment.

The use of probiotics [7; 8], prebiotics [9; 10], synbiotics [11; 12], postbiotics [13], phytobiotics [14], bacteriophages [15] and quorum sensing (QS) mechanisms is promising as alternative means of prevention and treatment of aquaculture objects [16].

In addition to inhibiting pathogens, many of the mentioned agents are a promising mechanism for enhancing the efficiency of aquaculture. For example, the introduction of prebiotics into fish diets has been observed to increase growth rates, improve feed efficiency, and reduce feed conversion ratios [17] (Fig. 1).

The present study analyzes and summarizes the main fish diseases in aquaculture, as well as promising methods for their prevention and treatment.

Materials and methods

In the study, a method of collecting, analyzing, and systematizing of published scientific sources was used. The collection of literary information was carried out using reference databases such as Science Direct, Research Gate, Google Scholar, National Library of Medicine, Wiley Online Library, and others. To search for suitable scientific publications, keywords such as «aquaculture», «diseases», «bacterial fish diseases», «probiotics», «prebiotics», «synbiotics», «bacteriocins», «phytobiotics», and «quorum sensing» were used individually or in various combinations. The search period was limited to scientific works published between 2014 and 2024.

Results and discussion

1.1 Fish bacterial diseases in aquaculture

In aquaculture, the most popular species are those from the sturgeon family (*Acipenseridae*), carp family (*Cyprinidae*), salmon family (*Salmonidae*), and catfish family (*Siluridae*). Among these cultivated species, bacterial pathogens are widespread, causing significant economic losses [18]. In aquaculture, both gram-positive and gram-negative bacteria can cause fish diseases. The genus *Aeromonas* is most often responsible for diseases and, hence, financial losses in the industry [19]. The estimation of the losses in China, caused by *Aeromonas* and some other bacteria, showed that the damage is equal to 120 million dollars for the period 1990-1992 [20]. In 2010, an outbreak of Motile Aeromonas septicemia (MAS) at fish farms in Alabama (United States) caused 3 million dollars damage [21].

Aeromonads are gram-negative motile rods that are typical representatives of the microbiota in water bodies [22]. The analysis of the 16S rRNA sequence allowed the classification of these bacteria into the family *Aeromonadaceae*, class *Gammaproteobacteria*, order *Aeromonadales*. [23]. Among the 31 species of the genus *Aeromonas* [24], a typical representative is *Aeromonas hydrophila*. This species is a freshwater facultative anaerobe with a chemoorganotrophic type of nutrition, characterized by a positive reaction in tests for catalase, oxidase, and indole. [25]. *A. hydrophila* causes septicemia, hemorrhagic septicemia, and ulcerative disease in fish. Clinical (external) manifestations of the disease include hemorrhages, ulcers on the body surface, and accumulation of free fluid in the abdominal cavity [20] (Fig. 2).

In some regions, other species of the *Aeromonas* genus may dominate. For example, studies in southern China have shown that *A. veronii* is the dominant etiological agent of MAS in this region [26].

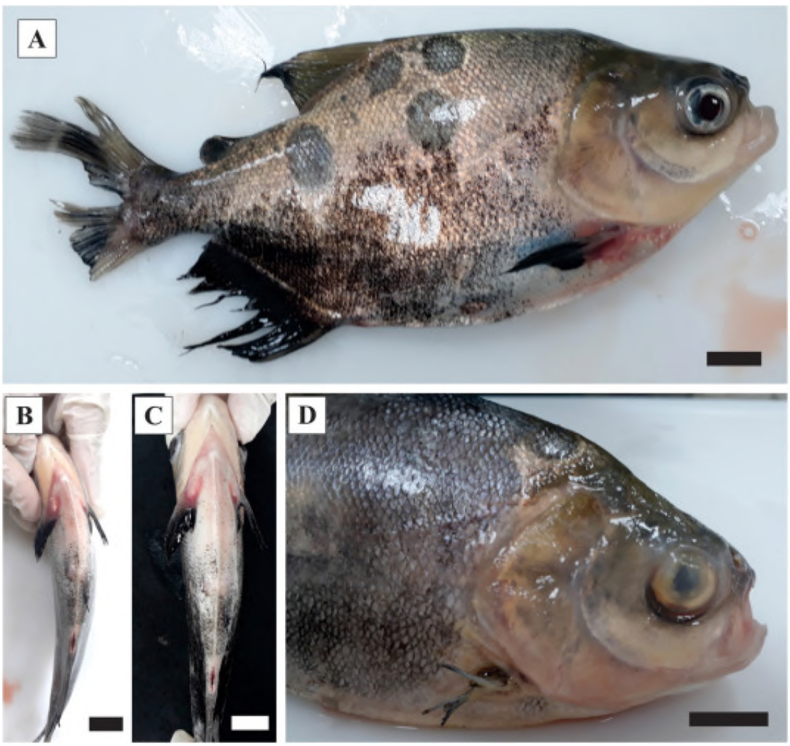

Fig. 2. External signs of *Motile Aeromonas* septicemia in *Colossoma macropomum*: A – lesions on the skin at the base of the fin, B, C – hemorrhages on the ventral side of the body, D – eye opacity
Source: https://doi.org/10.1016/j.aquaculture.2020.736068 [31]

Other gram-negative bacteria, causing diseases in aquaculture, include representatives of the genus *Pseudomona*s, which comprises more than 200 species [27]. Despite the fact that these bacteria are described as opportunistic pathogens, some studies report cases of 100% mortality in trout, bream, and other species [28]. The virulence of *Pseudomonas aeruginosa* is coordinated by the quorum sensing (QS), which increases the risks of pseudomonas outbreaks in aquaculture. This strain is recognized as one of the 10 most dangerous bacteria in the world for humans and animals [29]. In addition, due to the irrational use of pharmaceuticals, *P. aeruginosa* has developed resistance to most antibiotics and is therefore included in the ESKAPE list as a dangerous pathogen [30].

1.2 Methods of disease treatment and prevention in aquaculture

For a long time, there has been irrational use of nonspecialized antibacterial therapy in aquaculture. In most cases, antibiotics were used for prophylactic purposes. The lack of control has led to the formation of communities of bacteria resistant to antimicrobial agents (AMRB) [32]. Moreover, there is a threat of the emergence of superbacteria, partly due to the possibility of horizontal gene transfer among bacteria [33; 34]. To prevent further development of resistance in bacteria in aquaculture, it is necessary to impose a ban on the use of antibiotics as growth promoters and for disease prevention. Additionally, guidelines should be developed to reduce the frequency of antibiotic use in favor of alternative treatment methods [35].

There are already examples in the world practice. Some countries have introduced alternative methods aimed at preventing and treating bacterial diseases in fish farming technology. In Norway, which has been a leader in salmon farming for a long period of time, the use of vaccines has proven their efficiency [32].

As alternative methods, vaccination, quorum sensing inhibition, bacteriophages, as well as probiotics, prebiotics, phytobiotics, and others can be used (Fig. 3) [36].

The state of the fish microbiome has an important impact on the likelihood of developing of infectious processes [37, 38]. For example, it has been reported that fish with a healthy microbiome more effectively controlled and suppressed the colonization and dissemination of bacteria of the genus *Aeromonas* than fish with a disrupted microbiota [39]. Currently, probiotic microorganisms are most commonly used as agents that can influence the microflora and correct the microbial balance [36]. Probiotics are most commonly represented with bacteria, including species from cultures *Bacillus* sp., *Lactococcus* sp., *Micrococcus* sp., *Carnobacterium* sp., *Enterococcus* sp., *Lactobacillus* sp., *Streptococcus* and *Weissella* sp. Some strains of yeast and algae may be used too [40].

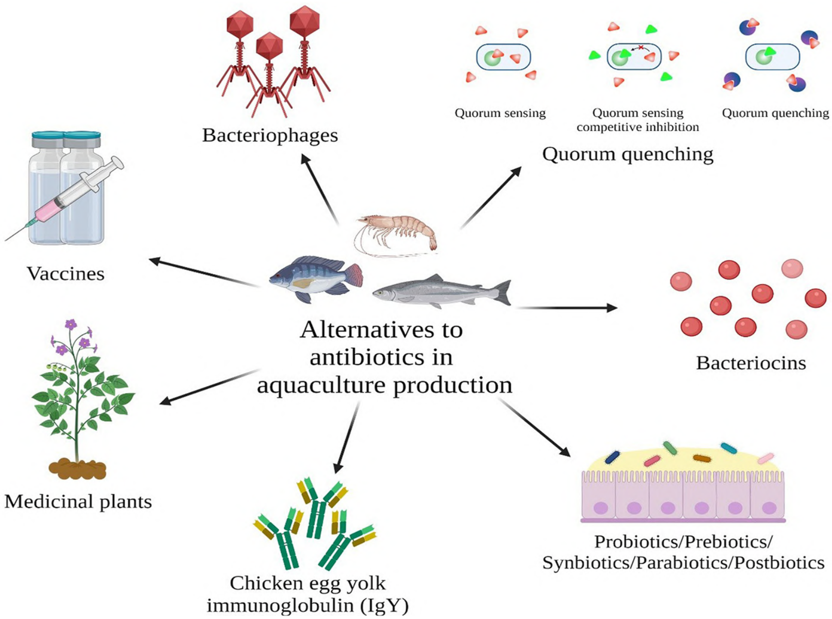

Fig. 3. Alternative methods of fish disease prevention and treatment in aquaculture
Source: https://doi.org/10.1111/raq.12786 [36]

Probiotics are most commonly represented with a group of lactic acid bacteria, as among all microorganisms with registered probiotic properties, they are considered to have a higher safety profile. They can produce antimicrobial substances and positively influence the immune system of the macroorganism [41]. Probiotics used in aquaculture must undergo a special assessment to determine their potential for application, taking into account the specifics of the industry [42]. The main spectrum of action of probiotic microorganisms in the intestines of aquatic organisms lies in their anti-adhesive effect against pathogenic strains, the production of antimicrobial substances (including bacteriocins and defensins), competition with pathogenic flora, enhancement of the host's resistance properties, alteration of the intestinal pH level, and activation of the immune system [36]. The mechanisms of action of probiotics and bacteriocins are graphically presented in Fig. 4.

Both prebiotics and probiotics can be used separately or together, with prebiotics serving as a nutritional substrate for the host's own microbiota. This enhances the competitive action of the host's microbiome by suppressing and modulating the concentration of pathogenic and opportunistic microorganisms

[43]. Synbiotics are a combination of probiotics and prebiotics, which include indigestible fiber, further stimulating the activity of commensal microorganisms in the gut and enhancing both systemic and local immunity in fish, thereby reducing the likelihood of developing infectious diseases [44].

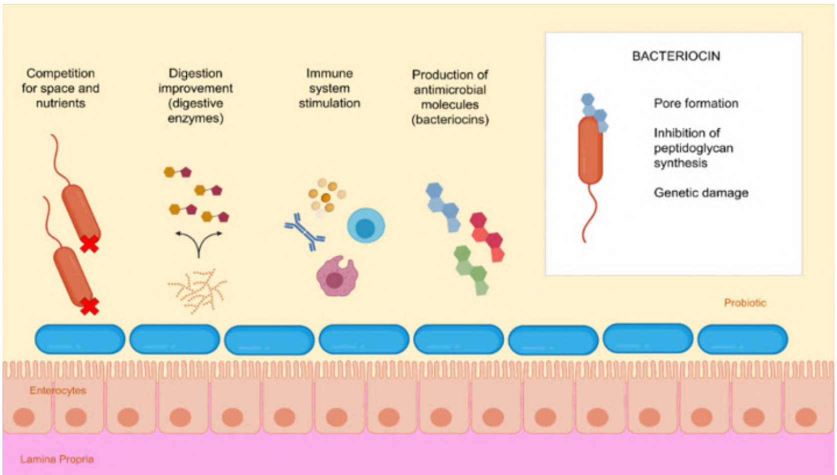

Fig. 4. Probiotics and bacteriocins mode of action
Source: https://doi.org/10.3390/microorganisms10091705 [42]

In recent years, bacteriocins have played a significant role in controlling fish health. Bacteriocins are low-molecular-weight bactericidal peptides synthesized by ribosomes. Their advantages include having less negative impact on the macroorganism while maintaining antagonistic effects against pathogenic microorganisms and stimulating the growth of beneficial microflora [36]. The action mechanism of bacteriocins is diverse and can depend on the characteristics of the molecules. Primarily, the mechanism of action is associated with damaging the bacterial cell wall by forming pores and disrupting the function of peptidoglycan transporters. They can also affect microorganisms through their genetic material and protein synthesis at the ribosomal level. However, the spectrum of action of bacteriocins depends on the presence of receptors in the microorganism for their absorption, which is why they can be classified as agents with a narrow spectrum of activity [42]. Bacteriocins, isolated from lactic acid bacteria, are used in the food industry, such as pediocin PA-1 produced by *Pediococcus acidilactici*, which exerts antimicrobial activity against *Listeria monocytogenes* in meat and dairy products [45].

Conclusion

Thus, despite the intensification of aquaculture and the increased likelihood of infectious diseases in aquaculture species, the worsening issue of antibiotic resistance and the irrational use of antibacterial drugs necessitate the development and implementation of alternative methods for controlling fish diseases.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

STUDY OF METAL FOREIGN MATTERS IN STARTER COMPOUND FEEDS FOR AQUACULTURE

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Abstract

Background. The article presents results of the investigation of metal foreign matter content in starter compound feeds for aquaculture objects. Metallomagnetic particles can get into compound feeds at different stages of their production, which is dangerous for fish health, especially at the early stages of their development. The relevance of the study is due to the increase in production of valuable fish species in aquaculture and the need to improve the quality of compound feeds. In the course of the analysis the sources of contamination were identified and measures for their elimination were proposed, which contributes to improving the conditions of fish farming and increasing its productivity. The importance of the obtained results lies in the possibility of their practical application for the optimization of technological processes of feed production, which will reduce the content of impurities and improve the quality of products, which, in turn, will contribute to the development of aquaculture and food security.

Purpose. The objective of the present study is to investigate methods for providing food safety of starter compound feeds for aquaculture.

Materials and methods. In the production of starter compound feeds, we measured the amount of metallomagnetic impurities, according to GOST 31484-2012 (GOST – Russian National Standard). Preliminary grinding in a porcelain mortar to the state of homogeneous mass, 4 control measurements were carried out, the results of which are reflected in the article. Three measurement repetitions were carried out using a horseshoe magnet with a magnetic induction value of 0.12 Tesla. The fourth one was performed with the help of the device “UZ-DIMP” for extraction of metallomagnetic impurities with the value of magnetic induction 0.2 Tesla. The metallomagnetic impurities were collected from the surface of the screen of non-magnetic material placed on top of the magnet. Placing the collected material on paper, we determine the size and measure the mass of impurities on analytical scales. Subtracting the mass of paper, we obtain the value of the mass of metallomagnetic impurities.

Results. In the course of the study, measurements of the content of metallomagnetic impurities in starter compound feeds for aquaculture facilities were carried out. The results confirmed the presence of these impurities, indicating the need for stricter quality control at all feed production stages. Metallomagnetic particles, which may enter the feed during its pelleting or grinding, pose a risk to fish health, especially at the stage of their early development, when sensitivity to external factors is at its maximum.

The relevance of this study is due to the growing demand for aquaculture products in the context of global food security. In recent years, in Russia and other countries, there has been an active development of fish farming, which requires an increase in feed quality standards. Since compound feed is the main source of nutrients for fish, control of its purity and composition is of strategic importance for the health of aquatic bioresources and increasing their productivity.

Conclusion. The importance of the obtained results lies in their practical application. Detection of sources of metallomagnetic impurities in mixed fodders allows to optimize technological processes aimed at reducing feed contamination, and contributes to the development of methods of effective elimination of such impurities. This, in turn, will lead to improved growth and survival rates of fish, reducing the cost of prevention and treatment of diseases caused by the presence of foreign particles in feed.

Thus, the results of the study contribute to improving the quality of feed production and strengthening the aquaculture sector, which is particularly important in the face of increasing demand for environmentally friendly products and resources for sustainable fish farming.

Keywords: metal shavings; fish farming; fry survival; metallomagnetic particles; horseshoe magnet; feed mix; food industry

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Научная статья

ИССЛЕДОВАНИЕ НАЛИЧИЯ МЕТАЛЛОМАГНИТНЫХ ПРИМЕСЕЙ В СТАРТОВЫХ КОМБИКОРМАХ ДЛЯ АКВАКУЛЬТУРЕ

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Аннотация

Обоснование. В статье представлены результаты исследования содержания металломагнитных примесей в стартовых комбикормах для объектов аквакультуры. Металломагнитные частицы могут попадать в комбикорма на различных этапах их производства, что представляет опасность для здоровья рыб, особенно на ранних стадиях развития. Актуальность исследования обусловлена увеличением производства ценных видов рыб в аквакультуре и необходимостью повышения качества комбикормов. В ходе анализа были выявлены источники загрязнения и предложены меры по их устранению, что способствует улучшению условий выращивания рыбы и повышению её продуктивности. Важность полученных результатов заключается в возможности их практического применения для оптимизации технологических процессов производства кормов, что позволит снизить содержание примесей и улучшить качество продукции, что, в свою очередь, будет способствовать развитию аквакультуры и обеспечению продовольственной безопасности.

Цель. Целью настоящего исследования является изучение методов обеспечения продовольственной безопасности стартовых комбикормов для аквакультуры.

Материалы и методы. При производстве стартового комбикорма нбыло измерено количество металломагнитных примесей, согласно ГОСТ 31484–2012. Предварительно измельчив в фарфоровой ступке до состояния однородной массы, было проведено 4 контрольных измерения, результаты которых отражены в статье. Три измерительных повтора провели с помощью подковообразного магнита со значением магнитной индукции 0,12 Тл. Четвёртый – с помощью устройства «УЗ-ДИМП» для извлечения металломагнитных примесей со значением магнитной индукции 0,2 Тл. С поверхности экрана из немагнитного материала, установленного поверх магнита, были собраны металломагнитные примеси. Поместив собранный материал на бумагу, был определен размер частиц и была измерена на аналитических весах масса примесей. При вычите массы бумаги, было получено значение массы металломагнитных примесей.

Результаты. В ходе исследования были проведены измерения содержания металломагнитных примесей в стартовых комбикормах для объектов аквакультуры. Полученные результаты подтвердили наличие этих примесей, что указывает на необходимость более строгого контроля качества на этапах производства комбикормов. Металломагнитные частицы, которые могут попадать в корм в процессе его гранулирования или измельчения, представляют опасность для здоровья рыб, особенно на стадии их раннего развития, когда чувствительность к внешним факторам максимальна. Актуальность данного исследования обусловлена растущим спросом на продукцию аквакультуры в условиях глобальной продовольственной безопасности. В последние годы в России и других странах наблюдается активное развитие рыбоводства, что требует повышения стандартов качества кормов. Поскольку комбикорм является основным источником питательных веществ для рыб, контроль его чистоты и состава имеет стратегическое значение для здоровья водных биоресурсов и повышения их продуктивности.

Заключение. Важность полученных результатов заключается в их практическом применении. Обнаружение источников металломагнитных примесей в комбикормах позволяет оптимизировать технологические процессы, направленные на уменьшение загрязнения кормов, и способствует разработке методов эффективного устранения таких примесей. Это, в свою очередь, приведёт к улучшению показателей роста и выживаемости рыб, снижению затрат на профилактику и лечение заболеваний, вызванных наличием посторонних частиц в кормах.

Таким образом, результаты исследования способствуют повышению качества производства кормов и укреплению аквакультурного сектора, что особенно важно в условиях увеличивающегося спроса на экологически чистую продукцию и ресурсы для устойчивого развития рыбоводства.

Ключевые слова: металлическая стружка; рыбоводство; выживаемость мальков; металломагнитные частицы; подковообразный магнит; кормовая смесь; пищевая промышленность

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Introduction

Currently, there is an increase in the production of valuable fish species in aquaculture. In order to ensure food security, starter feed is becoming a strategically important product, as its quality directly affects the growth and survival rates of fry. Against the backdrop of declining natural fish populations, industrial aquaculture specialists are striving to restore them as soon as possible. In this regard, it is necessary to pay special attention to the quality and balance of starter feeds due to the biological characteristics of juvenile fish at early stages of ontogenesis and to ensure their sustainable development. As a consequence, volumes of compound feed production increase annually in Russia. Knowing the nutritional needs of growing species, it is possible to make nutritionally balanced feeds.

Materials and methods

High-quality starter compound feed is balanced in terms of nutrients and biologically active additives, meets the requirements of moisture resistance and crumbliness. Every year in Russia the volume of production of compound feeds for fish is increasing, shown in Fig. 1.

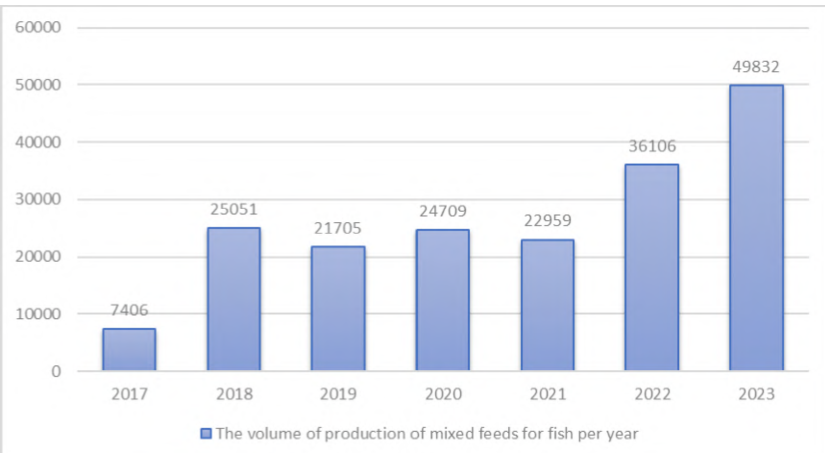

Fig. 1. Production volume of mixed fodder for fish per year, thousand tons

Production of compound feeds. At manufacture of starter compound feeds on the basis of basic components, such as: fish, wheat, meat-bone and chicken meal, soybean meal, etc. the following technological process is carried out. Production of starter compound feeds consists of operations presented in Fig. 2.

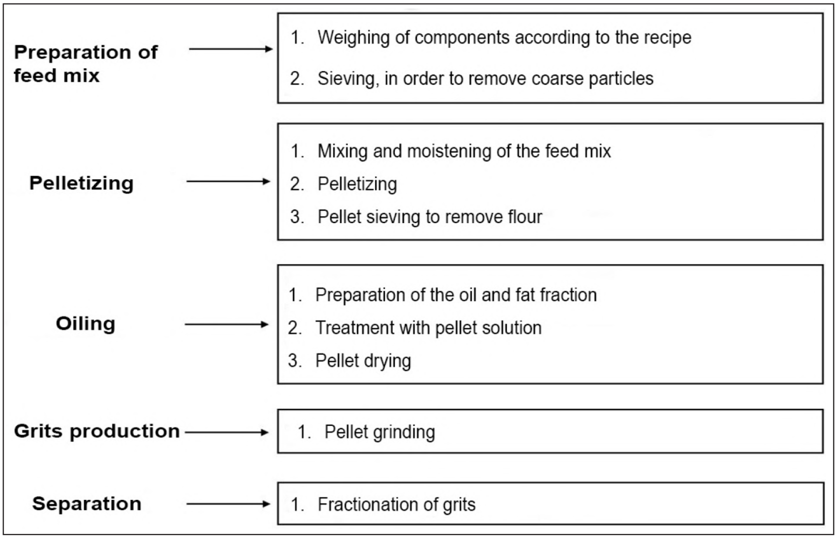

Fig. 2. Technological production processes of starter compound feeds

When the finished feed is sieved using a vibrating screen on the discharge platform equipped with magnetic catchers, metal and magnetic impurities are detected. Having analyzed the technological line of feed production, two probable sources of metal shavings were identified:

1. Friction of rollers against the matrix during the pelletizing process;
2. Friction between rollers in pellet shredders

In the production of starter compound feeds, we measured the amount of metallomagnetic impurities, according to GOST 31484-2012 (GOST – Russian National Standard). Preliminary grinding in a porcelain mortar to the state of homogeneous mass, 4 control measurements were carried out, the results of which are reflected in Table 1. Three measurement repetitions were carried out using a horseshoe magnet with a magnetic induction value of 0.12 Tesla. The fourth one was performed with the help of the device "UZ-DIMP" for extraction of metallomagnetic impurities with the value of magnetic induction 0.2 Tesla. The metallomagnetic impurities were collected from the surface of the screen of non-magnetic material placed on top of the magnet. Placing the collected material on paper, we determine the size and measure the mass of impurities on analytical scales. Subtracting the mass of paper, we obtain the value of the mass of metallomagnetic impurities.

Table 1.

Results of parallel measurements

Experiment №	Results, g
1	0,0048
2	0,00477
3	0,00498
4	0,0052

Calculation have been made using the formula (1):

$$|x_1-x_2| \le r \quad (1)$$

where x_1 and x_2 – results of the first and second parallel measurements, mg⁄kg .

r – value of the repeatability limit – 1,4 mg⁄kg .

$$\text{(I) } |4,8-4,77|=0,03$$

$$|x_3-x_4| \le R$$

where x_3 and x_4 – results of the first and second parallel measurements, mg⁄kg .

R – value of the reproducibility limit – 2,0 mg⁄kg .

$$\text{(II) } |4,98-5,2|=0,22$$

According to GOST, the accuracy of changes should be within ±5% of the specified value, it follows from the confidence probability equal to 0.95. Let's carry out calculations and compare the obtained values with the required parameters.

$$4,77\times0,95=4,53$$

$$4,77-4,53=0,24$$

$$\text{(I) } 0,03\le0,24$$

$$4,98\times0,95=4,73$$

$$4,98-4,73=0,25$$

$$\text{(II) } 0,22\le0,25$$

Having measured the amount of metallomagnetic impurities in the prepared feed, let's compare the obtained values with the norms specified in GOST 10385-88. Mass fraction of metallomagnetic impurity (particles up to 2 mm in size inclusive) mg in 1 kg of feed for gilts, not more than 15 mg. According to the results indicated in Table 1, the obtained values are within the permissible values of the state standard.

Results

In the course of the study, measurements of the content of metallomagnetic impurities in starter compound feeds for aquaculture facilities were carried out. The results confirmed the presence of these impurities, indicating the need for stricter quality control at all feed production stages. Metallomagnetic particles, which may enter the feed during its pelleting or grinding, pose a risk to fish health, especially at the stage of their early development, when sensitivity to external factors is at its maximum. The relevance of this study is due to the growing demand for aquaculture products in the context of global food security. In recent years, in Russia and other countries, there has been an active development of fish farming, which requires an increase in feed quality standards. Since compound feed is the main source of nutrients for fish, control of its purity and composition is of strategic importance for the health of aquatic bioresources and increasing their productivity.

Discussion and conclusion

The importance of the obtained results lies in their practical application. Detection of sources of metallomagnetic impurities in mixed fodders allows to optimize technological processes aimed at reducing feed contamination, and contributes to the development of methods of effective elimination of such impurities. This, in turn, will lead to improved growth and survival rates of fish, reducing the cost of prevention and treatment of diseases caused by the presence of foreign particles in feed.

Thus, the results of the study contribute to improving the quality of feed production and strengthening the aquaculture sector, which is particularly important in the face of increasing demand for environmentally friendly products and resources for sustainable fish farming.

Conflict of interest information. The authors declare that they have no conflict of interest.

Sponsorship information. The work is carried out as part of the project “Development of personalized feeds of a new generation with plant and probiotic additives to increase the survival rate and improve the health of fish” (FZNE-2023-0003).

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Original article

THE ROLE OF DIAGNOSTICS IN IMPROVING THE OBJECTIVITY OF ASSESSING THE TECHNICAL CONDITION OF AGRICULTURAL MACHINERY

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Abstract

Background. During operation, the condition of the machine is subject to constant changes, occurring unpredictably and depending on a multitude of operating factors that affect the wear and tear of individual machine components to varying degrees, requiring different amounts of repair and maintenance for each piece of equipment. Preliminary diagnosis of the entire system or its individual parts helps to accurately determine the amount of maintenance or repair required. This study analyzes methods for improving the accuracy and reliability of machine technical condition assessment. Also considered are the key factors of technical diagnostics that provide assessment of the current parameters of the object and prediction of the state on the basis of data obtained through direct or indirect measurements. The authors propose a method of evaluating the efficiency of diagnostic procedures taking into account various combinations of influencing factors. The influence of the marginal cost of diagnostics on the total specific repair costs is shown.

Purpose. The purpose of the research is to study the role of diagnostics in the issues of improving the objectivity of the assessment of the technical condition of machines

Materials and methods. Availability of information on specific values of controlled parameters allows to control the threat of disturbance of normal operation of machines. Assessment of the state of machinery is carried out by comparing the actual values of parameters with the specified norms. Detailed control requires methods of monitoring the monitored parameters, including the collection of additional data on how these parameters change over time. Modern technical devices are equipped with a continuous condition monitoring function, which makes it possible to continuously monitor the operation of machines and equipment. Early fault detection includes a set of measures to identify emerging defects, determine their root causes, and carefully analyze the nature and degree of development of these problems. Technical diagnostics consists in assessment and forecasting of the object state based on the results of direct or indirect measurements of state parameters or diagnostic parameters.

Results. The results of this study show that diagnostics allows management at two levels: technical state and technological process. At the first level, diagnostics is directly related to maintenance (TO), while at the second level it is more related to the organization of technological processes.

Conclusion. Application of modern methods, tools and approaches to diagnostics in the system of maintenance and repair will increase its efficiency due to more complete utilization of operational characteristics of each individual object.

Keywords: technical diagnostics; technical condition assessment; reliability; safety; machine

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Научная статья

РОЛЬ ДИАГНОСТИКИ В ВОПРОСАХ ПОВЫШЕНИЯ ОБЪЕКТИВНОСТИ ОЦЕНКИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

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Аннотация

Обоснование. В процессе эксплуатации состояние машины подвергается постоянным изменениям, происходящим непредсказуемо и зависимо от множества эксплуатационных факторов, в разной степени влияющих на износ отдельных компонентов машин, что требует различного объема ремонта и обслуживания для каждой единицы оборудования. Предварительная диагностика всей системы или ее отдельных частей помогает точно определить объем необходимого обслуживания или ремонта. В рамках данного исследования проведен анализ методов улучшения точности и достоверности оценки технического состояния машин. Также рассмотрены ключевые факторы технической диагностики, обеспечивающие оценку текущих параметров объекта и прогнозирование состояния на основании данных, полученных через прямые или косвенные измерения. Авторами предложен метод оценивания эффективности применения диагностических процедур с учетом различных комбинаций воздействующих факторов. Показано влияние предельной стоимости диагностирования на суммарные удельные затраты на ремонт

Цель. Цель исследования заключается в изучении роли диагностики в вопросах повышения объективности оценки технического состояния машин

Материалы и методы. Наличие информации о конкретных значениях контролируемых показателей, позволяет контролировать угрозу нарушения нормального функционирования машин. Оценка состояния техники осуществляется путем сравнения фактических значений параметров с заданными нормами. Для детального контроля необходимы методы мониторинга отслеживаемых параметров, включающие сбор дополнительных сведений о том, как эти параметры меняются со временем. Современные технические устройства оснащены функцией непрерывного мониторинга состояния, что дает возможность постоянно контролировать работу машин и оборудования. Обнаружение неисправностей на ранних этапах эксплуатации включает в себя комплекс мероприятий по выявлению возникающих дефектов, определению их первопричин, а также тщательный анализ характера и степени развития этих проблем. Техническая диагностика заключается в оценке и прогнозировании состояния объекта на основе результатов прямых или косвенных измерений параметров состояния либо диагностических параметров.

Результаты. Результаты проведенного исследования показывают, что диагностирование позволяет осуществлять управление на двух уровнях: техническом состоянии и технологическом процессе. На первом уровне диагностика напрямую связана с проведением технического обслуживания (ТО), тогда как на втором она больше касается организации технологических процессов.

Заключение. Применение современных методов, инструментов и подходов к диагностике в системе обслуживания и ремонта повысит её эффективность благодаря более полному использованию эксплуатационных характеристик каждого отдельного объекта.

Ключевые слова: техническая диагностика; оценка технического состояния; надежность; безопасность; машина

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Introduction

Modern tendencies of machine building development are aimed at constructive complications and, as a consequence, increasing the cost of technical systems. Therefore, in order to ensure the required level of technical characteristics during the operation of machines, there is an inevitable need to solve diagnostic tasks, including determination of their technical condition, identification of possible failures and determination of residual life. Taking into account the growing requirements to increase the productivity of technically complex devices, the process of diagnostics must meet high quality standards. The use of complex and expensive automated systems for controlling technical objects requires qualitative analysis of their technical condition, accurate identification of failures and reliable prediction of remaining service life. Improving the efficiency of machine operation remains an urgent task, which is directly related to the level and quality of applied diagnostic methods and tools [1].

Technical diagnostics plays a key role in ensuring safety, reliability and efficiency of technical systems, helps to reduce maintenance costs and losses caused by downtime due to breakdowns and early repair of equipment [2-5].

Diagnostics allows not only troubleshooting, but also controlling the quality of maintenance and repair of machinery and equipment. In addition, the effectiveness of the measures taken is evaluated, compliance with the established standards and norms is checked, and the compliance of the results achieved with the planned indicators is analyzed. Diagnostics helps to predict the remaining life both for individual components and modules of the system and for the whole plant, to plan in advance the necessary repairs, to reduce the probability of emergencies and to optimize operating costs.

Different diagnostic methods are used for a more accurate assessment of the current state of the equipment. For example, the D-1 procedure is performed before and during the first technical service (TO-1) to assess the condition of the main units and assemblies that affect the safety of use and availability of the vehicle. A D-2 diagnosis is performed prior to the second maintenance (TO-2) to analyze the overall condition of all critical system elements such as units, assemblies and vehicle systems. This makes it possible to determine the amount of maintenance and repair work required.

Modern methods and means of technical diagnostics allow to improve the processes of solving many tasks important for the production process. The most important tasks include the reduction of operating costs by reducing labor costs and time for repair work and failure prevention, as well as increasing service life by early detection of defects [6-9].

Materials and methods

The key tasks of machine condition diagnostics systems are primarily focused on the observation of measured parameters. This function allows continuous monitoring and analysis of the main characteristics of the machine or equipment operation. The process includes the collection of information about the key performance indicators of machinery [10-12].

The next, no less important task of the systems for diagnosing the technical condition of machines is aimed at identifying malfunctions in machines and equipment. Identification of specific problems or failures in the operation of machinery is necessary not only to detect the malfunction, but also to establish the causes of its occurrence. In this case, the control is aimed at wear and tear of components, violation of operating rules, adjustment errors or the influence of external factors on the functioning of equipment [13].

The third task of technical condition diagnostics is aimed at predicting potential changes in the operation of machines or equipment over time. By analyzing actual data, it is possible to predict the behavior of machinery, which allows planning preventive measures or repair work in advance before the onset of serious breakdowns [14-15].

Thus, for successful performance of basic diagnostic manipulations it is necessary to have data on changes and permissible limits of key operating parameters. Availability of information on specific values of controlled parameters allows to control the threat of disturbance of normal operation of machines.

Assessment of the state of machinery is carried out by comparing the actual values of parameters with the specified norms. In other words, when diagnosing or analyzing equipment performance, real data (such as temperature, pressure, speed, etc.) are compared with the normative values set by technical documents or the manufacturer. Any deviation from the standard values is considered as an indication of a defect or problem.

Detailed control requires methods of monitoring the monitored parameters, including the collection of additional data on how these parameters change over time. Therefore, more advanced monitoring techniques are envisioned that not only record current parameter values, but also track their changes over a period of time. This approach helps to identify defect trends before they cause serious consequences, as well as to predict possible failures and plan prevention in advance.

Modern technical devices are equipped with a continuous condition monitoring function, which makes it possible to continuously monitor the operation of machines and equipment. This process facilitates the timely detection of deviations from normal operation and the taking of corrective action before problems become a serious threat. Continuous monitoring prevents unexpected damage, accidents or sudden breakdowns, and reduces the risk of critical machinery-related situations.

Early fault detection includes a set of measures to identify emerging defects, determine their root causes, and carefully analyze the nature and degree of development of these problems. Forecasting of possible changes in the technical condition of the equipment allows effective planning of preventive maintenance and repair work. As a result, it is possible to respond to emerging problems in a timely manner and prevent serious breakdowns, thereby increasing the level of reliability and extending the service life of the equipment used.

Technical diagnostics consists in assessment and forecasting of the object state based on the results of direct or indirect measurements of state parameters or diagnostic parameters. Diagnostic parameter by itself does not allow to estimate the technical state of the object. It is important to take into account both the current state of the object D_{fact}, and its normative technical value $D_{\text{n.–t.}}$. The difference between the actual and reference values of diagnostic parameters is called diagnostic symptom Δ.

$$\Delta = D_{fact} - D_{\text{n.–t.}} \tag{1}$$

The technical condition of an object is assessed by the value of a diagnostic symptom and comparison with acceptable technical or design parameters. In order to carry out condition assessment, appropriate information is required.

For systematic maintenance and repair, reliability information is collected and processed in the format of statistical variation series of controlled indicators, and diagnostic information, which is individual when considering a particular object. Reliability data are formed by collecting information through the analysis of failures of typical components or machines, and individual diagnostic information is formed directly by measuring the parameters of a particular object.

The collected statistical information allows to make intermediate conclusions on the volume of regularity of maintenance with a certain degree of probability.

Based on the diagnostic information obtained, the parameters are adjusted for a specific vehicle. Such sequence of actions allows to reduce labor and, as a consequence, economic costs for routine maintenance of vehicles and their restoration after failures. Specifically, the amount of savings in scheduled maintenance works depends on the coefficient of variation of vehicle resource, the cost of emergency repairs, the cost of preventive maintenance and diagnostics.

Figure 1 in nomogram format shows the graph of dependence of diagnostics efficiency and its cost. Thus, it is visually demonstrated how the economic efficiency of using different diagnostic approaches changes when combining different factors affecting technical diagnostics.

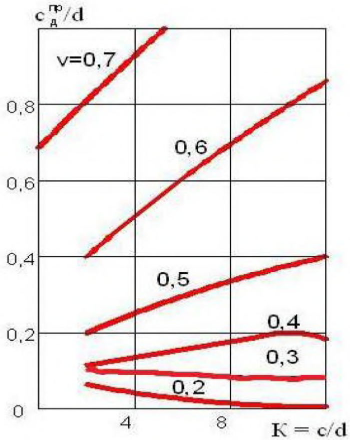

Fig. 1. Nomogram of marginal cost of diagnostics

Nomograms are based on the assumption that total costs of repair, preventive maintenance and diagnostics cannot exceed the unit costs of repair and preventive maintenance alone, excluding the costs of diagnostics:

$$\frac{cq_d + d(1 - q_d) + c_d n_d}{I_l^{fact}} \leq \frac{cq + d(1 - q)}{I_{\text{p}}^{fact}} \tag{2}$$

where c – emergency repair costs; q_d and q – probabilities of occurrence of emergency failures during maintenance with and without diagnostics; I_l^{fact} и I_p^{fact} weighted average actual mileage before restoration with and without diagnostics; n_d – number of diagnostics before recovery; d – maintenance costs.

In accordance with the character of curve changes, it can be stated that the efficiency of diagnostics depends on the increase in the coefficient of variation of resource and probability of unit failure during scheduled maintenance and the growth of costs for elimination of such failures.

Nomograms help to determine the marginal cost of diagnostics of a certain mechanism under given conditions, exceeding which makes it more profitable to use scheduled maintenance without preliminary diagnostics. It has been previously found that the use of diagnostics can reduce vehicle maintenance and repair costs by 10-25%.

Another significant benefit of diagnostics is the ability to improve the resource utilization of assemblies and components through accurate information support in the planning and execution of various operations such as repair, procurement, fuel economy, road safety and other tasks.

Vehicle diagnostics is a key aspect of integration of modern maintenance and repair technologies, focused on optimizing the use of internal resources by fully unlocking the potential and technical characteristics of the equipment. The efficiency of diagnostics of various units and systems is directly related to testability – the property of the vehicle that allows diagnostics to obtain accurate information about the current technical condition with minimal labor, time and material resources. In order to assess maintainability, a simple measurable output parameter is defined that demonstrates a change in performance characteristics. Parameters allow the collection of detailed information on the performance of each device and element of a technical system, taking into account its unique characteristics. Accordingly, diagnostics are organized in the same manner as maintenance and repair procedures (Figure 2).

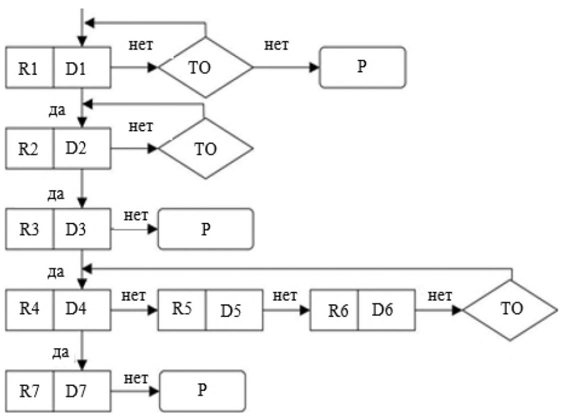

Fig. 2. Diagnostics algorithm scheme: R and D – diagnostics by parameter D1- D7 in R1- R7 mode; TO – maintenance service; P – repair

The technical condition of the vehicle is monitored by means of built-in diagnostics, and daily maintenance is carried out by means of control inspections. During Maintenance and Repair TO-1, comprehensive diagnostics of the main systems affecting safety is performed. Advanced diagnostics of assemblies and units is carried out before maintenance and repair TO-2, and during the elimination of detected defects within the framework of TO the system of DR diagnostics is used. To ensure intermediate and final quality control of adjustment and repair work, diagnostic procedures are combined with maintenance and repair operations.

Results

The results of this study show that diagnostics allows management at two levels: technical state and technological process. At the first level, diagnostics is directly related to maintenance (TO), while at the second level it is more related to the organization of technological processes. In the further development of diagnostics it is supposed to create automated diagnostic tools that will be part of automated production management systems, as well as the introduction of embedded diagnostics. This will allow to use diagnostics for operational management of maintenance and repair processes. Application of modern methods, tools and approaches to diagnostics in the system of maintenance and repair will increase its efficiency due to more complete utilization of operational characteristics of each individual object.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

CLEANING METHOD OF WORKING VOLUMES OF HYDRAULIC CYLINDERS OF AGRICULTURAL MACHINES WITHOUT PRELIMINARY DISMANTLING

S.I. Popov, N.S. Dontsov, J.V. Marchenko, D.V. Rudoy, A.V. Olshevskaya, A.S. Prutskov, S.V. Teplyakova

Abstract

Background. More and more often lifting equipment is equipped with a hydraulic drive, which allows to develop the highest tractive force. However, this type of drive is prone to a reduction in the speed of the mechanism due to possible clogging of the working fluid. The performance of the hydraulic system directly depends on the cleanliness of the working fluid, which is operated in the equipment or machine. Dirt, the presence of air, as well as the presence of metal particles formed as a result of rubbing parts, all this negatively affects the service life and reliability of the hydraulic system. The paper describes a bench method of cleaning the working volume of the hydraulic cylinder without preliminary dismantling. The principal hydraulic scheme with a detailed description of the washing system operation is offered. The possibility of dispersing the flushing fluid flow by air bubbles is described.

Purpose. The purpose of the research is a method of cleaning the working volumes of hydraulic cylinders of agricultural machines without preliminary dismantling

Materials and methods. In most cases, the hydraulic system is flushed with the help of special stands. The flushing stand itself is a rather complex system of interaction of hydraulic units

The design feature of the developed unit is the pressurized supply of a gas-liquid mixture. It consists of air bubbles and washing liquid.

For the formation of air bubbles in the liquid a cavitator is installed. The flushing liquid is fed to the cavitator due to the pressure generated on the surface of the flushing liquid by the compressor. In parallel from the compressor there is a branch with air to the cavitator. As a result, from the cavitator the gas-liquid mixture enters one of the cavities of the double-acting hydraulic cylinder. After the piston takes the opposite extreme position, the hydraulic valve is switched, and the gas-liquid mixture enters the next cavity. The process is then repeated. After the cavity has been cleaned, the contaminants are removed by draining with the spent flushing fluid.

Results. Flushing unit with the use of air bubbles significantly increases the viscosity of the flushing fluid, and this reduces the rate of settling only flushed contaminants in the cavity of the product, which improves the removal of contaminants through the spigots.

In particular, for the mentioned parameters of the cylinder gas bubbles should be the size of 5 mm, the speed of surfacing of which is 12.3 mm/s, which justifies the need to fill/empty the cavity of the hydraulic cylinder within 10 seconds, at the same time for flushing the hydraulic system create a flow of fluid with a Reynolds number of at least 4000, and the nominal pressure in the hydraulic cylinder is 18 MPa.

Conclusion. The developed basic hydraulic scheme and the proposed design of the flushing stand provide high efficiency of the cleaning process. In addition, the calculations and experiments confirm the correctness of the selected parameters and schemes, which makes this method promising for wide application in industry.

Keywords: hydraulic cylinder; cleaning of the working volume; dispersing of the flushing liquid

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Научная статья

СПОСОБ ОЧИСТКИ РАБОЧИХ ОБЪЕМОВ ГИДРОЦИЛИНДРОВ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН БЕЗ ПРЕДВАРИТЕЛЬНОГО ДЕМОНТАЖА

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Аннотация

Обоснование. Все чаще грузоподъемную технику оснащают гидравлическим приводом, который позволяет развивать наибольшее тяговое усилие. Однако данный вид приводов склонен к снижению скорости работы механиз-

ма по причине возможного засорения рабочей жидкости. Работоспособность гидравлической системы напрямую зависит от чистоты рабочей жидкости, которая эксплуатируется в оборудовании или машине. Грязь, наличие воздуха, а также наличие металлических частиц, образованных в результате трущихся деталей, все это негативно сказывается на сроке службы и надежности гидросистемы. В работе описан стендовый способ очистки рабочего объема гидроцилиндра без предварительного демонтажа. Предложена принципиальная гидравлическая схема с подробным описанием работы промывочной системы. Описана возможность диспергирования потока промывочной жидкости пузырьками воздуха

Цель. Цель исследования заключается в способе очистки рабочих объемов гидроцилиндров сельскохозяйственных машин без предварительного демонтажа

Материалы и методы. В большинстве случаев гидросистему промывают с помощью специальных стендов. Сам промывочный стенд представляет собой достаточно сложную систему взаимодействия гидравлических агрегатов

Конструктивной особенностью разрабатываемой установки является подача под давлением газожидкостной смеси. Она состоит из пузырей воздуха и промывочной жидкости.

Для образования пузырьков воздуха в жидкости установлен кавитатор. Промывочная жидкость подается к кавитатору за счет давления, образованного на поверхности промывочной жидкости компрессором. Параллельно от компрессора идет ветка с воздухом к кавитатору. В результате от кавитатора газожидкостная смесь поступает в одну из полостей гидроцилиндра двойного действия. После того как поршень принимает противоположнее крайнее положение, происходит переключение гидрораспределителя, и газожидкостная смесь поступает в следующую полость. Далее процесс повторяется. После очистки полости, загрязнения удаляются путем слива вместе с отработанной промывочной жидкостью.

Результаты. Промывочная установка с применением пузырьков воздуха существенно увеличивает вязкость промывочной жидкости, а это снижает скорость оседания только смытых загрязнений в полости изделия, что улучшает выведение загрязнений через патрубки.

В частности, для упомянутых параметров цилиндра пузырьки газа должны быть размерами 5 мм, скорость всплытия которых 12,3 мм/с, что обосновывает необходимость заполнения/опорожнения полости гидроцилиндра в течение 10 секунд, при это для промывки гидросистемы создают поток жидкости с числом Рейнольдса не менее 4000, а номинальное давление в гидроцилиндре составляет 18 Мпа.

Заключение. Разработанная принципиальная гидравлическая схема и предложенная конструкция промывочного стенда обеспечивают высокую эффективность процесса очистки. Кроме того, проведенные расчеты и эксперименты подтверждают правильность выбранных параметров и схем, что делает этот метод перспективным для широкого применения в промышленности.

Ключевые слова: гидроцилиндр; очистка рабочего объема; диспергирование промывочной жидкости

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Introduction

Reliability, serviceability and durability of hydraulic system elements directly depend on the cleanliness of internal surfaces and working fluid [1-7]. Installation – dismantling of the hydraulic system is an expensive and time-consuming operation. In industry, the level of cleanliness of internal surfaces of hydraulic units is regulated by the state standard GOST 17216-2001. This standard also establishes the classification of industrial cleanliness for those fluids that are used during the operation of the unit or aggregate, as well as equipment or machinery.

Previously, the method of flushing with a stationary flow was actively used to clean the hydraulic system [8-12]. However, this method has a number of significant disadvantages, which further negatively affected the stage of controlling the degree of cleanliness of the system. Thus, for example, there were known cases when from the contaminated system after cleaning the degree of cleanliness of the working fluid was higher than when it was poured into the system. This is explained by the fact that the cleanliness of the fluid is controlled at a reduced flow rate, and the process itself is characterized not by cleaning, but on the contrary – contamination of the unit, due to the fact that particles settle on the inner surface.

This problem is actual in the operation of truck cranes. In this case, the hydraulic cylinders of the crane's support extension are subjected to contamination of the internal cavity. Standard cleaning with washing machines as a rule does not give a proper level of cleanliness, and on internal hollow parts, about 90% of dirt and metal chips are removed, and residual deposits of dirt in the spigots in such cleaning is almost impossible to remove [13-16].

In accordance with this, to achieve the required level of surface cleanliness it is necessary to dismantle the part, and then to clean it by immersing the hydraulic cylinder in an ultrasonic bath, which implies a preliminary process of dismantling the hydraulic cylinder, consisting of several stages, including unscrewing the nuts from the hydraulic cylinder socket and rod cavity pipeline nut, removal of the cotter pin, washer; removal of the rod pipeline; disconnection of the rod eye and, finally, removal of the hydraulic cylinder from the outrigger.

As can be seen, the dismantling of the hydraulic cylinder is a rather labor-intensive process. Based on the above, it is proposed to use a washing stand for washing the internal cavity of the hydraulic cylinder.

Materials and methods

In most cases, the hydraulic system is flushed with the help of special stands. The flushing stand itself is a rather complex system of interaction of hydraulic units.

The design feature of the developed unit is the pressurized supply of a gas-liquid mixture. It consists of air bubbles and washing liquid.

For the formation of air bubbles in the liquid a cavitator is installed. The flushing liquid is fed to the cavitator due to the pressure generated on the surface of the flushing liquid by the compressor. In parallel from the compressor there is a branch with air to the cavitator. As a result, from the cavitator the gas-liquid mixture enters one of the cavities of the double-acting hydraulic cylinder. After the piston takes the opposite extreme position, the hydraulic valve is switched, and the gas-liquid mixture enters the next cavity. The process is then repeated. After the cavity has been cleaned, the contaminants are removed by draining with the spent flushing fluid.

Flushing is carried out by cyclic movement of the piston to the extreme positions and alternate supply of gas-liquid flow of washing fluid into the cavities of the hydraulic cylinder. The principle scheme of operation of the flushing stand is shown in Fig. 2.

The peculiarity of hydraulic cylinder flushing by the developed method is in the pressurized supply of gas-liquid mixture consisting of flushing liquid and air bubbles into the system.

The flushing stand provides for the possibility of dispersing the flushing liquid flow by air bubbles. Air bubbles moving in the fluid flow eventually collapse, releasing a large amount of kinetic energy. This process is explained by the physics of cavitation. When a cavitation bubble collapses, it emits a wave accompanied by hydraulic shocks, thus destroying the crystal lattice of contaminants on the walls of hollow parts and assemblies.

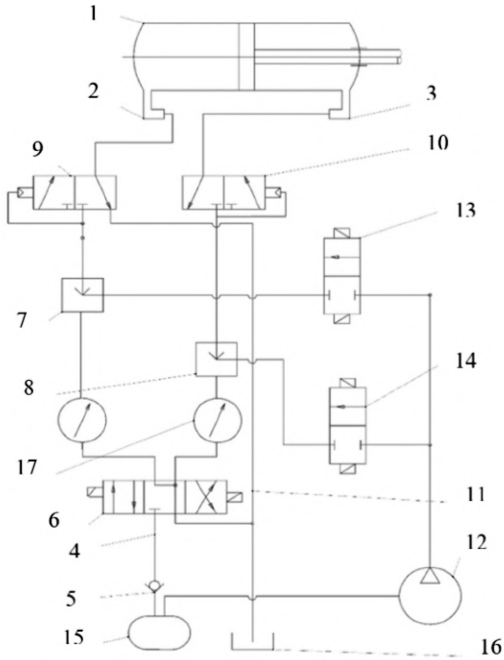

Fig. 1. Hydraulic schematic diagram: 1 – hydraulic cylinder, 2 – piston cavity connector, 3 – stem cavity connector, 4 – discharge line, 5 – check valve, 6 – hydraulic distributor, 7 – piston cavity cavitator, 8 – stem cavity cavitator, 9, 10 – overflow valve, 11 – drain line, 12 – compressor, 13 – piston cavity valve, 14 – stem cavity valve, 15 – flushing fluid tank, 16 – drain tank, 17 – manometer.

The flushing liquid enters the hydraulic system due to the pressure created on the surface of the liquid by the compressor, so that the supply process is pressurized. In parallel to the supply of the flushing liquid, gas bubbles are introduced into the flow under pressure by means of a connection. As a result of the interaction of the above components, a gas-liquid mixture is formed.

Moving through the high-pressure hoses, the flow enters one of the cavities of the double-acting hydraulic cylinder, which drives the piston. After filling the cavity and moving the piston to the opposite extreme position, the distributor is switched and the liquid is redirected to the other cavity of the hydraulic cylinder. The process is repeated. As a result of the above manipulations, the hydraulic cylinder cavities are cleaned and contaminants are removed by draining, together with the flushing fluid.

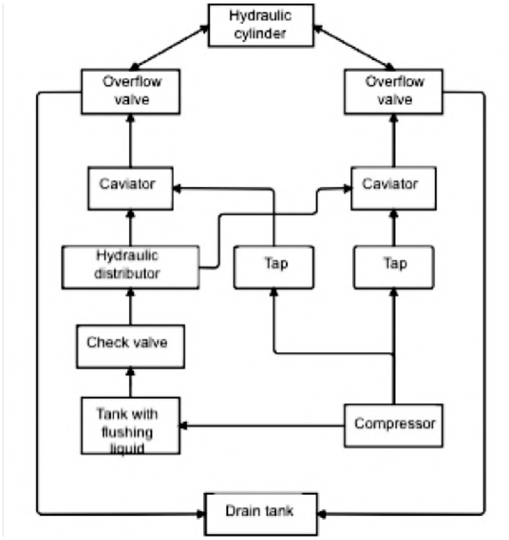

Fig. 2. Schematic diagram of the flushing stand

This method will almost completely remove deposits of contamination on the walls of the cylinder [13].

It is important to consider the size of the introduced bubbles. By their nature, air bubbles are quite unstable and tend to separate from the fluid in the hydraulic cylinder cavity. Therefore, the air is introduced into the system at a rate so that the size of the bubbles, resist instantaneous separation from the liquid.

Necessary sizes of bubbles are determined by the known dependences of the speed of surfacing of bubbles on their sizes

Thus, the speed of surfacing of a single bubble, graphically can be represented as a dependency $V = f(d_п)$ (Fig. 3).

The first region is characterized by the following indications - bubble diameter does not exceed 1.5 mm, bubble motion is similar to a solid sphere, since it is carried out under laminar flow conditions.

In the second region, the diameter of bubbles varies from 1.5 to 6 mm, it is characterized by the absence of a tendency to increase the velocity, because due to the oscillation of the bubble shape, its cross-sectional area increases.

The third region is characterized by the destruction of the gas bubble, since the velocity does not increase, with constant fluctuations in the shape of the bubble. [14]

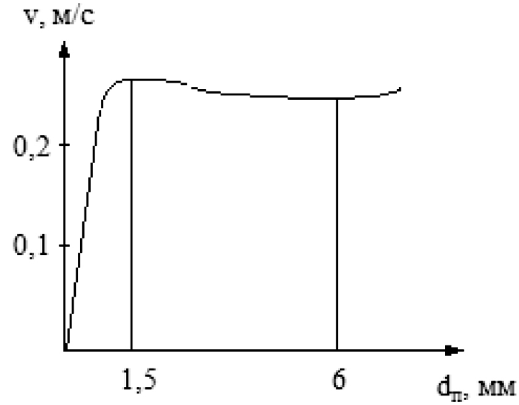

Fig. 3. Dependence of the floating velocity of a single bubble

Based on the graph, it can be observed that the optimal bubble popping speed, in terms of bench performance is within 0.25 m/s.

Thus, the topic of bubble motion in liquid is raised by G. Kotkin in the article "Pop-up air bubble and Archimedes' law". He compares the motion of bubbles in a liquid medium with the motion of weights connected by a thread and thrown over a stationary block. One of these blocks takes the role of a bubble with mass m, and the other takes the role of water, and its mass will be M, hence the pushing force will be the thread T.

Then Newton's second law will take the following form:

$$m \cdot a = T - m \cdot g \tag{1}$$

If the load is held, then the tension of the thread will characterize the weight of the load mg. However, if we substitute the above equality into the equation, we can come to a false conclusion about the huge acceleration of the bubble.

The solution to this error will be the necessity to consider the motion of the weight of mass m and the motion of the "displaced" water.

In the booth is predominantly turbulent flow, which is created directly by the bubbles themselves. Reducing the resistance of the medium is achieved by communicating the fluid continuous flow direction of the bubbles popping.

Based on the above, it can be concluded that the surfacing velocity of a group of bubbles is much higher than that of a single bubble.

The surfacing velocity of the bubble flow can be described by the equation:

$$V_p = 1{,}74\sqrt{d_p \cdot g} \tag{1}$$

where d_p – average bubble size. In the case of a polydisperse system under mass bubbling, the characteristic bubble size is rather difficult to determine and can be calculated using the formula:

$$V_p = 1{,}5\left(\frac{\sigma g \Delta\rho}{\rho_z^2}\right)^{0{,}25} \quad (1)$$

For example, the following calculation example is given in the patent "Methods of flushing hollow products". When washing a power hydraulic cylinder with a piston diameter of 125 mm and the time of filling and draining the liquid from the cavity of 5 s, the diameter of bubbles should be 0.2 mm or less, because the speed of surfacing of such bubbles (2 mm/s) prevents their separation in the cylinder cavity, and during the time of 5 s even in the absence of agitation, the bubble manages to float by 10 mm, i.e. by 0.1 of the piston diameter.

Flushing unit with the use of air bubbles significantly increases the viscosity of the flushing fluid, and this reduces the rate of settling only flushed contaminants in the cavity of the product, which improves the removal of contaminants through the spigots.

In particular, for the mentioned parameters of the cylinder gas bubbles should be the size of 5 mm, the speed of surfacing of which is 12.3 mm/s, which justifies the need to fill/empty the cavity of the hydraulic cylinder within 10 seconds, at the same time for flushing the hydraulic system create a flow of fluid with a Reynolds number of at least 4000, and the nominal pressure in the hydraulic cylinder is 18 MPa.

Results

The article describes a new method of cleaning the working volumes of hydraulic cylinders without the need for preliminary dismantling, based on the use of a flushing stand. This method makes it possible to effectively clean the internal cavities of hydraulic cylinders from various contaminants, including metal chips and other solid particles, which makes it possible to significantly extend the service life of the equipment and increase its reliability. Cleaning is carried out with the help of a gas-liquid mixture containing air bubbles, which contribute to the destruction of the crystal lattice of contaminants and their effective removal from the system. The developed basic hydraulic scheme and the proposed design of the flushing stand provide high efficiency of the cleaning process. In addition, the calculations and experiments confirm the correctness of the selected parameters and schemes, which makes this method promising for wide application in industry.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

JUSTIFICATION OF THE VIBRATION PLATE INSTALLATION TYPE OF THE HOPPER OF FERTILIZER APPLYING MACHINE

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Abstract

Background. The main units of an agricultural machines for subsoil fertilizer application are the hopper and metering unit, which provides uniform fertilizer supply to all sowing working bodies. As a result of the main research, a hopper and metering device with a vibratory plate operating in forced oscillation mode was proposed, and in this paper installation types of vibratory plate on a chamber have been theatrically investigated. The main goal of the study is to define more effective type of installation. The vibratory plate was modeled as a flexible rod with two fixed ends and one degree of freedom, then the vibration amplitudes and frequencies for 4 types of mounting were investigated. According to theoretical studies, a rational model for fixing the vibrating plate is a fixed rod with two ends fixed pivotally.

Purpose. The aim of the present study is to perform the justification of the vibration plate installation type of the hopper of the fertilizer applying machine.

Materials and methods. Figure 1 presents the scheme and experimental example of the proposed hopper. To simulate the fastening scheme of the AB plate ends, 4 ways of fixing are proposed in Figure 3. As a result, we calculate the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. During the research, it has been calculated the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. To solve the problem described above, in the first approximation, the oscillation of the AB plate is modeled as the oscillation of an elastic system with one degree of freedom presented in Figure 4. The unknown parameters are determined by boundary conditions.

Results. The effective installation type of the vibratory plate has determined by modeling it as a flexible plate with two ends fixed with one degree of freedom. Vibration amplitudes and frequencies for the 4 ways of fixing the plate as vibrations of an elastic system were determined. By modeling a fixed vibrating plate with two ends that is a one-dimensional continuous system, amplitude problems and frequency equations of specific and involuntary vibrations of the plate were obtained. According to results it concluded that the rational model of a vibrating plate is a fixed plate with two ends hinged. The specific frequency of the plate was approximately the same as the results of the calculation of the body model identified earlier.

Conclusion. The studied data is required for further analysis using computational fluid dynamics (CFD) and discrete element method (DEM).

According to the general search, it should be noted that the seeding device with the proposed compensating chamber provides 4.37–6.63% seeding unevenness and 5–5.8% seeding instability.

Keywords: amplitude; seeder hopper; oscillation; fertilizer; subsoil

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Научная статья

ОБОСНОВАНИЕ ТИПА УСТАНОВКИ ВИБРОПЛИТЫ В БУНКЕРЕ МАШИНЫ ДЛЯ ВНЕСЕНИЯ УДОБРЕНИЙ

С.О. Нукешев, Х.К. Танбаев, А.К. Молдажанов, А.Т. Кабдулина

Аннотация

Обоснование. Основными узлами сельскохозяйственных машин для подпочвенного внесения удобрений являются бункер и дозатор, которые обеспечивают равномерную подачу удобрений ко всем рабочим органам сеялки. В результате основных исследований был предложен бункер-дозатор с виброплитой, работающей в режиме вынужденных колебаний, а в данной работе театрально исследованы типы установки виброплиты на камеру. Основной целью исследования является определение более эффективного типа установки. Виброплита моделировалась как гибкий стержень с двумя фиксированными концами и одной степенью свободы, затем были исследованы амплитуды и частоты колебаний для 4 типов установки. Согласно теоретическим исследованиям, рациональной моделью крепления виброплиты является неподвижный стержень с двумя концами, закрепленными шарнирно.

Цель. Целью настоящего исследования является обоснование типа установки виброплиты в бункере машины для внесения удобрений.

Материалы и методы. На рисунке 1 представлена схема и экспериментальный пример предлагаемого бункера. Для моделирования схемы крепления торцов пластин AB на рисунке 3 предложены 4 способа крепления. В результате мы рассчитываем частоту для каждой цепи, сравниваем ее с реальной частотой и выбираем один из четырех способов крепления. В ходе исследования были рассчитаны частоты для каждого контура, сравнены с реальными частотами и выбран один из четырех способов крепления. Для решения описанной выше задачи в первом приближении колебания пластины AB моделируются как колебания упругой системы с одной степенью свободы, представленной на рисунке 4. Неизвестные параметры определяются граничными условиями.

Результаты. Эффективный тип установки виброплиты был определен путем моделирования ее как гибкой пластины, два конца которой закреплены с одной степенью свободы. Определены амплитуды и частоты колебаний для 4-х способов крепления плиты как колебаний упругой системы. При моделировании неподвижной вибрирующей пластины с двумя концами, представляющей собой одномерную непрерывную систему, получены амплитудные задачи и частотные уравнения собственных и вынужденных колебаний пластины. По результатам сделан вывод, что рациональной моделью вибрирующей пластины является неподвижная пластина с двумя шарнирно закрепленными концами. Удельная частота пластины примерно совпала с результатами расчета модели тела, определенной ранее.

Заключение. Исследованные данные необходимы для дальнейшего анализа с использованием вычислительной гидродинамики (CFD) и метода дискретных элементов (DEM).

По результатам общего поиска следует отметить, что высевающий аппарат с предложенной компенсационной камерой обеспечивает неравномерность высева 4,37-6,63% и нестабильность высева 5-5,8%.

Ключевые слова: амплитуда; бункер сеялки; колебания; удобрения; почва

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Introduction

The main component of agricultural units for intra-soil fertilizer application is the presence of a hopper and dosing device, which ensures uniform fertilizer delivery to all working bodies. However, most machines cannot efficiently allocate and apply the fertilizer in the soil. One of the problems faced by farmers and fertilizer machines operators is vaulting in hoppers; the accumulation and sticking of fertilizer in the corners and low parts of the hoppers, the formation of vaults (clogging) above the seeding windows [1-4]. It makes difficult to dose fertilizer evenly and, by disrupting the technological process of fertilizer application it leads to a reduction of agronomic efficiency [5-7]. In this regard, a hopper-dosing machine that operates under forced vibration was developed. The hopper equipped with a vibrator and compensation chamber [8; 9] to induce a vibration. The main work component is the vibrating plate that mounted in the compensation chamber. Currently, the known types of hopper vibrator designs are suspended rigid vibration drive, crank vibration drive, pulley vibration drive, recessed vibration driver, etc. The design of the vibration motor, which is usually installed on the hopper, depends on the size, shape and design of the body, the angle of inclination of the base, the thickness of the walls, the strength of the supports, as well as many factors, such as the design of the vibration motor. Vibrators are divided into electromechanical, electromagnetic, hydraulic and pneumatic actuators [10-13]. Vibratory thrusters are also characterized by complexity in design, control and maintenance. Energy consumption is only insignificant. Vibration from the vibration actuator is transmitted to the wall of the hopper or directly to the material. At the same time, a significant disadvantage of these actuators is that vibration not only loosens the material, however also contributes to the compaction of the material [14; 15].

On the proposed design the vibrating motor installed independently and influences to the vibrating plate that according to owned amplitude and according to its property vibration condition multiples. The connection type of the vibrating plate to the chamber walls is very important to obtain the required vibration amplitude and its rising. The vibratory plate was modeled as a flexible rod with two fixed ends and one degree of freedom, then the vibration amplitudes and frequencies for 4 types of mounting were investigated. The main *purpose* of the study is to determine and theoretically substantiate the most acceptable type of installation of the vibratory plate.

Materials and methods

Figure 1 presents the scheme and experimental example of the proposed hopper. The bulk of the fertilizer in the hopper (1) falls into the chamber (3) under the action of the conic-helical spring. The vibrating plate (5) ensures that the fertilizer falls continuously and evenly onto the belt, which then guides the fertilizer into the pipes. The connection type (6) of the vibrating plate to the chamber walls is very important to obtain the required vibration amplitude that provide fertilizer fall-flow without any vaulting problems.

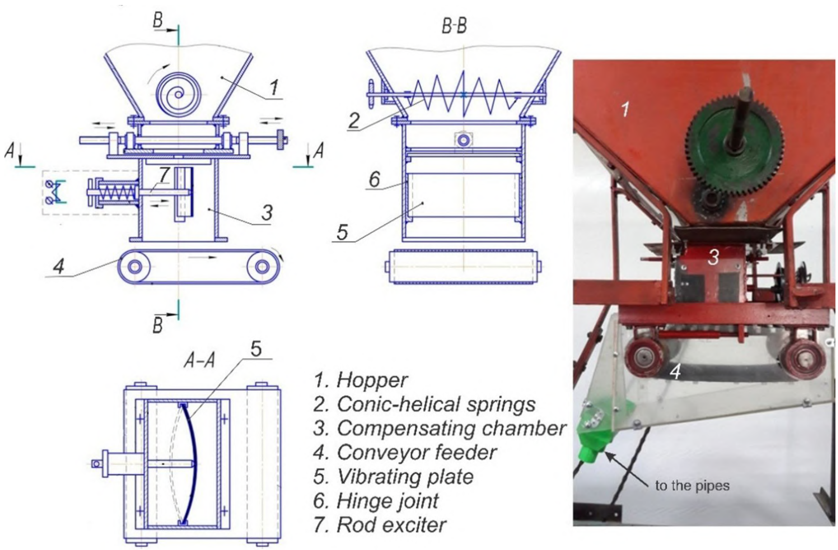


Fig. 1. The scheme and experimental example of the proposed hopper

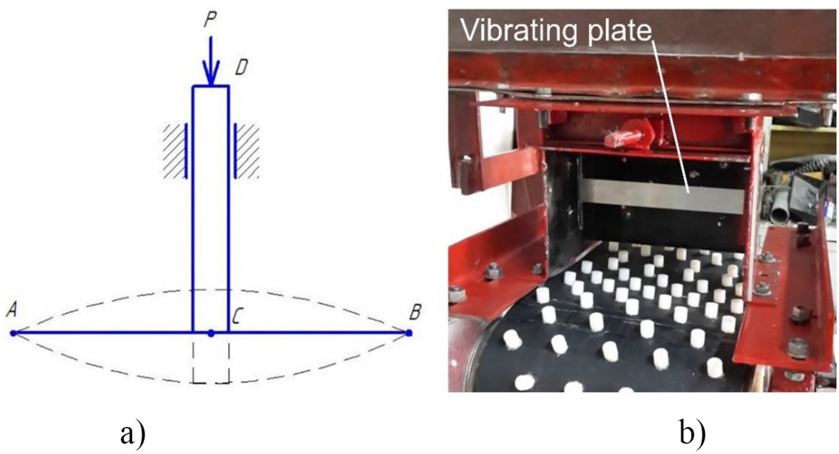
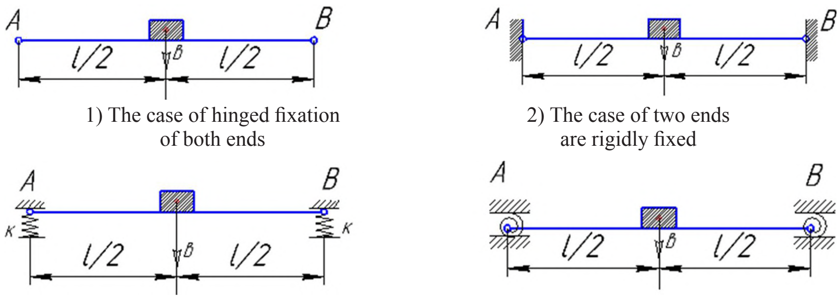


Fig. 2. The scheme of the plate and pole position

The AB ends of the thin elastic vibrating plate are fixed on the chamber wall. The rod exciter DC is perpendicularly fixed with the end C on the center of the plate AB. In this case, the plate AB makes horizontal vibrations [8; 9] (Fig. 2).

To simulate the fastening scheme of the AB plate ends, 4 ways of fixing are proposed (Fig. 3). As a result, we calculate the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing. During the research, it has been calculated the frequency for each circuit, compare them with real frequencies and select one of the four ways of fixing.



1) The case of hinged fixation of both ends

2) The case of two ends are rigidly fixed

3) The case of the two ends are fixed by springs

4) The case of two ends are secured by swing springs

Fig. 3. Ways of fixing the plate ends (AB)

To solve the problem described above, in the first approximation, the oscillation of the AB plate is modeled as the oscillation of an elastic system with one degree of freedom (Fig. 4). Consider the specific oscillation of a plate with two ends rigidly fixed. The plate is affected by the elastic force $\vec{F_c}$ and gravity $\vec{G}$.

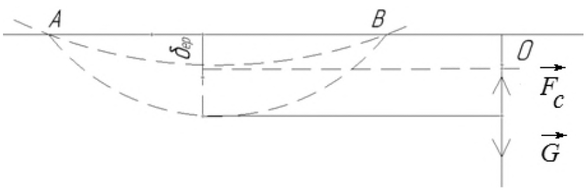


Fig. 4. Forces acting on the bent plate element

If the plate is affected by an elastic force F_c, then the load is in free swing along with the plate. The specific cyclic frequency can be found using the formula:

$$\omega = \sqrt{\frac{c}{m}}, \tag{1}$$

where, c – is the springiness of the plate,

m – is the given mass of the plate, which takes into account the mass of the load on the plate and the mass of the plate.

The specified mass of the plate using the coefficient of adjustment K_m:

$$m = \frac{G}{g} + K_m \rho l. \tag{2}$$

The kinetic energy of the plate and the kinetic energy of the additional mass oscillating with the load are determined by equation [16].

$$K_m = \frac{2}{\delta_{\text{ст}}^2} \int_0^{1/2} y^2 d\xi. \tag{3}$$

where, K_m – is the plate mass reduction factor, y is the plate bending function depending on the coordinates of the plate points, $\delta_{\text{ст}}^2$ is the maximum static bending of the plate.

Then, the cyclic frequency of the system – ω and the period – τ are calculated using the following equations:

$$\begin{cases} \omega = \sqrt{\frac{g}{\delta_{\text{ст}}} \cdot \frac{1}{1+K_m \frac{\rho g l}{G}}}, \\ \tau = 2\pi \sqrt{\frac{\delta_{\text{ст}}}{g}\left(1 + K_m \frac{\rho g l}{G}\right)}. \end{cases} \tag{4}$$

As can be seen from the equation (2.28), to calculate the frequency and period, it is necessary to know the static bending and the given mass coefficient, depending on the ways of fixing the plate. To determine the static bending of the plate, we use the method of initial parameters [16], (Fig. 5). The bend of the plate can be written as:

$$y = y_0 + \theta_0 x + \frac{1}{EI}\left[M_0 \frac{x^2}{2!} + Q_0 \frac{x^3}{3!} - G \frac{\left(x - \frac{l}{2}\right)^3}{3!}\right], \tag{5}$$

where y_0 and θ_0 – is the angle of bending and bending of the plate at point O;

E – longitudinal elastic module of the plate;

J – the inertial moment of the cross section of the plate;

M_0 and Q_0 – bending moment and horizontal force at the point O;

x – longitudinal axis of the plate.

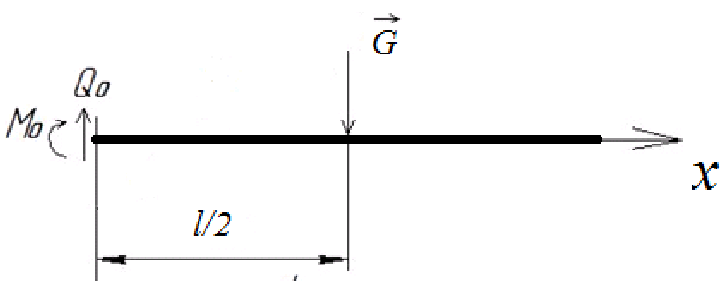


Fig. 5. Diagram of the force acting on the plate

The center of the plate is affected by gravity $\vec{G}$. The bending moment M_0 and the transverse force Q_0 at point O are equal to the reverse effect of the fixing moment and the support at the left end of the plate, respectively. They, in turn, are determined from the equilibrium conditions of known statics.

Table 1.

The opposite effect of supports in different ways of fastening the plate when gravity falls on the center of the plate

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$M_0 = 0; \quad Q_0 = \frac{G}{2}$
2. The case of two ends are rigidly fixed	$M_0 = -\frac{Gl}{8}; \quad Q_0 = \frac{G}{2}$
3. The case of the two ends are fixed by springs	$M_0 = -\frac{Gl}{8}; \quad Q_0 = \frac{G}{2}.$
4. The case of two ends are secured by swing springs	$M_0 = -\frac{Gl}{2^3(\mu+1)}; \quad Q_0 = \frac{G}{2}$

The boundary conditions for the 4 ways of fixing the plate ends are given in Table 2.

Table 2.

Boundary conditions for fixing plate ends

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$y\|_{x=0} = 0; \quad \left.\frac{d^2y}{dx^2}\right\|_{x=0} = 0.$
2. The case of two ends are rigidly fixed	$\left.\frac{dy}{dx}\right\|_{x=0} = 0; \quad y\|_{x=0} = 0.$
3. The case of the two ends are fixed by springs	$\left.\frac{dy}{dx}\right\|_{x=0} = 0; \quad EI\left.\frac{d^3y}{dx^3}\right\|_{x=0} - k \cdot y\|_{x=0} = 0.$
4. The case of two ends are secured by swing springs	$\left.\frac{d^2y}{dx^2}\right\|_{x=0} - \frac{k_1}{EI} \cdot \left.\frac{dy}{dx}\right\|_{x=0} = 0; y\|_{x=0} = 0.$

where k is the spring stiffness, k_1 is the torsion spring stiffness (Fig. 3).

The unknown parameters y_0 and θ_0 are determined by boundary conditions. If set the equation (5) to the conditions given in Table 2, it allows to obtain the above parameters. The results are presented in Table 3.

Table 3.

Initial conditions of y_0 and θ_0 for the ways of fixing the plate ends

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$y_0 = 0; \quad \theta_0 = -\frac{1}{EI}\frac{G}{4}l^2.$
2. The case of two ends are rigidly fixed	$y_0 = 0; \quad \theta_0 = 0.$
3. The case of the two ends are fixed by springs	$y_0 = \frac{G}{2k}; \quad \theta_0 = 0.$
4. The case of two ends are secured by swing springs	$y_0 = 0; \quad \theta_0 = -\frac{Gl}{2^3 k_1(\mu+1)}.$

As a result, according to those given in tables 1 and 3, the unknown quantities in the equation (5) the y_0 and θ_0, the M_0 and Q_0 were determined for all fixing types. Further, from the equations (3) and (5), we find the static bending and the given mass coefficient for all four ways of fixing the plate ends. The results are presented in Table 4.

Table 4.

The equations and values of the $\delta_{ст}$ the static bending and K_m – the plate mass reduction coefficient for 4 ways of fixing the plate ends.

Types of fixing the ends of the vibrating plate	Equations
1. The case of hinged fixation of both ends	$\delta_{ст} = y_{max} = \frac{Gl^3}{48EI}$ $K_m = \frac{17}{35}$
2. The case of two ends are rigidly fixed	$\delta_{ст} = y_{max} = \frac{Gl^3}{192EI}$ $K_m = \frac{13}{35}$
3. The case of the two ends are fixed by springs	$\delta_{ст} = y_{max} = \frac{Gl^3}{3 \cdot 2^6 EI}(3 \cdot 2^5 r - 1)$ $K_m = \frac{2^5}{(3 \cdot 2^5 r - 1)^2}\left(3^2 \cdot 2^5 r^2 - 3r - \frac{3}{7 \cdot 7 \cdot 2^5}\right)^2$

4. The case of two ends are secured by swing springs	$$\delta_{\text{ст}} = y_{max} = -\frac{Gl^3}{2^6 \cdot 3EI} \cdot \frac{4\mu+1}{\mu+1}$$ $$K_m = \frac{3 \cdot 2^4 \delta_{\text{ст}}(\mu+1)}{4\mu+1}\left[-\frac{\mu}{2^3(\mu+1)} \cdot \frac{1}{2^3} - \frac{1}{2^6 \cdot 3(\mu+1)} + \frac{1}{3 \cdot 2^6}\right]$$

where $\mu = \frac{2}{l}\frac{EI}{k_1}$, $r = \frac{EI}{k \cdot l^3}$.

Suppose that the return force F_c acts on the plate as the resistance force $R = -a\dot{y}$ and the forcing force $S = H \sin \rho t$. Here, the plate involuntarily oscillates, where α is the coefficient of resistance of the external environment, H is the amplitude of the acting force, p is its cyclic frequency. Here, the movement of the load can be written with this differential equation. Involuntary oscillation is an independent solution to the differential equation of plate oscillation:

$$\ddot{y} + 2n\dot{y} - \omega^2 y = h \sin pt, \tag{6}$$

where $2n = \frac{\alpha}{m}$; $\omega^2 = \frac{c}{m}$; $h = \frac{H}{m}$.

The independent solution of the equation in case $n < \omega$ (6) is written as:

$$y_{\text{дерб}} = \frac{h}{\sqrt{(\omega^2 - p^2)^2 + 4n^2p^2}} \sin\left(pt - \tan^{-1}\left(\frac{2np}{\omega^2 - p^2}\right)\right). \tag{7}$$

According to the equations of Table 4 and Eq. (4), the theoretical values of the frequency are determined (Table 5).

Table 5.

Theoretical frequency values for different types of fixing

Methods of fastening of plate ends	The case of hinged fixation of both ends	The case of two ends are rigidly fixed	The case of the two ends are fixed by springs	The case of two ends are secured by swing springs
Frequency, Hz	3.45	4.069	2.005	2.022

Results and conclusion

The effective installation type of the vibratory plate has determined by modeling it as a flexible plate with two ends fixed with one degree of freedom. Vibration amplitudes and frequencies for the 4 ways of fixing the plate as vibrations of an elastic system were determined. By modeling a fixed vibrating plate with two ends that is a one-dimensional continuous system, amplitude problems and frequency equations of specific and involuntary vibrations of the plate were obtained. According to results it concluded that the rational model of a vibrating plate is a fixed plate with two ends hinged. The specific frequency of the plate was approximately the same as the results of the calculation of the body model identified earlier.

The studied data is required for further analysis using computational fluid dynamics (CFD) and discrete element method (DEM).

According to the general search, it should be noted that the seeding device with the proposed compensating chamber provides 4.37–6.63% seeding unevenness and 5–5.8% seeding instability.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

OPTIMIZATION OF THE STRUCTURE OF THE AGRICULTURAL MACHINERY REPAIR CYCLE IS CORRECT

E.A. Shapiro

Abstract

Background. This article provides a justification for the structure of the repair cycle of agricultural machinery. It is considered how this technique with disparate service life of parts has a very low repair adaptability and does not meet the basic requirements of scientific planning of current and major repairs. The drawings presented in the work illustrate a scheme for maintaining the permissible gap in the joint by carrying out periodic repairs, a scheme for wearing parts with different wear rates and different service lives, a scheme for creating a rational structure of the repair cycle of machines, etc. This article is prepared for specialists of the agro-industrial complex, researchers, teachers, postgraduates, undergraduates and students of agricultural universities in the field of training "Agroengineering".

Purpose. The purpose of the study is to optimize the structure of the repair cycle of agricultural machinery

Materials and methods. To substantiate the structure of the repair cycle, this article uses a detailed analysis of the wear patterns of machine parts and their service life.

Results. One of the most important directions for improving the planning of scientific, technical and production activities of agricultural enterprises of the Krasnodar Territory is to strengthen a systematic, integrated approach to the technical service of agricultural machinery. Another direction is related to the need to significantly improve the technical level and quality of agricultural machinery while simultaneously increasing its output and reducing production costs.

In order to determine specific measures to improve the effectiveness of scientific research and development (R&D) in agricultural engineering, it is necessary to thoroughly and in detail analyze the existing state of work on the creation of new equipment, trends and prospects for the development of technologies and the material and technical base of agricultural production.

When analyzing the directions of development of agricultural machinery, first of all, there is a steady growth trend in the unit capacity of tractors, working machines and vehicles intended for agriculture.

This direction has so far been associated with the solution of one of the main tasks of the development of agricultural production - optimization of the structure of the repair cycle of machines.

Conclusion. Thus, it can be concluded that using the expressions obtained, it is possible to optimize the repair cycle of a tractor, combine harvester, car, or other agricultural machine.

Keywords: repair cycle; frequency; justification; gaps; repair; service life; labor intensity; MTZ-82 tractor; inter-repair period

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Научная статья

ОПТИМИЗАЦИЯ СТРУКТУРЫ ЦИКЛА РЕМОНТА СЕЛЬСКОХОЗЯЙСТВЕННОЙ ТЕХНИКИ

Е.А. Шапиро

Аннотация

Обоснование. В статье дано обоснование структуры ремонтного цикла сельскохозяйственной техники. Рассмотрено, как эта техника с разрозненными сроками службы деталей имеет очень низкую ремонтопригодность и не отвечает основным требованиям научного планирования текущих и капитальных ремонтов. Приведенные в работе рисунки иллюстрируют схему поддержания допустимого зазора в соединении путем проведения периодических ремонтов, схему изнашивания деталей с различной интенсивностью изнашивания и различными сроками службы, схему создания рациональной структуры ремонтного цикла машин и др. Статья подготовлена для специалистов агропромышленного комплекса, научных работников, преподавателей, аспирантов, магистрантов и студентов сельскохозяйственных вузов по направлению подготовки «Агроинженерия».

Цель. Целью исследования является оптимизация структуры цикла ремонта сельскохозяйственной техники

Материалы и методы. Для обоснования структуры ремонтного цикла в данной статье использован детальный анализ закономерностей изнашивания деталей машин и сроков их службы.

Результаты. Одним из важнейших направлений совершенствования планирования научно-технической и производственной деятельности сельскохозяйственных предприятий Краснодарского края является усиление системного, комплексного подхода к техническому сервису сельскохозяйственной техники. Другое направление связано с необходимостью существенного повышения технического уровня и качества сельскохозяйственной техники при одновременном увеличении ее выпуска и снижении себестоимости.

Для того чтобы определить конкретные меры по повышению эффективности научно-исследовательских и опытно-конструкторских работ (НИОКР) в сельскохозяйственном машиностроении, необходимо тщательно и детально проанализировать существующее состояние работ по созданию новой техники, тенденции и перспективы развития технологий и материально-технической базы сельскохозяйственного производства.

Анализируя направления развития сельскохозяйственной техники, прежде всего, следует отметить устойчивую тенденцию роста единичной мощности тракторов, рабочих машин и автомобилей, предназначенных для сельского хозяйства.

Это направление до сих пор было связано с решением одной из основных задач развития сельскохозяйственного производства - оптимизацией структуры ремонтного цикла машин.

Заключение. Можно сделать вывод, что, используя полученные выражения, можно оптимизировать ремонтный цикл трактора, комбайна, автомобиля или другой сельскохозяйственной машины.

Ключевые слова: ремонтный цикл; периодичность; обоснование; зазоры; ремонт; срок службы; трудоемкость; трактор МТЗ-82; межремонтный период

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Introduction

With the introduction of sophisticated agricultural machinery in the agricultural farms of the Krasnodar Territory, special requirements are imposed for the justification of scientifically based repair cycles of machines. Coverage of the basic theoretical principles of technical service, description of devices and equipment for maintenance and repair are available in a number of scientific and technical books.

Therefore, there is no need to dwell on general issues here. Let's consider only the description of some of the most widely used schemes for forming the structure of the repair cycle. Machine repair systems and structures of their repair cycles must meet the following basic requirements [1, 2, 3]:

– there should be no emergency forms of wear of parts in friction units;

– when repairing machines, there should be no rejection of parts with unused working capacity resources;

– the frequency and structure of repairs should meet the minimum total cost of repairs and coverage of damage caused by machine downtime due to malfunction.

Considering the issue related to the justification of the structure of the belt cycle of machines, it is necessary to briefly focus on the main types and methods of repair. Firstly, it should be noted that the repair of machines is a set of works that ensures the restoration of the main operational parameters of machines.

At the same time, the technical condition of the machines is revealed both by external signs (visually, by touch, by ear) and with the help of devices, devices and tools.

Emergency, routine and major repairs can often be found in the regulatory and technical documentation. In case of emergency repairs, a complete machine must be cleaned, disassembled, carbon deposits and scale removed from worn structural elements, then the repaired machine must be tested at idle, and if necessary, under load.

During major repairs, the machine is completely disassembled, all parts are washed, parts and assembly units are defective, repaired, assembled, adjusted and tested by aggregates and the machine as a whole. Secondly, it should be noted that the repair method is a method and organization of repair production with the dismemberment and specialization of repair work on individual units, assembly units and parts.

A fairly simple nodal method is also possible, in which the entire complex of works is divided into separate parts, each of which represents a completely completed repair process of the assembly unit.

In this repair method, there is specialization and division of labor. Each worker, doing the same job all the time, improves his skills, as a result of which the quality of machine repair is significantly improved, labor productivity increases, equipment, fixtures, tools and the area of repair shops are better used.

The flow-node method is a form of machine repair organization in which the entire range of work is divided into separate operations, representing a complete repair process, and the assembly of machines is carried out on mobile stands.

Assembly units are repaired and assembled at specialized workplaces and installed on a machine that moves from one workplace to another in accordance with the technological process.

With the aggregate repair method, defective units are replaced with repaired ones from the exchange fund or new ones, and defective units are sent to repair and technical enterprises.

This method not only reduces the downtime of machines due to technical malfunctions, but also improves the quality of repairs, reduces the cost of its cost. The method of periodic replacement of repair complexes (MANPADS) is a form of organization of repair of agricultural machinery, when individual units, assembly units and parts with approximately the same service life during disassembly are grouped, taking into account this methodology for optimizing the structure of the repair cycle, into separate kits and sent to mechanical repair plants.

In the workshops of agricultural enterprises, repaired kits are installed on machines.

This method allows you to restore the performance of machines by replacing worn-out sets with repaired ones, which significantly increases the utilization rate of agricultural machinery.

The flow method is used in repair and technical enterprises (factories, workshops). This is the most advanced form of production organization in enterprises with a sufficiently large volume of production program, where similar machines are repaired with uniform loading throughout the year.

Taking into account the present methodology developed by us to substantiate the structure of the repair cycle, in line production, the time for each operation is equal to or a multiple of the production cycle.

Materials and methods

To substantiate the structure of the repair cycle, this article uses a detailed analysis of the wear patterns of machine parts and their service life. In order to comply with the basic principles of scientific research, a systematic approach was applied, methods of induction and deduction, abstraction and concretization, etc. were used.

The integrated approach used in this article includes a number of particular methodological approaches, including such as [4, 5, 6]: – functional approach; – methodological approach related to logical analysis and synthesis; – an approach involving consideration of the life cycle of machines.

With the modern organization of maintenance and repair of agricultural machinery, cars and other machines, when parts and assemblies are discolored during major repairs, machines lose their components, it is possible to determine the degree of deterioration of their performance with operating time only for specific use cases.

Therefore, in this work, such a method is also used as an assessment of the technical condition of machines, taking into account resource conservation.

Results of the research

During the operation of machines, their parts wear out or get damaged. At the same time, their sizes change, the geometric shapes of the working surfaces are violated, bends, twisting, etc. are obtained.

The modern level of modern agricultural machinery allows you to restore a significant part of worn and damaged parts. Repair of worn parts is of great technical and economic importance, therefore it is necessary to systematically expand the range of repaired parts and improve the technology of their repair.

At the same time, the cost of repaired parts is lower than the cost of new parts. Repair of parts will have a great economic effect by saving metal, freeing up labor and equipment engaged in the manufacture of new parts, as well as by justifying the structure of the repair cycle of machines, taking into account the methodology presented in this article.

Currently, the following methods of quality management of car maintenance and repair have been applied in the practice of repair enterprises. The principles of construction of KSUK TOR cars play a special role.

They define the starting points that employees at all levels should follow when developing and operating the system. These principles are interrelated and work simultaneously. Improving the quality of maintenance and repair of cars largely depends on the correctness and completeness of their use at all stages of the creation of KSUK.

Currently, the issues of forming the principles of organizing the development, construction, implementation and operation of product quality management systems in agricultural enterprises and in associations, industries, as well as at the level of the national economy as a whole, are widely covered in the literature [5, 7, 8, 9] and especially fully in the work [5].

From the perspective of the problem under consideration, it seems correct to divide these principles of building and organizing quality management systems into two groups:

– general principles of building all management systems in agricultural production;

– specific principles of building product quality management systems.

The principles of the first group are widely described in the technical literature. Therefore, we will consider the basic principles of only the second group.

The principle of an individual approach. When creating a KSUK TO and R in each association (enterprise), its application involves the creation and organization of the functioning of the system, taking into account the specifics of production and economic activities (transportation process, traffic volumes, number of branches, type of rolling stock, etc.), while ensuring its sufficiently high efficiency.

At the same time, the requirement of maximum use of standard solutions in the system should be taken into account.

The principle of complex problem solving. According to this principle, the system should be focused on the development of integrated programs (impacts) in the management of maintenance and repair quality.

It is necessary to focus on improving the quality of the technical condition of cars while ensuring that all necessary private tasks of the system are solved in terms of time and resources.

The principle of continuous development of the system. It assumes that the KSUK TOR is being developed as an open system to be expanded as agricultural production and management systems develop. Considering the issue related to the optimization of the structure of the repair cycle of machines, it should be noted that currently the technical conditions for the repair and maintenance of tractors have established the following structure of repair and maintenance effects (table 1).

Table 1.

Structure of repair and maintenance impacts for tractors

Type of repair and maintenance impact	Frequency of performance of this action, moto-h
1. Tractor running-in (TO-O)	10±5
2. Daily maintenance (ETO)	10±2
3. First maintenance (TO-1)	125±10
4. Second maintenance (TO-2)	500±20
5. Third maintenance (TO-3)	1000±20
6. Emergency Repair (AR)	according to need
7. Current repairs (TR)	2000±20
8. Major repairs (KR)	6000±20

At the same time, it should be noted that this structure of repair and maintenance impacts for modern energy-saturated tractors is insufficiently rational and requires further optimization. Further, it should be noted that in addition to those given in the work related to the optimization of the structure of the repair cycle of modern tractors, it is proposed to use a number of principles at the stage of their production and technical operation, which, according to the author, should also be taken into account when creating KSUK TOR [10, 11, 12].

These principles characterize mainly the requirements for the preparation of machines for the start of production operation:

– comprehensive preparation of agricultural machinery for the use of the system;

– active participation of the engineering and technical staff of the agricultural farm in the development and implementation of methods for optimizing the repair cycle of machines.

At the stage of development of the quality management system, its improvement based on the economic strategy of the agricultural farm administration should be based on the following additional principles [13, 14]:

– the principle of the predominance of the interests of the agricultural farm as a whole over the interests of collective and personal;

– the principle of systematic development of quality management of technical service of machines.

Research and practice have shown that the construction of KSUK TOR, taking into account the above principles, ensures the creation of an effective system with specified parameters for optimizing the structure of the repair cycle of machines.

However, the solution of economic and organizational issues and compliance with the general principles of building a technical service system are important in its development.

One of the most important directions for improving the planning of scientific, technical and production activities of agricultural enterprises of the Krasnodar Territory is to strengthen a systematic, integrated approach to the technical service of agricultural machinery. Another direction is related to the need to significantly improve the technical level and quality of agricultural machinery while simultaneously increasing its output and reducing production costs.

In order to determine specific measures to improve the effectiveness of scientific research and development (R&D) in agricultural engineering, it is necessary to thoroughly and in detail analyze the existing state of work on the creation of new equipment, trends and prospects for the development of technologies and the material and technical base of agricultural production.

When analyzing the directions of development of agricultural machinery, first of all, there is a steady growth trend in the unit capacity of tractors, working machines and vehicles intended for agriculture.

This direction has so far been associated with the solution of one of the main tasks of the development of agricultural production - optimization of the structure of the repair cycle of machines.

The following data characterize the growth trend in the energy capacity of mobile technical equipment: currently, the average power of agricultural tractors was 43.5 kw.

The capacity of individual tractor models now reaches 169...235 kw, and in the near future we can expect the appearance of ultra–high power samples - 294...334 kw.

However, with the increase in the unit capacity of tractors, combines and vehicles, a contradiction is growing, which is very difficult to resolve within the framework of traditional technological methods still used in agriculture. This is explained by the fact that with the increase in the unit capacity of technical means used in agriculture, their weight and size characteristics increase, and mechanical loads on the soil increase, which now exceed the permissible average by three times.

As a result of excessive compaction of not only arable, but also sub–arable soil layers, difficult-to-eliminate negative environmental consequences arise - air, water and biochemical exchange regimes are disrupted, fertility reserves are significantly reduced, and erosion processes increase. In this regard, the problem of optimizing the structure of the repair cycle of agricultural machinery is acute.

As can be seen from Fig. 1, over the entire life of the production operation of the machine as a whole, the Tm bearing we are considering will be restored repeatedly.

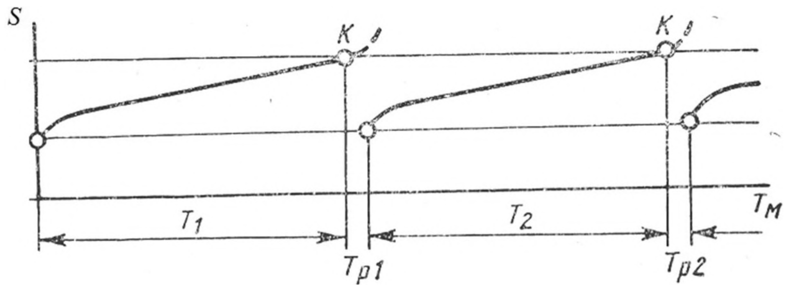

Fig. 1. The general scheme of maintaining the permissible gap in the connection by carrying out routine repairs

In turn, for a machine whose service life of parts is not equal to each other, the order of current repairs can be graphically represented as shown in Fig. 2.

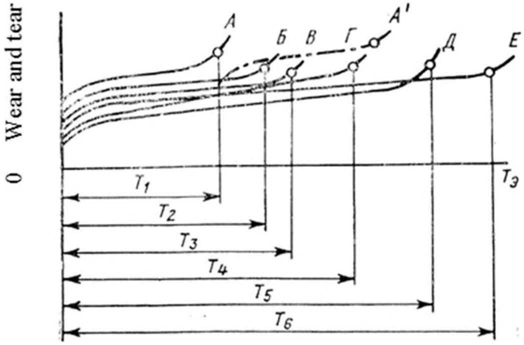

Fig.2. The wear pattern of parts with different wear rates and different service life

The following types of electroplating coatings are widely used in repair practice: chrome plating, cooling, copper plating, nickel plating, galvanizing, cadmium plating. Pressure repair of parts is of great interest for agroengineering practice. This repair method includes the following types of processing: sedimentation, indentation, distribution, compression, extraction, knurling and straightening.

It is used to restore parts that have changed the size of the working surfaces and geometric shape as a result of wear. Repair of parts by refilling antifriction alloys (babbit, lead bronze). This method restores the main and connecting rod bearings of the engines, as well as the bushings of the camshafts.

Repair of parts by electric spark buildup allows you to strengthen parts in order to increase wear resistance and build up worn parts. Repair of parts by machining as a method of repairing parts includes: repair of parts by machining to the repair size; repair by setting additional parts; repair by replacing a part of a part.

With this in mind, for parts whose service lives are formed, but not multiples of each other, according to Fig. 3, the restoration of parts A and B should be carried out through the operating time T1. In turn, for parts B and D, restoration should be carried out through the running time of T2, and parts D and E, respectively, through the running time of T3.

The general scheme allowing to optimize the general structure of the repair cycle of machines is shown in Fig. 4. In this diagram, the operating time of the machine is shown along the abscitz axis, and the maximum resource of the structural element of the machine is shown according to the ordinate [14, 15].

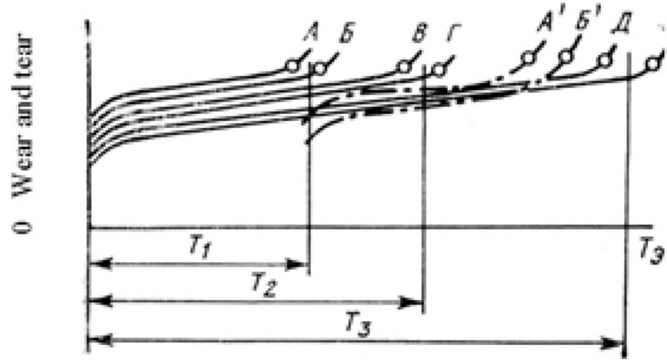

Fig. 3. A diagram of the wear of parts whose service life is formed, but not a multiple of each other

In this figure, for all groups of restored parts, a circle shows in which type of repair (current or capital) it should be placed. At the same time, it is important to note that with the increase in wear of individual structural elements of the machine, the need for one or another type of repair of its parts increases dramatically.

For example, for the case of Tc = 9T0, we will have a 10-period cycle (K = 9), the structure of which is: I I II I I II I I III. It should also be noted that at one time, associate professor of the Kuban State University Karpenko V.D. proposed a 6-period cycle, the structure of which is I II III II I IV, where I and II are the first and second emergency repairs, III current and IV capital [14].

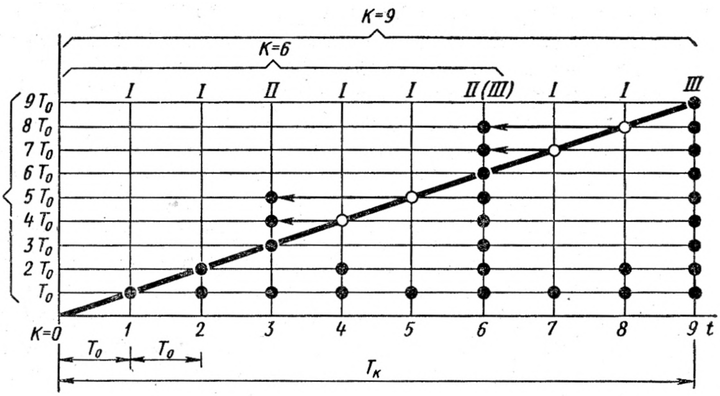

Fig. 4. Optimization of the overall structure of the repair cycle of machines

In particular, for the 10-period maintenance cycle of the MTZ-82 tractor, the following ratio will be used to optimize the repair cycle (Fig. 4):

$$\tau_{IX} = \frac{1}{9T_o}\left[9\tau_1 + 5\tau_2 + 3(\tau_3 + \tau_4 + \tau_5) + 2(\tau_6 + \tau_7 + \tau_8) + \tau_9\right] =$$
$$= \frac{1}{T_o}\left[\tau_1 + 0,555\tau_2 + 0,333(\tau_3 + \tau_4 + \tau_5) + 0,222(\tau_6 + \tau_7 + \tau_8) + 0,122\tau_9\right]. \quad (1)$$

In turn, for a 6-period maintenance cycle of a modern grain harvester «ACROS 595 Plus», you can write down such a mathematical expression that allows you to optimize the repair cycle of this combine:

$$\tau_{IV} = \frac{1}{6T_o}\left[6\tau_1 + 3\tau_2 + 2(\tau_3 + \tau_4 + \tau_5) + \tau_6 + \tau_7 + \tau_8 + \tau_9\right] =$$
$$= \frac{1}{T_o}\left[\tau_1 + 0,5\tau_2 + 0,333(\tau_3 + \tau_4 + \tau_5) + 0,167(\tau_6 + \tau_7 + \tau_8 + \tau_9)\right]. \quad (2)$$

And finally, using expressions (1) and (2), we obtain such a formula that allows us to optimize the repair cycle of a particular machine:

$$a = \frac{0,055}{T_0}(\tau_2 + \tau_6 + \tau_7 + \tau_8 - \tau_9). \quad (3)$$

Conclusion

Thus, it can be concluded that using the expressions obtained, it is possible to optimize the repair cycle of a tractor, combine harvester, car, or other agricultural machine. In particular, for the modern MTZ-82 tractor, a frequency of daily maintenance was planned equal to T_{ob} = 10 motorcycle hours and the following forms of maintenance were performed: TO-1 every 125±10 motorcycle hours, TO-2 after 500±20 hours, TO-3 after 1000±20 motorcycle hours.

These figures show that the optimal structure of the repair cycle presented here is determined by higher requirements for the reliability of modern agricultural machinery.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

ASSESSMENT OF THE GROWTH RATE OF JUVENILE AUSTRALIAN RED-CLAWED CRAYFISH *CHERAX QUADRICARINATUS* (von Martens, 1868)

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Abstract

Background. The study is devoted to the study of the main fish-breeding and biological characteristics (growth rates, survival, etc.) of juvenile Australian red-clawed crayfish *Cherax quadricarinatus* (von Martens, 1868) when kept in different temperature conditions. In the experiment, two temperature zones were compared: 22 °C (suboptimal conditions for commercial cultivation) and 26 °C (optimal conditions). The results showed that at a temperature of 22 °C, there was a higher increase in weight (18.03%) and length (4.19%) compared to suboptimal conditions (5.99% and 4.92%, respectively). The Fulton fatness ratio decreased in both groups. The data obtained is important for commercial aquaculture for the correct development of cultivation biotechnologies.

Purpose. The aim of the work was to study the main fish-breeding, biological and physiological parameters of juvenile *C. quadricarinatus* when they are kept in different temperature conditions.

Materials and methods. The study was conducted on 73-day-old *C. quadricarinatus* individuals (n=40), divided into 2 groups of 20 specimens each. in each. Group No. 1 was kept at a temperature of 22-23°C, group No. 2 – at 26-27°C. The specimens were placed in polypropylene containers with overall dimensions of 74x57x41 cm. Each tank had an individual recycled water filtration system. To reduce cannibalism, PVC pipe shelters were placed in the tank. The duration of the experiment was 28 days.

The main water parameters were monitored daily using specialized equipment and sets of test systems. Feeding was carried out twice a day: frozen chironomid larvae (50%) and young bean fruits (50%) in the amount of 6% of the biomass.

The body weight and length of each individual were measured every 7 days of the experiment. Based on the data obtained, the main fish-breeding and biological indicators (Fulton fatness coefficient, specific growth rate, survival rate) were calculated. Amino acid analysis was performed by capillary electrophoresis after acid/alkaline hydrolysis of muscle tissue. To minimize errors, averaged samples from individuals of different sizes were used.

Results. During the study, the hydrochemical regime corresponded to the optimal values for the content of C. quadricarinatus. The absence of toxic nitrogen compounds, as well as copper ions, made it possible to create the necessary conditions for the experiment. In group No. 1, the water temperature averaged 22.26 °C, and in group No. 2 – 26.96 °C. The concentration of dissolved oxygen (O2) during the experiment averaged 7.52 mg/l and 7.87 mg/l, respectively. As a result of the research, it was found that in group No. 1, the body weight of juveniles increased by 5.99%, length – by 4.92%, while the Fulton fatness coefficient decreased by 8.18%. In group No. 2, weight gain was more pronounced (18.03%), with a moderate increase in length (4.19%) and a smaller decrease in fatness ratio (4.1%). The analysis of the amino acid composition of muscle tissue revealed significant differences between the studied groups. The concentration of arginine in the muscles of juvenile crayfish from group 1 was significantly higher than in group 2. The total concentrations of glutamic acid and glutamine were also higher under suboptimal conditions. These changes most likely indicate metabolic adaptation to stressful conditions, especially at temperatures close to the lower optimal limit of the species. Thus, during the experiment, it was found that the water temperature of 26-27 °C contributes to higher growth rates and survival of juveniles, while 22-23 ° C causes changes in the physiological status of *C. quadricarinatus*.

Conclusion. The study revealed differences in the fish-biological and physiological parameters of *C. quadricarinatus* juveniles kept in different temperature conditions. At an average temperature of 26.96°C, the maximum increase in weight (18.03%) and body length (4.19%) was observed, while at 22.26°C these indicators were significantly lower (5.99% and 4.92%, respectively). Although the survival rate remained high (95-100%) in both cases, a decrease in the fatness coefficient by 8.18% at a lower temperature indicates the stress effect of this factor on the aquatic organisms. Amino acid analysis showed an increased content of arginine (5.315%) and glutamic acid (4.221%) in individuals kept at a temperature of 22-23 ° C, which indicates the activation of compensatory metabolic mechanisms. These data probably indicate the high possible adaptability of the species in question to changing environmental conditions. The results obtained are of great practical importance for the further development of crustacean aquaculture (astaculture) in the climatic conditions of the Russian Federation.

Keywords: aquaculture; *Cherax quadricarinatus*; Australian red-clawed crayfish; biotechnology; growth rates; crustaceans

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Научная статья

ОЦЕНКА ТЕМПОВ РОСТА МОЛОДИ АВСТРАЛИЙСКОГО КРАСНОКЛЕШНЕВОГО РАКА *CHERAX QUADRICARINATUS* (von Martens, 1868)

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Аннотация

Обоснование. Исследование посвящено изучению основных рыбоводно-биологических характеристик (темпы роста, выживаемость и др.) молоди австралийского красноклешневого рака *Cherax quadricarinatus* (von Martens, 1868) при их содержании в разных температурных условиях. В эксперименте сравнивались две температурные зоны содержания: 22 °C (неоптимальные условия для товарного выращивания) и 26 °C (оптимальные условия). Результаты показали, что при температуре 22 °C наблюдался более высокий прирост массы (18,03%) и длины (4,19%) по сравнению с неоптимальными условиями (5,99% и 4,92% соответственно). Коэффициент упитанности по Фультону снизился в обеих группах. Полученные данные имеют значение для товарной аквакультуры для корректной разработки биотехнологий выращивания.

Цель. Целью работы было изучение основных рыбоводно-биологических и физиологических показателей молоди *C. quadricarinatus* при их содержании в разных температурных условиях.

Материалы и методы. Исследование проводилось на 73-суточных особях *C. quadricarinatus* (n=40), разделенных на 2 группы по 20 экз. в каждой. Группа №1 содержалась при температуре 22-23°C, группа №2 – при 26-27°C. Особи размещались в полипропиленовых емкостях с габаритными размерами 74x57x41 см. Каждая емкость имела индивидуальную систему фильтрации оборотной воды. Для снижения каннибализма в емкости были помещены

укрытия из ПВХ-труб. Длительность эксперимента составила 28 суток.

Основные параметры воды контролировались ежедневно с использованием специализированного оборудования и наборов тест-систем. Кормление проводилось дважды в сутки: замороженными личинками хирономид (50%) и молодыми плодами фасоли (50%) в количестве 6% от биомассы.

Каждые 7 суток эксперимента измеряли массу и длину тела у каждой особи. На основании получаемых данных рассчитывали основные рыбоводно-биологические показатели (коэффициент упитанности по Фультону, удельную скорость роста, выживаемость). Аминокислотный анализ проводили методом капиллярного электрофореза после кислотного/щелочного гидролиза мышечной ткани. Для минимизации погрешностей использовали усредненные пробы от особей разного размера.

Результаты. В ходе исследования гидрохимический режим соответствовал оптимальным значениям для содержания *C. quadricarinatus*. Отсутствие токсичных соединений азота, а также ионов меди, позволило создать необходимые условия для проведения эксперимента. В группе №1 температура воды составляла в среднем 22,26 °C, а в группе №2 – 26,96 °C. Концентрация растворённого кислорода (O_2) в ходе эксперимента составляла в среднем 7,52 мг/л и 7,87 мг/л соответственно.

В результате исследований было установлено, что в группе №1 масса тела молоди увеличилась на 5,99%, длина – на 4,92%, тогда как коэффициент упитанности по Фультону снизился на 8,18%. В группе №2 прирост массы был более выраженным (18,03%), при умеренном увеличении длины (4,19%) и меньшем снижении коэффициента упитанности (4,1%).

Анализ аминокислотного состава мышечной ткани выявил значительные различия между исследуемыми группами. Концентрация аргинина в мышцах молоди раков из группы №1 значительно превышала показатели в группе №2. Суммарная концентрация глутаминовой кислоты и глутамина также была выше в неоптимальных условиях. Эти изменения, вероятнее всего, свидетельствуют о метаболической адаптации к стрессовым условиям, особенно при температурах, близких к нижней оптимальной границе вида.

Таким образом, в ходе эксперимента установлено, что температура воды 26-27°C способствуют более высоким темпам роста и выживаемости молоди, в то время как 22-23°C вызывают изменения в физиологическом статусе *C. quadricarinatus*.

Заключение. Проведенное исследование выявило различия в рыбоводно-биологических и физиологических показателях молоди *C. quadricarinatus,* содержащихся в различных температурных условиях. При средней температу-

ре 26,96°С наблюдался максимальный прирост массы (18,03%) и длины тела (4,19%), тогда как при температуре 22,26°С эти показатели были значительно ниже (5,99% и 4,92% соответственно). Хотя выживаемость оставалась высокой (95-100%) в обоих случаях, снижение коэффициента упитанности на 8,18% при более низкой температуре свидетельствует о стрессовом воздействии этого фактора на организм гидробионтов.

Аминокислотный анализ показал повышенное содержание аргинина (5,315%) и глутаминовой кислоты (4,221%) у особей, содержащихся при температуре 22-23°С, что указывает на активацию компенсаторных метаболических механизмов. Эти данные, вероятно, свидетельствуют о высокой возможной адаптивности рассматриваемого вида к изменяющимся условиям среды.

Полученные результаты имеют важное прикладное значение для дальнейшего развития аквакультуры ракообразных (астацикультуры) в климатических условиях Российской Федерации.

Ключевые слова: аквакультура; *Cherax quadricarinatus*; австралийский красноклешневый рак; биотехнология; темпы роста; ракообразные

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Introduction

Australian redclaw crayfish *Cherax quadricarinatus* (von Martens, 1868) is a promising species for aquaculture, characterized by a high growth rate and good survival compared to other cultivated crustaceans (shrimp, crabs). The species in question is a representative of a tropical faunal complex, whose natural habitat is the rivers and streams of Northern Australia [15].

The optimal temperature for keeping *C. quadricarinatus* is considered to be 28 °C [16]. However, in conditions of aquaculture (especially when grown in ponds), crustaceans can experience sudden changes in water temperature, including diurnal changes, which can negatively affect the physiological state of aquatic organisms, the success of cultivation and resistance to infectious and invasive agents [15].

The study of the fish-breeding and biological features of the Australian redclaw crayfish in various temperature conditions is of considerable interest from the point of view of developing sustainable biotechnologies for cultivation in the southern regions of the Russian Federation. The tropical origin of *C. quadricarinatus* necessitates the creation of optimal temperature conditions close to the natural environment to ensure the normal functioning of crustaceans and maximum productivity in aquaculture [12].

In most studies devoted to the development and improvement of *C. quadricarinatus* biotechnology, researchers determine the biological temperature optimum at which aquatic organisms are successfully contained and reproduced. However, for commercial aquaculture conditions, it is important to determine the technological temperature optimum at which commercial cultivation of *C. quadricarinatus* will be characterized by maximum efficiency in terms of heat transfer costs, feeding, etc. [3; 12; 14].

Thus, the study of the growth rates and other fish-breeding, biological and physiological characteristics of *C. quadricarinatus* under different temperature conditions is an important step in the development of technologies for growing this object in aquaculture.

Purpose. The aim of the work was to study the main fish-breeding, biological and physiological parameters of juvenile *C. quadricarinatus* when they are kept in different temperature conditions.

Materials and methods

The work was carried out in the research laboratory "Agrobiotechnology Center" and the laboratory of Industrial aquaculture of the Don State Technical University (DSTU) (Rostov-on-Don). The study was approved by the Local Independent Ethics Committee of DSTU. During the experiments, the recommendations on humane and ethical treatment of laboratory animals were followed, including the Directive 2010/63/EU of the European Parliament and of the Council dated September 22, 2010 "On the Protection of Animals Used for Scientific Purposes".

Clinically healthy individuals of the Australian redclaw crayfish *C. quadricarinatus* aged 73 days were used for the study. A total of 40 specimens were involved in the experiment, which were distributed into two containers of 20 specimens each, based on their average size to form a homogeneous size group. The average individual weight of individuals in group № 1 was 14.70±4.04 g, length – 8.13±0.76 cm. The average weight of experimental individuals in group № 2 was 6.38± 1.19 g, length – 6.20±0.44 cm. Group № 1 was kept at an average temperature of 22-23 °C, group № 2 – 26-27 °C.

The individuals were placed in polypropylene containers with overall dimensions of 74x57x41 cm with a water column height of 25 cm. Each tank was equipped with a combined Aquael Turbo Filter 1000 filter with a capacity of 1000 l/h (Aquael Sp., Poland), which provides mechanical and biological purification of recycled water. The necessary temperature conditions were ensured using Protemp S 50 W thermoregulators (JBL, Germany). Saturation of water with oxygen (O_2) was carried out using a single-channel Aquael Mini boost 100 compressor (Aquael Sp., Poland).

Every 7 days of the experiment, a partial 30 % water change was performed in each tank. Tap water was used for substitution, previously prepared by settling (at least 72 hours) to remove chlorine, as well as disinfection with ultraviolet radiation (wavelength 250 nm) in order to destroy pathogenic microorganisms.

Shelters were placed in each container to reduce cannibalism in the amount of 30 pieces/container. Cylindrical structures made of polyvinyl chloride (PVC) with a diameter of 3 cm and a length of 8 cm were used as shelters.

The 28-day experiment was accompanied by daily monitoring of the main physico-chemical parameters of water: temperature (t, °C) and concentration of dissolved oxygen (O_2, mg/l). The measurements were carried out using an Anion-7040 oximeter (scientific Industrial Enterprise “Infraspak-Analyte”, Russian Federation), which provides measurement accuracy of ±0.1 °C for temperature and ±0.01 mg/l for oxygen. Comprehensive hydrochemical analysis was performed at 7-day intervals using the Nilpa Pro test system (Nilpa, Russian Federation). Water acidity (pH), total water hardness (GH), carbonate hardness (KH), ammonium ions (NH_3/NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), phosphates (PO_4) were measured.

The crayfish’s diet consisted of frozen common beans, which were fed in the morning, and frozen larvae of ringworm mosquitoes (family Chironomidae), which were fed in the evening. The daily feeding rate was 6 % of the total weight of crayfish.

Control measurements (bonitization) were performed on a weekly basis. During the measurements, the individual weight of each individual (m, g) was recorded on a BEL LG-2202i II accuracy class laboratory scale (ChangZhou XingYun Electronic Equipment Co., China), and the total body length (L, mm) was determined using a caliper (measurement error ±0.03 mm).

To assess changes in fish-breeding and biological indicators, the following indicators were calculated:

– Fulton’s fatness coefficient (Q_F, c.u.) according to the formula:

$$\mathrm{QF} = \frac{m * 100}{l^3}$$

– individual weight gain (WGi, g) using the formula:

$$WGi = m_1 - m_0$$

– survival rate (S, %) was estimated using the formula:

$$S = 100 * \frac{N_1}{N_0}$$

– specific growth rate by weight (SGRw, %/day) was estimated in accordance with the formula:

$$SGRw = 100 * \frac{In(m_1) - In(m_0)}{t}$$

– specific growth rate in length (SGRL, %/day) was calculated using the formula:

$$SGRL = 100 * \frac{In(l_1) - In(l_0)}{t}$$

where m – average individual weight, g; m_0 – average individual weight at the beginning of the period, g; m_1 – average individual weight at the end of the period, g; l – total length, cm; l_0 – total length at the beginning of the period, cm; l_1 – total length at the end of the period, cm; N_0 – number of individuals at the beginning of the period, specimens; N_1 – number of individuals at the end of the period, specimens; t – duration of the period, days.

The amino acid composition of muscle tissue was analyzed on the 28th day of the experiment. Muscle tissue was selected from the abdomen and chelipeds from 10 specimens. in each group. The analysis was performed by capillary electrophoresis using the Kapel-105M system (Lumex, Russian Federation) according to the methods of measuring the mass fraction of amino acids [5; 9; 10]. The mass fraction of fat in muscle tissue was determined by the method of a filtering dividing funnel according to GOST 23042-2015 (GOST – Russian State Standard).

Results

During the experiment, the main hydrochemical parameters (temperature, pH, concentration of dissolved oxygen, concentration of nitrogenous compounds) corresponded to the reference values for *C. quadricarinatus* [4; 6; 8]. The average values of observations of water quality parameters are presented in Table 1.

Table 1.

The average values of water quality parameters during the experiment

Indicator	Group № 1	Group № 2
ph, c.u.	8.3±0.27	8.2±0.27
KH, c.u.	10.8±0.84	11.6±1.82

GH, c.u.	49.8±3.90	46.2±7.76
NO_2^-, mg/l	0.9±1.71	1.4±1.66
NO_3^-, mg/l	22.0±32.52	16.0±14.75
NH_3/NH_4^+, mg/l	0.6±0.55	0.4±0.55
PO_4, mg/l	1.4±2.19	2.5±2.40

The average concentration of dissolved oxygen in group № 1 was 7.52 mg/l, while in group № 2 this indicator reached 7.87 mg/l. The water temperature in group № 1 during the experiment averaged 22.26 °C, in group № 2 – 26.96 °C.

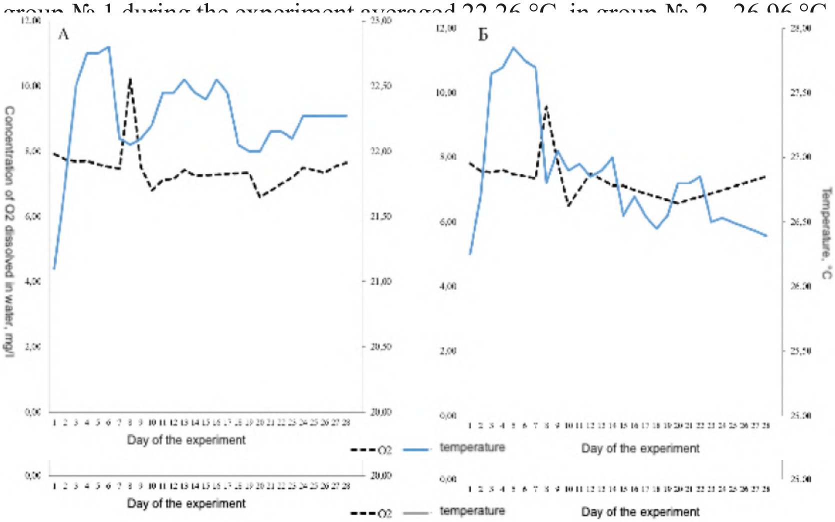

Fig. 1. Dynamics of changes in water temperature (°C) and concentration of oxygen dissolved in water (mg/l) during the experiment:
A) group № 1; B) group № 2.

The results of the study showed that during the 28 days of the experiment in group № 1, *C. quadricarinatus* juveniles increased their body weight by 5.99 % and their length by 4.92 %, while the Fulton's fatness coefficient decreased by 8.18 %.

In group № 2, over the same period, there was a more pronounced weight gain (18.03 %) with a moderate increase in body length (4.19 %) and a smaller decrease in the fatness ratio (4.1 %). The values of fish-biological parameters are presented in Table 2.

A biochemical analysis of the amino acid composition of muscle tissue of juvenile *C. quadricarinatus* revealed differences in the concentrations of a number of proteinogenic amino acids between the experimental groups. The results are presented in Table 3.

Table 2.

Growth rates *of C. quadricarinatus* juveniles when kept in different temperature conditions

Indicator	Group № 1		Group № 2	
	Beginning of the experiment	End of the experiment	Beginning of the experiment	End of the experiment
m ± SD, g	14.70±4.04	15.58±4.23	6.38±1.19	7.53±1.70
l ± SD, cm	8.13±0.76	8.53±0.76	6.20±0.44	6.46±0.63
Q_F, c.u.	2.69±0.26	2.47±0.27	2.68±0.43	2.79±0.42
WGt, g	-	0.88	-	1.15
SGRw, %/day	-	20	-	57.35
WGl, cm	-	4.02	-	23.16
SGRl, %/day	-	16.66	-	0.26
S, %	100	95	100	100

Footnote: Q_F – Fulton's fatness coefficient, WGt – individual weight gain, SGRw – specific growth rate by weight, WGl – individual gain by length, SGRl – specific growth rate in length, S –survival rate.

Table 3.

Amino acid composition of *C. quadricarinatus* muscle tissue under different temperature conditions

Name of the amino acid	Amino acid content, %	
	group № 1	group № 2
незаменимые аминокислоты		
lysine	1.77±0.6	0.86±0.30
phenylalanine	1.83±0.548	0.48±0.14
leucine (isoleucine)	2.27±0.69	1.54±0.4
methionine	0.24±0.08	0.16±0.05
valine	0.69±0.23	0.51±0.2
threonine	0.71±0.98	0.75±0.3
tryptophan	less than 0.01	less than 0.01
interchangeable amino acids		
arginine	5.31±2.126	0.92±0.36
tyrosine	0.44±0.132	0.55±0.166
histidine	less than 0.01	less than 0.01
proline	0.95±0.25	0.55±0.14
serine	0.45±0.11	0.44±0.11
alanine	0.93±0.24	0.75±0.19
glycine	0.61±0.2	0.49±0.16
glutamic acid+glutamine	4.22±1.68	0.72±0.28
aspartic acid	2.64±1.06	0.25±0.1

cystine	less than 0.01	less than 0.01

Among the essential amino acids, the greatest differences between the groups are found for lysine and phenylalanine. So, in group № 2, the lysine content was 51.56 % less than in group № 2, and the phenylalanine content was 73.35 % lower. As for non-essential amino acids, differences in the levels of arginine, glutamic and aspartic acids were revealed, while higher concentrations of these amino acids were observed in individuals from group № 1 who were kept at a reduced water temperature.

The mass fraction of fat in the muscle tissue of individuals from group № 1 was 9.74±0.07 %, from group № 2 – 8.45± 0.05 %.

Conclusion

The results of the study demonstrate differences in the fish-biological and physiological parameters of juvenile *C. quadricarinatus*, when they are kept in different temperature conditions. A comparison of two temperature regimes (26-27 °C and 22-23 °C) showed that a higher temperature promotes accelerated growth of experimental individuals. In the temperature range of 26-27 °C, there was a more pronounced increase in the average individual weight of individuals (+18.03 % of the initial) with a moderate increase in body length (4.19 %). In the temperature range of 22-23 °C, the increase in the individual weight of experimental individuals was 5.99 %, and in length – 4.92 %. The results obtained confirm the limiting value of the temperature factor in commercial cultivation of *C. quadricarinatus*.

The survival rate of juveniles in both cases remained high (95-100 %), which indicates the high adaptability of *C. quadricarinatus* to various environmental conditions. However, a decrease in the Fulton's fatness coefficient by 8.18 % in the temperature range of 22-23 °C indicates a possible stress effect that could affect the energy metabolism in the body of experimental individuals.

Of particular interest are the amino acid analysis data, which revealed differences in metabolic processes between the groups. The crayfish kept at a low temperature had an increased content of arginine and glutamic acid. This may be due to the activation of compensatory mechanisms aimed at maintaining energy balance and synthesis of stress proteins. Such changes are consistent with data from other studies, according to which suboptimal temperatures can cause metabolic restructuring in crustaceans, increasing the need for certain amino acids.

Conflict of interest information. The authors declare that they have no conflict of interest.

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Original article

PROSPECTS FOR THE DEVELOPMENT OF WINE TOURISM AS A KEY DIRECTION OF AGROTOURISM IN THE ROSTOV REGION

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Abstract

Background. The article analyzes the prospects for the development of wine tourism in the Rostov region as a key area of agritourism. The authors consider wine tourism as a dynamically developing sector that combines cultural, gastronomic and natural aspects, which can become an important element of the region's economy. The Rostov region, with its favorable climatic conditions and rich history of viticulture, has significant potential for the development of this area. The article analyzes the current state and prospects for the development of wine tourism, and offers recommendations for its successful implementation. Particular attention is paid to the integration of wine tourism with other types of tourism, such as cultural, ecological and rural tourism. The authors emphasize the need for infrastructure development, active promotion of the region in tourist markets and state support for the successful development of wine tourism. The article also discusses the Don Valley cluster, which combines the natural, cultural and infrastructural resources of the region, making it a promising area for tourism development. Specific activities such as wine festivals, master classes and educational programs are proposed that can help promote the region as a wine-making center.

Purpose. The purpose of this article is to analyse the prospects for the development of wine tourism in the Rostov region as one of the key areas of agritourism. The authors consider wine tourism as a dynamically developing industry combining cultural, gastronomic and natural aspects, which can become an important element of the region's economy.

Materials and methods. Currently, such a direction as agrotourism is becoming increasingly popular, an important component of which is wine tourism, which contributes to the development and promotion of products of small and medium-sized

agricultural enterprises. In this regard, there is a tendency to organize narrowly focused wine tourist routes, including visits to vineyards and tastings of the products produced there.

Agricultural tourism has several directions in determining its meaning. Thus, N. A. Mironova, 2020 and M. V. Muravyeva, 2016 consider the legal aspects of the Russian Federation in relation to agricultural tourism, which reveal the type of tourism under study as an activity that is directly aimed at improving social conditions, increasing the economic efficiency of a particular rural area and creating a competitive environment in the tourism market through the participation of tourists in agricultural processes. They emphasize that agritourism allows tourists not only to relax in the natural environment, but also to take part in agricultural work, which makes it attractive for those who seek an authentic experience.

Results. The development of wine tourism in the Rostov region demonstrates significant potential, but requires a systematic approach and consideration of current trends. The analysis conducted allowed us to identify key aspects that can contribute to the successful implementation of this direction.

Rostov Region has unique natural conditions for viticulture. The region's climate, which combines moderate continentality and a sufficient number of sunny days, creates favorable conditions for growing industrial grape varieties. According to the Russian Ministry of Agriculture, in 2022, the area of vineyards in the region amounted to 1,850 hectares, which is 15% more than in 2020. This indicates a growing interest in winemaking in the region.

The infrastructure of wine-making enterprises is actively developing in the region. Today, there are more than 20 wineries in the region, including large enterprises such as Tsimlyanskie Viny and Elbuzd. These enterprises not only produce wine, but also offer excursions, tastings and master classes, which forms the basis for wine tourism.

Another important aspect is the growing interest in domestic tourism in Russia. Currently, there is a reorientation towards domestic tourism. This creates favorable conditions for the development of wine tourism in the Rostov region, which can offer unique tourist products.

Conclusion. The conducted research allows us to draw a number of conclusions. Rostov Region has favorable natural conditions for viticulture and a rich history of winemaking, which creates a solid foundation for the development of wine tourism. There are already more than 20 wineries in the region offering excursions, tastings and master classes, which forms the basis for further development of this area.

The Don Valley cluster has significant potential for tourism development. The combination of natural, cultural and infrastructure resources makes the cluster a

promising direction for tourism development in the Rostov Region. Its unique natural conditions, rich cultural and historical heritage and developed transport network create favorable conditions for attracting tourists.

Keywords: wine tourism; agrotourism; Rostov region; development prospects; events

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Научная статья

ПЕРСПЕКТИВЫ РАЗВИТИЯ ВИННОГО ТУРИЗМА КАК КЛЮЧЕВОГО НАПРАВЛЕНИЯ АГРОТУРИЗМА В РОСТОВСКОЙ ОБЛАСТИ

Л.Н. Казьмина, В.В. Провоторина,
В.С. Макаренко, А.В. Мирошниченко

Аннотация

Обоснование. В статье анализируются перспективы развития винного туризма в Ростовской области как одного из ключевых направлений агротуризма. Авторы рассматривают винный туризм как динамично развивающуюся отрасль, сочетающую культурные, гастрономические и природные аспекты, которая может стать важным элементом экономики региона. Ростовская область с ее благоприятными климатическими условиями и богатой историей виноградарства обладает значительным потенциалом для развития данного направления. В статье анализируется современное состояние и перспективы развития винного туризма, а также предлагаются рекомендации для его успешной реализации. Особое внимание уделяется интеграции винного туризма с другими видами туризма, такими как культурный, экологический и сельский. Авторы подчеркивают необходимость развития инфраструктуры, активного продвижения региона на туристических рынках и государственной поддержки для успешного развития винного туризма. В статье также рассматривается кластер «Долина Дона», который объединяет природные, культурные и инфраструктурные ресурсы региона, что делает его перспективной зоной для развития туризма. Предлагаются конкретные мероприятия, такие как винные

фестивали, мастер-классы и образовательные программы, которые могут способствовать продвижению региона как центра виноделия.

Цель. Целью данной статьи является анализ перспектив развития винного туризма в Ростовской области как одного из ключевых направлений агротуризма. Авторы рассматривают винный туризм как динамично развивающуюся отрасль, сочетающую культурные, гастрономические и природные аспекты, которая может стать важным элементом экономики региона.

Материалы и методы. В настоящее время все большую популярность приобретает такое направление, как агротуризм, важной составляющей которого является винный туризм, способствующий развитию и продвижению продукции малых и средних сельскохозяйственных предприятий. В связи с этим наблюдается тенденция к организации узконаправленных винных туристических маршрутов, включающих посещение виноградников и дегустацию производимой там продукции.

Сельскохозяйственный туризм имеет несколько направлений в определении своего значения. Так, Н. А. Миронова, 2020 [1] и М.В. Муравьева, 2016 [2] рассматривают правовые аспекты Российской Федерации в отношении сельскохозяйственного туризма, которые раскрывают исследуемый вид туризма как деятельность, непосредственно направленную на улучшение социальных условий, повышение экономической эффективности конкретной сельской территории и создание конкурентной среды на туристском рынке посредством участия туристов в сельскохозяйственных процессах. Они подчеркивают, что агротуризм позволяет туристам не только отдыхать в природной среде, но и принимать участие в сельскохозяйственных работах, что делает его привлекательным для тех, кто ищет аутентичные впечатления.

Результаты. Развитие винного туризма в Ростовской области демонстрирует значительный потенциал, но требует системного подхода и учета современных тенденций. Проведенный анализ позволил выделить ключевые аспекты, которые могут способствовать успешной реализации данного направления.

Ростовская область обладает уникальными природными условиями для виноградарства. Климат региона, сочетающий умеренную континентальность и достаточное количество солнечных дней, создает благоприятные условия для выращивания промышленных сортов винограда. По данным Министерства сельского хозяйства РФ, в 2022 году площадь виноградников в регионе составит 1 850 га, что на 15 % больше, чем в 2020 году. Это говорит о растущем интересе к виноделию в регионе.

В регионе активно развивается инфраструктура винодельческих предприятий. Сегодня в регионе насчитывается более 20 винодельческих предприятий,

в том числе такие крупные, как «Цимлянские вина» и «Эльбузд». Эти предприятия не только производят вино, но и проводят экскурсии, дегустации и мастер-классы, что является основой винного туризма.

Еще один важный аспект – растущий интерес к внутреннему туризму в России. В настоящее время происходит переориентация на внутренний туризм. Это создает благоприятные условия для развития винного туризма в Ростовской области, которая может предложить уникальные туристические продукты.

Заключение. Проведенное исследование позволяет сделать ряд выводов. Ростовская область обладает благоприятными природными условиями для виноградарства и богатой историей виноделия, что создает прочную основу для развития винного туризма. В регионе уже более 20 виноделен предлагают экскурсии, дегустации и мастер-классы, что создает основу для дальнейшего развития этого направления.

Кластер «Долина Дона» обладает значительным потенциалом для развития туризма. Сочетание природных, культурных и инфраструктурных ресурсов делает кластер перспективным направлением для развития туризма в Ростовской области. Уникальные природные условия, богатое культурно-историческое наследие и развитая транспортная сеть создают благоприятные условия для привлечения туристов.

Ключевые слова: винный туризм; агротуризм; Ростовская область; перспективы развития; события

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Introduction

Wine tourism, as one of the most dynamically developing areas of agrotourism, is becoming increasingly popular in the world. This type of tourism combines cultural, gastronomic and natural aspects, offering tourists a unique experience of getting to know the winemaking traditions of the region. Rostov District, with its favorable climate conditions and rich history of viticulture, has significant potential for the development of this area.

Historically, winemaking in the Don has deep roots, dating back to the times of the ancient Greeks and developing in the era of the Don Cossacks. Today, the Rostov Region is one of the key wine regions of Russia, where wines with protected geographical indication are produced. This creates a solid foundation for the development of wine tourism, which can become an important element of the region's economy.

Agritourism, of which wine tourism is a part, is a promising direction for rural areas. It contributes to the diversification of the economy, the creation of new jobs and the development of infrastructure. For the Rostov Region, where a significant part of the population lives in rural areas, the development of wine tourism can become a tool for solving socio-economic problems.

Wine tourism also helps popularize the region's cultural heritage. Visiting wineries, participating in tastings, learning about the traditions of viticulture and winemaking - all this forms a deep understanding of the uniqueness of the territory in tourists. Rostov Oblast, with its rich history and culture of the Don Cossacks, can offer tourists not only high-quality wines, but also an authentic cultural experience.

However, the development of wine tourism in the region faces a number of constraints. Among them are the lack of specialized infrastructure, the need to improve the quality of services and promote the region in the domestic and international tourism markets. Solving these problems requires a comprehensive approach, including interaction between the state, business and local communities.

The purpose of this article is to analyze the prospects for the development of wine tourism in the Rostov region as a key direction of agrotourism. The work analyzes the current state and development prospects, and also offers recommendations for the successful implementation of this direction in the region.

The main objectives of the study:

– to analyze the scientific research base of the issue of wine tourism development in the regions;

– to consider the territory of the Rostov region from the standpoint of wine tourism development;

– to identify promising regions for wine tourism and provide recommendations for its implementation.

Purpose. The purpose of this article is to analyse the prospects for the development of wine tourism in the Rostov region as one of the key areas of agritourism. The authors consider wine tourism as a dynamically developing industry combining cultural, gastronomic and natural aspects, which can become an important element of the region's economy.

Materials and methods

Currently, such a direction as agrotourism is becoming increasingly popular, an important component of which is wine tourism, which contributes to the development and promotion of products of small and medium-sized agricultural enterprises. In this regard, there is a tendency to organize narrowly focused wine tourist routes, including visits to vineyards and tastings of the products produced there.

Agricultural tourism has several directions in determining its meaning. Thus, N. A. Mironova, 2020 [1] and M. V. Muravyeva, 2016 [2] consider the legal aspects of the Russian Federation in relation to agricultural tourism, which reveal the type of tourism under study as an activity that is directly aimed at improving social conditions, increasing the economic efficiency of a particular rural area and creating a competitive environment in the tourism market through the participation of tourists in agricultural processes. They emphasize that agritourism allows tourists not only to relax in the natural environment, but also to take part in agricultural work, which makes it attractive for those who seek an authentic experience.

Other researchers, A. G. Sarafanova, N. V. Shabalina, A. A. Sarafanov, R. V. Mikhailova, V. G. Semenov, A. S. Tikhonov, A. E. Makushev, K. V. Fadeeva, O. N. Fedorova, M. A. Pronin, M. I. Ivleva, A. S. Kornilova, 2020, 2022 [3; 4] consider agrotourism as a component of rural tourism, which involves living in rural areas and getting acquainted with the traditions and culture of the population. At the same time, many authors, such as M. Rakhimberdinova, E. Nurekenova, M. Ordabayeva, M. Konyrbekov, Yu. Saifullina, N. Kuttybaeva, 2022 [5] note that an important component of agrotourism is the agro-industrial complex, which includes different sectors of the economy. In their studies, they draw attention to the fact that the development of the agro-industrial complex plays a key role in the creation of agrotourism zones, contributing not only to economic growth, but also to the sustainable development of rural areas. V. G. Zakshevsky, O. G. Charykova, I. N. Merenkova, 2018 [6] highlight the strategic priorities for the development of the agro-industrial complex and rural areas, which include infrastructure development, support for small and medium-sized businesses, as well as the introduction of innovative technologies in agriculture and the creation of favorable conditions for the growth of tourist activity. N. Kovshun, A. Kliuchnyk, S. Tymchuk, O. Orlenko, O. Soloviova, K. Horiunova, 2023 [7] in their work indicate that agrotourism not only contributes to an increase in the income of rural residents, but also helps to preserve cultural heritage and traditions.

Thus, the integration of tourism and the agro-industrial complex allows creating additional sources of income for local residents, promotes infrastructure development and increases employment. In addition, the study by N.V. Ovchinnikova, I.G. Generalov, A.E. Shamina, 2024 [8] emphasizes that agritourism helps popularize local products, which in turn stimulates the development of small and medium businesses in rural areas. The directions and specializations of production are studied in the works of N.A. Shelamova, 2021 [9]. These include such enterprises as the wineries of V.A. Semiglazov, 2019 [10]. It is worth noting that many authors, such as T. Koblianidze, N. Sachaleli and K.H. Mandabach, 2022 [11; 12], note that wine tourism is an important element of agritourism, bringing benefits to public and private structures, which is very important for regional development, especially for developing areas where unemployment, especially in rural areas, is still a huge problem. In the study of J.M. Crick, D. Crick, N. Tebbett, 2020 [13], devoted to wineries located in rural clusters, special attention is paid to strategies for creating added value. These strategies are also of considerable interest for interdisciplinary research, including areas such as economic geography, tourism and marketing.

The foreign experience described in the studies of M. Ingrassia, L. Altamore, C. Bellia, G.L. Grasso, P. Silva, S. Bacarella, P. Columba, S. Chironi, Germinario, D. G., Drejerska, N., Fiore, M., 2022 [14;15] defines wine routes as roads surrounded by natural, cultural and environmental heritage in wine regions. A distinctive feature is that tourists can independently visit wineries, taste and buy wine. At the same time, visitors can communicate with the local population, get acquainted with typical dishes and traditions, learn about the local culture, architectural, natural and landscape beauties. Thus, as a result, visitors gain access to other services that complement the wine itself. As a result, these territories themselves represent a “specialized tourist offer”. Also, US scientists S. D. Deng, B. Marlowe, R. J. Harrington, 2022 [16]. in their works analyze the phenomenon of “gentrification”, or the improvement of rural areas under the influence of wine tourism. However, the authors also point out possible negative consequences, such as rising real estate prices and displacement of local residents, which requires proper management and rational planning in this area.

For the sake of completeness of the study, research on wine tourism and winemaking in Russia was also studied and analyzed. Thus, it was revealed that enogastronomic tourism is widespread mainly in the south of the country, which is primarily due to favorable climatic and natural conditions for growing vineyards, I. K. Nagornykh, A. V. Kuzmin, N. V. Alesina, L. M. Romanova, N. K. Serdyukova, S. D. Serdyukov, 2021 [17; 18; 19]. In addition, in the works of I.F. Zhukovskaya, A.Yu. Ovchinnikov, 2022 [20] it is indicated that 1/3 of wineries operating in the Russian Federation do not accept tourists.

As for the development of tourism specifically in the Don region, the works of R. I. Sukhov, L. Kazmina, V. Makarenko, V. Provotorina, E. Shevchenko, 2021 [21; 22; 23] were studied for its analysis. The presented studies analyzed the key aspects influencing the development of the tourism industry, assessed its tourism and recreational opportunities, and substantiated the importance of creating an effective tourism business model that takes into account the unique features of the territory.

The research methodology is based on the application of the following methods:

- comparative analysis, used in comparing the development of wine tourism in the districts of the Rostov region;
- statistical analysis, consisting in identifying and subsequently analyzing the patterns of distribution of tourist resources,
- descriptive, used in characterizing modern trends in the development of wine tourism in rural areas;
- prospective, used in identifying the prospects for the development of wine tourism in the Rostov region.

Results

The development of wine tourism in the Rostov region demonstrates significant potential, but requires a systematic approach and consideration of current trends. The analysis conducted allowed us to identify key aspects that can contribute to the successful implementation of this direction.

Rostov Region has unique natural conditions for viticulture. The region's climate, which combines moderate continentality and a sufficient number of sunny days, creates favorable conditions for growing industrial grape varieties. According to the Russian Ministry of Agriculture, in 2022, the area of vineyards in the region amounted to 1,850 hectares, which is 15% more than in 2020. This indicates a growing interest in winemaking in the region.

The infrastructure of wine-making enterprises is actively developing in the region. Today, there are more than 20 wineries in the region, including large enterprises such as Tsimlyanskie Viny and Elbuzd. These enterprises not only produce wine, but also offer excursions, tastings and master classes, which forms the basis for wine tourism.

Another important aspect is the growing interest in domestic tourism in Russia. Currently, there is a reorientation towards domestic tourism. This creates favorable conditions for the development of wine tourism in the Rostov region, which can offer unique tourist products.

It is also worth noting the potential for integrating wine tourism with other areas of agrotourism. For example, combining wine tours with visits to Cossack farmsteads, ethnographic museums and natural attractions can significantly increase the attractiveness of the region. An important issue is the need to develop infrastructure. Despite the presence of wineries, many of them do not have a sufficient number of hotels, restaurants and transport accessibility.

Let us highlight the educational potential of wine tourism. Wineries can become venues for master classes, lectures and seminars on viticulture and winemaking. This will not only attract tourists, but also increase the level of knowledge of the local population. At the same time, it is necessary to promote the region in the tourist market. Rostov Region is not yet well known as a center of wine tourism. This requires an active marketing strategy, including participation in international exhibitions and festivals.

Wine tourism development should take into account environmental risks, such as the impact on natural resources and waste disposal. Note the socio-economic effect. Wine tourism development can create up to 1,000 new jobs in the region by 2025. This is especially important for rural areas, where unemployment remains high.

The Don Valley cluster has been created in the region, which is a promising association of natural, cultural and infrastructural resources aimed at developing tourism in the Rostov region. From a scientific point of view, the analysis of this cluster allows us to identify its potential, problems and development prospects. Let us consider the key aspects.

Geographical location and natural resources The Don Valley is located in the central and southern parts of the Rostov Region, along the Don River, which is a key natural site in the region. This provides the following advantages: natural diversity: the Don River, its tributaries, floodplain meadows, steppe landscapes and forests create unique conditions for the development of ecotourism, climatic conditions: a moderate continental climate with warm summers and mild winters contributes to a long tourist season, biodiversity: the presence of rare species of flora and fauna (for example, Don herring, steppe plants) makes the territory attractive for scientific and ecotourism.

Cultural and historical heritage. The Don Valley cluster has a rich cultural potential, which is confirmed by the following facts: Cossack heritage: the territory is historically associated with the Don Cossacks, which creates the basis for ethnographic tourism. Objects such as the village of Starocherkasskaya (the former capital of the Don Cossacks) attract tourists, archaeological sites: the ancient city of Tanais, located in the Don delta, is an important cultural heritage site, religious sites: monasteries and temples (for example, the Holy Don Starocherkassky Monastery) attract pilgrims and history buffs.

Infrastructure and transport accessibility. In terms of infrastructure, the Don Valley cluster has both strengths and limitations: transport accessibility: a developed network of roads (including the M-4 “Don” highway) and rail links provide convenient access to key cluster facilities. Accommodation: the cluster includes hotels, recreation centers, guest houses and campsites, but their quantity and quality vary depending on the location. Food facilities: restaurants and cafes serving Don cuisine (ukha, crayfish, pies) are an important element of the tourist infrastructure.

Economic potential. From an economic point of view, the Don Valley cluster has significant potential. Tourism development contributes to employment in the service sector, hotel business and agriculture. Also, the tourism cluster can become attractive to investors, especially in the field of infrastructure and agrotourism.

The study analyzed some wine tourism sites in the Rostov region, as well as the tourist and excursion activities implemented there. The results of the analysis are presented in Table 1.

Table 1.

Some objects of wine tourism development in the Rostov region

N	Object	Location	Tourist and excursion services	Specifics
1	Winery «Tsimlyanskie Viny»	Tsimlyansky district	Tours of the winery, wine tastings, master classes in winemaking	Production of sparkling wines using traditional technologies, historical cellars
2	Winery «Usadba «Sarkel»	Tsimlyansky district	Tours of the winery, wine tastings, master classes in winemaking	Family winery, emphasis on authentic Don grape varieties
3	Winery «Chateau Elbuzd»	Azov district	Excursions, tastings, gastronomic tours	Modern equipment, production of organic wines
4	Winery «Vedernikov»	Ust-Donetsk district	Excursions, tastings, master classes, Cossack traditions	Complex with a picturesque view of the Don valley, a combination of wine and cultural tourism
5	Wine House «Arpachin»	Myasnikovsky District	Excursions, tastings, gastronomic tours	Wine production using modern technologies, ethnographic programs
6	Winery «Villa Zvezda»	Martynovsky district	Excursions, tastings, gastronomic tours	Wine production in an ecologically clean steppe zone

Table 1 shows that wine tourism sites are located in different districts of the Rostov Region. Tsimlyansky District: Tsimlyanskie Vina and Usadba Sarkel Wineries. This is the historical center of winemaking in the region, famous for its sparkling wine production. Azov District: Chateau Elbuzd Winery. A district with developed infrastructure and proximity to the Sea of Azov. Ust-Donetsk District: Vedernikov Winery. A district with picturesque views of the Don Valley, which makes it attractive to tourists. Myasnikovsky District: Arpachin Wine House. A district with rich ethnographic traditions, which adds cultural value to the tourist product. Martynovsky District: Villa Zvezda Winery. A district with ecologically clean steppe zones, which emphasizes the environmental focus of tourism. The geographical distribution of wine tourism sites covers both historical and natural landscape zones, which contributes to the diversity of tourist offers.

All facilities offer a standard set of services, including winery tours: an introduction to the wine production process, wine tastings: the opportunity to try different types of wine, winemaking master classes: participation in wine production processes. Some facilities, such as Vedernikov and Arpachin, complement their services with ethnographic programs and gastronomic tours, which increases their attractiveness to tourists. The presence of standard and additional services allows facilities to differentiate themselves in the market and attract different categories of tourists.

Thus, the results of the study confirm that wine tourism has significant potential for development in the Rostov region. However, its successful implementation requires a comprehensive approach, including infrastructure development, marketing activity and government support.

Discussion

The development of wine tourism in the Rostov region requires a comprehensive approach that takes into account the natural, cultural and economic characteristics of the region. Below are key areas that can contribute to the successful development of this sector.

It is important to further create wine routes, in particular, to unite wineries into single routes with the inclusion of cultural and natural attractions. At the same time, it is important to promote such routes, including through event-based activities. In particular, wine and gastronomic festivals are possible: organizing annual events such as “Donskaya Ukha with Wine” or “Festival of Young Wine”, restaurants and cafes with local cuisine: creating gastronomic points where tourists can try Don cuisine dishes in combination with local wines, culinary master classes: holding culinary master classes using local products and wines.

The proposed event activities are reflected in Table 2.

Table 2.

Proposed wine tourism events in the Rostov region

№	Event	Location	Contents
1	Festival of young wine	Myasnikovsky district	A festival dedicated to the presentation of young wines of the new harvest.
2	Don fish soup with wine	Rostov-on-Don	Gastronomic festival combining wine tasting and Don cuisine.
3	Cossack Wine Festival	Azov District	An event dedicated to Cossack traditions with wine tasting and folk festivities.
4	Sparkling Wine Festival	Tsimlyansky District	A festival dedicated to sparkling wines, with master classes on their production.
5	Wine quest	Ust-Donetsk	Interactive game with visiting wineries and solving problems related to winemaking.
6	Winemaking Master Classes	Various areas of the region	Educational events where tourists can learn about the wine production process.

The proposed events may become an important element in the development of wine tourism in the Rostov Region. They will not only attract tourists, but also strengthen the region's image as a center of winemaking and cultural heritage. For the successful implementation of these events, it is necessary to coordinate the efforts of wineries, tourism organizations and local authorities.

It is expected that wine tourism will be included in educational programs. In particular, wine schools are possible: organizing courses and master classes on winemaking for tourists and local residents, excursions with an educational focus: conducting excursions where tourists can learn about the history of winemaking, production technologies and grape varieties, as well as cooperation with universities: attracting students and scientists for research in the field of viticulture and winemaking.

Cultural and historical integration is also necessary, in particular, the inclusion of elements of Cossack culture in tourist programs, such as Cossack songs, dances and traditional rituals, combining wine tourism with visits to historical monuments such as Tanais or the village of Starocherkasskaya, holding festivals and events dedicated to the culture of the Don Cossacks.

It is important to combine wine tourism with other types of tourism, as well as event activities. It is possible to hold such events as harvest festivals, festivals dedicated to grape varieties, such as “Krasnostop Zolotovsky”, “Varyushkin”, “Kosorotovsky”, cultivated on the Don in the first half of the 19th century. At the same time, it is supposed to be rational to hold master classes on the traditional culture of drinking wine of local residents, which will become a “growth point” of interest in the Don culture and traditions.

The development of wine tourism in the Rostov Region has significant potential, which can be realized through the integration of the region’s natural, cultural and economic resources. Successful development of this area will require joint efforts of the state, business and local communities, as well as active promotion of the region at the Russian and international levels.

Conclusion

The conducted research allows us to draw a number of conclusions. Rostov Region has favorable natural conditions for viticulture and a rich history of winemaking, which creates a solid foundation for the development of wine tourism. There are already more than 20 wineries in the region offering excursions, tastings and master classes, which forms the basis for further development of this area.

The Don Valley cluster has significant potential for tourism development. The combination of natural, cultural and infrastructure resources makes the cluster a promising direction for tourism development in the Rostov Region. Its unique natural conditions, rich cultural and historical heritage and developed transport network create favorable conditions for attracting tourists.

Wine tourism can be successfully integrated with cultural, ecological and rural tourism. For example, combining wine tours with visits to Cossack farmsteads, ethnographic museums and natural attractions can significantly increase the attractiveness of the region for tourists.

Conducting master classes, lectures and seminars on viticulture and winemaking, as well as organizing wine festivals (for example, the “Young Wine Festival” or “Donskaya Ukha with Wine”) can attract tourists and increase the level of knowledge of the local population. These events also contribute to the popularization of the region as a center of winemaking.

For the successful development of wine tourism, active state support is necessary, including subsidies, tax breaks and participation in international exhibitions. In addition, it is important to develop a marketing strategy aimed at promoting the region as a center of wine tourism at the Russian and international levels.

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Научная статья

ОЦЕНКА РЫБОВОДНЫХ ПАРАМЕТРОВ СЕГОЛЕТКОВ ГИБРИДА F1 *ACIPENSER GUELDENSTAEDTII* BRANDT, 1833 X *ACIPENSER BAERII* BRANDT, 1869 ПРИ КРАТКОВРЕМЕННОМ ВВЕДЕНИИ В РАЦИОН ПРОБИОТИКОВ РАЗНОГО СПЕКТРА ДЕЙСТВИЯ

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Аннотация

Обоснование. В условиях глобального дефицита доступных животных белков актуальной задачей становится разработка эффективных стратегий, направленных на минимизацию негативных последствий интенсификации производства и оптимизацию экономических показателей в аквакультуре. Одним из перспективных направлений в данном контексте выступает применение пробиотических добавок, демонстрирующих значительный потенциал для повышения продуктивности при выращивании гидробионтов.

Цель исследования заключалась в оценке рыбоводных параметров сеголетков гибрида F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 при кратковременном введении в рацион пробиотиков ферментативного и антимикробного спектра действия.

Материалы и методы. Исследовательские работы осуществлялись в условиях комплексного рыбоводного предприятия в Волгоградской области. Материалом послужили 900 экз. сеголетков F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 (РоЛо) в возрасте 53 суток, которые были распределены на 3 группы (контроль, опыт № 1, опыт № 2). Рацион животных составляли корма с содержанием сырого протеина 56,0±1,5%. Опытные группы рыб дополнительно в составе рациона получали пробиотические добавки: опыт № 1 – мультиштаммовый пробиотик с антимикробным спектром действия (штаммы *Bacillus velezensis* MT55, *B. velezensis* MT155), опыт № 2 – мультиштаммовый пробиотик с ферментативным спектром действия (штаммы *B. velezensis* MT14, *B. velezensis* MT42). В комбикормах обеих опытных групп содержалось 0,1% пробиотического порошка. Эксперимент проводили в течение 10 суток. Для оценки рыбоводных критериев в начале и конце эксперимента проводили измерения морфометрических характеристик рыб. Значимость различий полученных величин определяли с применением теста ANOVA. Отличия между группами считали достоверными при р <0,05.

Результаты. В ходе 10 суток наблюдений установлено положительное влияние ферментативного пробиотика (штаммы бактерий *B. velezensis* MT14, *B. velezensis* MT42) на темпы роста гибрида F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869: средняя индивидуальная масса особей, получавшей в рационе ферментативный пробиотик, была на 36,89% выше по сравнению с контрольной группой (p>0,05). Прирост общей биомассы в этой группе оказался на был на 56,95% выше, чем в контроле. Значения удельного темпы роста в этой группе рыб были также выше по сравнению с контролем и опытной группой №1.

Заключение. Полученные данные подтверждают перспективность применения пробиотиков, особенно ферментативного спектра действия, для интенсификации аквакультуры осетровых, улучшения их роста и снижения затрат на корма. Исследование подчеркивает важность дальнейших разработок в области специализированных пробиотических добавок для повышения эффективности рыбоводства.

Ключевые слова: пробиотик; *Bacillus*; аквакультура; кормление; *Acipenser gueldenstaedtii*; *Acipenser baerii*; темпы роста

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Original article

EVALUATION OF FISH-BREEDING PARAMETERS OF YEARLINGS OF THE F1 HYBRID *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 WITH SHORT-TERM INTRODUCTION OF PROBIOTICS OF DIFFERENT ACTION SPECTRUM INTO THE DIET

D.V. Rudoy, A.A. Korchunov, A.V. Olshevskaya, V.N. Shevchenko, A.V. Startsev, T.A. Maltseva, M.S. Mazanko

Abstract

Background. Under the conditions of the global shortage of accessible animal proteins, the task to develop the effective strategy aimed at the minimizing negative consequences of the production intensification and optimization of economic indicators in aquaculture becomes urgent. One of the most promising directions in this regard is the use of probiotic additives demonstrating substantial potential for increasing productivity in the farming of aquatic organisms.

Purpose. The aim of the present study was to evaluate the fish farming parameters of fingerlings of the F1 hybrid *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 with short-term administration of probiotics of enzymatic and antimicrobial spectrum of action into the diet.

Materials and methods. The research work was carried out in the conditions of an integrated fish farming enterprise in the Volgograd region. The material was 900 specimen of fingerlings F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 (RoLo) at the age of 53 days, which were divided into 3 groups (control, experiment No. 1, experiment No. 2). Fish' diet consisted of feed with a crude protein content of 56.0±1.5%. The experimental groups of fish additionally received probiotic supplements as part of their diet: experiment No. 1 – a multi-strain probiotic with an antimicrobial spectrum of action (strains *Bacillus velezensis* MT55, *B. velezensis* MT155), experiment No. 2 – a multi-strain probiotic with an enzymatic spectrum of action (strains *B. velezensis* MT14, *B. velezensis* MT42). The compound feeds of both experimental groups contained 0.1% probiotic powder. The experiment was carried out for 10 days. To assess the fish farming criteria, morphometric characteristics of fish were measured at the beginning and end of the experiment. The significance of the differences in the obtained values was determined using the ANOVA test. The differences between the groups were considered significant at $p < 0.05$.

Results. During 10 days of observations, a positive effect of an enzymatic probiotic (bacterial strains *B. velezensis* MT14, *B. velezensis* MT42) on the growth rate of the F1 hybrid *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 was established: the average individual weight of individuals receiving an enzymatic probiotic in the diet was 36.89% higher compared with the control group ($p > 0.05$). The increase in total biomass in this group was 56.95% higher than in the control group. The values of the specific growth rate in this group of fish were also higher compared to the control and experimental group No. 1.

Conclusion. The data obtained confirm the prospects of using probiotics, especially the enzymatic spectrum of action, to intensify sturgeon aquaculture, improve their growth and reduce feed costs. The study highlights the importance of further developments in the field of specialized probiotic supplements to improve the efficiency of fish farming.

Keywords: probiotic; *Bacillus*; aquaculture; feeding; *Acipenser gueldenstaedtii*; *Acipenser baerii*; growth rates

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Введение

Аквакультура сегодня – динамично развивающаяся отрасль сельского хозяйства, имеющая богатую историю своего становления. Представители семейства осетровых Acipenseridae Bonaparte, 1831 занимают особо место в рыбоводстве. Антропогенное преобразование водных экосистем, а также незаконный, несообщаемый и нерегулируемый промысел (ННН-промысел) привели к критическому снижению запасов осетровых во многих бассейнах, в том числе и в Азовском море. Успешное развитие аквакультуры осетровых – возможность восстановления и сохранения генофонда этих рыб [1].

Перспективным способом повышения эффективности выращивания молоди осетровых является введение в рацион пробиотических добавок. Одно из многочисленных преимуществ использования пробиотиков заключается в подавлении развития патогенных и условно-патогенных бактерий [2], что делает их перспективной заменой антибиотикам [3-5].

Согласно определению Продовольственной и сельскохозяйственной организации (ФАО) и Всемирной организации здравоохранения (ВОЗ), пробиотики – это живые микроорганизмы, которые используются перорально, принося некоторую ощутимую пользу для здоровья хозяина [6].

Для пробиотиков, применяемых непосредственно в аквакультуре, определение термина было уточнено: «пробиотический организм можно рассматривать как живой, мертвый или компонент микробной клетки, который вводится через корм или в воду для выращивания, принося пользу хозяину за счет улучшения устойчивости к болезням, состояния здоровья, показателей роста, использования корма, реакции на стресс или общей энергии, что достигается, по крайней мере, частично за счет улучшения микробного баланса хозяина или микробного баланса окружающей среды» [7]. В качестве пробиотиков могут быть использованы бактерии, бактериофаги, микроводоросли, дрожжи, которые добавляют в корм гидробионтов, либо вводят непосредственно в воду [8].

В современной аквакультуре пробиотики рассматриваются как средство улучшения усвоения кормов, борьбы с патогенными микроорганизмами [9]. Использование в аквакультуре специализированных пробиотических штаммов было предложено в 1999 г. [10], когда была выдвинута гипотеза о том, что автохтонные бактерии будут характеризоваться большей устойчивостью в кишечнике гидробионтов по сравнению с коммерческими препаратами для сельского хозяйства и, соответственно, будут более эффективны.

Цель исследования – оценка рыбоводных параметров сеголетков гибрида F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 при кратковременном введении в рацион пробиотиков ферментативного и антимикробного спектра действия.

Материалы и методы

Исследовательские работы осуществлялись в условиях производственных мощностей ООО «Прибой» (Волгоградская область). Материалом послужили 900 экз. сеголетков гибрида F1 *Acipenser gueldenstaedtii* Brandt, 1833 x *Acipenser baerii* Brandt, 1869 (РоЛо). Возраст рыб в начале эксперимента составлял 53 дня. Рыб в случайном порядке распределили на 3 группы (контроль, опыт № 1, опыт № 2). Каждая группа содержалась в индивидуальном бассейне (объем по 2 м^3). Водоснабжение бассейнов осуществлялось по прямоточному типу. Плотность посадки рыб в обеих группах составляла 150 экз./м^3. Средняя индивидуальная масса рыб в начале эксперимента в группе «опыт № 1» составила 5,13±0,32 г (общая биомасса 1539 г), «опыт № 2» - 5,15±0,31 (общая биомасса 1546 г), в контрольной группе – 5,06±0,24 г (общая биомасса 1518 г).

В ходе исследования 2 раза в сутки измеряли температуру воды (t, °C) и концентрацию растворенного в воде кислорода (O_2, мг/г) с использованием термооксиметра Анион-7040 (Инфраспак-Аналит НПП, г. Новосибирск, Российская Федерация). Ежедневно производился учет погибших особей.

Рацион гидробионтов составляли корма, экспериментальные партии которых были произведены в лаборатории «Технологическая линия производства кормов» (Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация). Состав и качество кормов во всех группах имели аналогичные характеристики, соответствующие ГОСТ 10385-2014 «Комбикорма для рыб. Общие технические условия». Показатели используемых кормов следующие: сырой протеин 56,0±1,5%, сырой жир 12,0±1,5%, сырая зола (не более) 11%, сырая клетчатка (не более) 1,5%.

В рацион особей из опытных групп дополнительно были включены пробиотические добавки разного спектра действия: группа «опыт № 1» получала мультиштаммовый пробиотик с антимикробным спектром действия (штаммы *Bacillus velezensis* MT55, *B. velezensis* MT155), группа «опыт № 2» получала мультиштаммовый пробиотик с ферментативным спектром действия (штаммы *B. velezensis* MT14, *B. velezensis* MT42). Штаммы бактерий, входящих в состав пробиотического препарата, выделены из проб донных отложений, отобранных из акватории р. Дон (Ростовская область) на глубине 0-5 см. Бактерии *B. velezensis* MT55 и *B. velezensis* MT155 при микробиологическом скрининге проявляли антагонистическую активность против *Pseudomonas putida* – возбудителя псевдомоноза у объектов аквакультуры. *B. velezensis* MT14, *B. velezensis* MT42 синтезировали экзогенные протеазы и амилазы с высокой степенью активности.

Готовый пробиотический препарат в виде порошка получали методом твердофазной ферментации соевых бобов. Концентрация пробиотических штаммов в готовом препарате составляла $3{,}4 \cdot 10^9$ КОЕ/г. В комбикормах обеих опытных групп содержалось 0,1% пробиотического порошка.

В рацион особей из контрольной группы входили комбикорма без добавления пробиотика.

Продолжительность эксперимента составила 10 дней, в ходе которых рыб кормили 6 раз в сутки, общая суточная порция составляла 10,0% от биомассы рыб в бассейне.

По окончанию эксперимента на 24 часа было прекращено кормление. Из каждой группы изъята случайная выборка в количестве 60 экз. и произведено их анестезирование с использованием порошка гвоздики (150 мг/л) для определения биометрических параметров: длина рыб (l, см) измерялась с использованием цифрового штангенциркуля Gigant 0-300 мм GSMI-300 (Китай) с точностью измерений 0,01 мм; масса рыб (m, г) определялась с помощью лабораторных весов II класса точности BEL LG-2202i с дискретностью 0,01 г (ChangZhou XingYun Electronic Equipment Co., Китай).

Для оценки эффективности кормления производили расчет следующих показателей в каждой группе:

– коэффициент упитанности по Фультону (QF, усл. ед.) согласно формуле:

$$Q_F = \frac{m * 100}{l^3}$$

– средний индивидуальный прирост массы (WGi, г) с применением формулы:

$$WGi = m_1 - m_0$$

– общий прирост биомассы (WGt, кг) согласно:

$$WGt = M_1 - M_0$$

– коэффициент конверсии корма (FCR, кг/кг) на основании формулы:

$$FCR = {}^{M_f}/_{WGt}$$

– выживаемость рыб (S, %) оценивали с применением формулы:

$$S = 100 * \frac{N_1}{N_0}$$

– удельная скорость роста массы (SGRW, %/день) определяли согласно:

$$SGRW = 100 * \frac{In(m_1) - In(m_0)}{t}$$

– удельная скорость роста рыб по длине (SGRL, %/день) с использованием формулы:

$$SGRL = 100 * \frac{In(l_1) - In(l_0)}{t}$$

где t – продолжительность эксперимента, суток; l_1 – длина в конце эксперимента, см; l_0 – длина в начале эксперимента, см; m_1 – масса в конце эксперимента, г; m_0 – масса в начале эксперимента, г; N_1 – количество рыб в конце эксперимента, экз.; N_0 – количество рыб в начале эксперимента, экз.; M_f – затраченное количество корма в период проведения эксперимента, кг; M_1 – биомасса рыб в конце эксперимента кг; M_0 – биомасса рыб в начале эксперимента, кг; m – масса, г; l – длина, см.

Значимость различий полученных величин определяли с применением теста ANOVA. Отличия между группами считали достоверными при $p < 0,05$.

Результаты исследования

В период эксперимента средняя температура воды в бассейне с контрольной группой рыб составляла 24,15±0,34 (23,41-24,63) °С, в группе «опыт № 1» – 23,79±0,16 (23,22-24,17) °С, в группе «опыт № 2» – 23,81±0,18 (23,56-24,47) °С. Концентрация растворенного в воде кислорода (O_2, мг/г) в бассейне с контрольной группой рыб составляла 5,89±0,33 (5,05-6,37) мг/л, в группе «опыт № 1» – 6,21,79±0,27 (5,72-6,83) мг/л, в группе «опыт № 2» – 6,64±0,17 (6,31-6,96) мг/л.

Изменение размерно-массовых показателей сеголетков РоЛо в ходе эксперимента представлены в таблице 1.

Средняя индивидуальная масса особей в группе, получавшей в рационе пробиотик с ферментативным спектром действия, спустя 10 суток эксперимента оказалась на 36,89% выше, чем в контрольной группе ($p>0,05$).

Средняя масса особей, получавшей в ходе эксперимента пробиотики с выраженной антимикробной активностью, была 10,28% выше, чем в контрольной группе (p>0,05). Наибольшая упитанность рыб наблюдалась в опытной группе №2. По окончанию эксперимента коэффициент упитанности в этой группе особей был на 20,20% выше, чем в контрольной (p>0,05) и на 9,17% выше, чем в опытной группе № 1 (p>0,05).

Таблица 1.

Изменение размерно-массовых показателей сеголетков гибрида РоЛо при введении в рацион мультиштаммовых пробиотических добавок на основе штаммов *B. velezensis*

Наименование показателя, ед. изм.	Группа рыб					
	контроль		опыт № 1		опыт № 2	
	t_0[1]	t_1[2]	t_0	t_1	t_0	t_1
$m_{средняя}$, г	5,06±0,24	7,78±2,21	5,13±0,32	8,58±2,31	5,15±0,31	10,65±2,26
m_{min}, г	4,51	5,13	4,52	5,82	4,48	6,37
m_{max}, г	5,48	12,44	5,71	15,06	5,54	17,72
$l_{средняя}$, см	7,82±0,25	9,27±1,14	7,95±0,18	9,37±1,11	7,78±0,26	9,67±0,86
l_{min}, см	7,40	8,10	7,70	8,30	7,30	9,20
l_{max}, см	8,10	12,20	8,20	11,50	8,20	12,10
Коэффициент упитанности по Фультону (Q_F), усл. ед.	1,07±0,09	0,99±0,12	1,02±0,04	1,09±0,08	1,09±0,08	1,19±0,14

Примечание:
1 – начало эксперимента; 2 – окончание эксперимента (10 сутки).

Выживаемость сеголетков РоЛо в течение 10 суток в анализируемых группах различалась незначительно (таблица 2).

Высокие значения темпов индивидуального роста рыб позволили достичь биомассы гидробионтов по окончанию эксперимента в группе с ферментативным пробиотиком в 3,15 кг, в группе с антимикробным пробиотиком – 2,49 кг. В группе контрольных особей биомасса составила 2,23 кг. Прирост биомассы в опытной группе №2 был на 56,95% выше, чем в контроле и на 41,81%, чем в опытной группе №1.

Особи из группы с ферментативным пробиотиком в составе корма продемонстрировали существенное преимущество по всем проанализированным показателям эффективности выращивания по сравнению с контролем и группой «опыт №1». Коэффициент конверсии корма в этой группе был на 44,71% меньше, чем в контрольной группе и на 40,38% меньше, чем в группе с антимикробным пробиотиком в составе рациона. По показателям удельной скорости роста полученные значения были также выше.

Таблица 2.

Рыбоводно-биологические показатели роста гибрида РоЛо при добавлении в рацион мультиштаммовых пробиотических добавок на основе штаммов *B. velezensis*

Наименование критерия	Группа рыб		
	контроль	опыт № 1	опыт № 2
Средний индивидуальный прирост массы (WGi), г	2,72	3,45	5,50
Средний индивидуальный прирост массы (WGi), %	53,75	67,25	106,79
Общий прирост биомассы (WGt), кг	0,72	0,96	1,61
Общий прирост биомассы (WGt), %	47,09	62,23	104,04
Коэффициент конверсии корма (FCR), кг/кг	2,08	1,56	0,93
Выживаемость рыб (S), %	95,67	97,00	98,67
Удельная скорость роста массы (SGRW), %/день	4,30	5,10	7,30
Удельная скорость роста рыб по длине (SGRL), %/день	1,6	1,7	2,2

Обсуждение и заключение

В мировой аквакультуре вопросы интенсификации производства способствуют распространению практики использования пробиотических добавок на разных этапах выращивания гидробионтов. Множеством научных исследований показано, что пробиотики способны повышать резистентность объектов аквакультуры к патогенным микроорганизмам, ускорять темпы роста животных, повышать доступность питательных веществ, поступаемых с кормом, тем самым, увеличивая производительность отрасли. Некоторые штаммы пробиотических бактерий способствуют улучшению гидрохимического режима в системах выращивания [15].

В ходе эксперимента были получены сведения, свидетельствующие о перспективности использования специализированных кормовых пробиотических добавок, что также подтверждается результатами различных исследований [6; 13]. При необходимости увеличения размерно-массовых характеристик объектов аквакультуры рекомендуется добавлять в рацион рыб специализированные пробиотики. Среди таких препаратов наиболее перспективными являются те, при создании которых используются штаммы с выраженной экзоферментной активностью (продуцирование амилаз, протеаз, липаз и т.д.). Подобные препараты способствуют снижению коэффициента конверсии корма [5].

Схожие результаты были получены при апробации автохтонных пробиотиков на тиляпии *Oreochromis niloticus*. Введение пробиотика в рацион поспособствовало увеличению темпов роста и иммунного статуса рыб [14]. Полученные в настоящем исследовании результаты также согласуются с ранее проведенными отечественными исследованиями по аналогичной тематике [3]. Положительное влияние пробиотиков было подтверждено исследованиями группы ученых из Астраханского государственного технического университета, которыми были показаны более высокие значения массонакопления у молоди осетровых (севрюга), получавших в рационе пробиотик (препарат «Субтилис», в состав которого входят *Bacilus subtilis* и *Bacilus licheniformis*) [2].

Рассчитанные коэффициенты, направленные на оценку темпов роста и других рыбоводных показателей, в опытной группе №2 за 10 суток наблюдений оказались выше, чем в контрольной группе и опытной группе №1.

Таким образом, в ходе 10 суток наблюдений установлено положительное влияние ферментативного пробиотика (штаммы бактерий *B. velezensis* MT14, *B. velezensis* MT42) на темпы роста гибрида РоЛо: средняя индивидуальная масса особей, получавшей в рационе ферментативный пробиотик, была на 36,89% выше по сравнению с контрольной группой ($p>0,05$). Прирост общей биомассы в этой группе оказался на был на 56,95% выше, чем в контроле. Значения удельного темпы роста в этой группе рыб были также выше по сравнению с контролем и опытной группой №1.

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Научные обзоры

СУБСТРАТЫ ДЛЯ ВЫДЕЛЕНИЯ БАКТЕРИОЦИНОВ: ОБЗОР

Т.С. Дмитриенко, Т.А. Мальцева, В.Н. Шевченко, Е.Н. Косолапова, Д.В. Старостин

Аннотация

Обоснование. В связи с увеличением спроса на рыбную продукцию, запас дикой рыбы непрерывно истощается. Это приводит к высокому уровню развития аквакультуры в мире. Высокое содержание микроорганизмов в воде, в том числе патогенных, может негативно сказываться на его качестве и безопасности. Особую опасность для объектов аквакультуры представляет сальмонелла. Гидробионты могут являться носителями данной бактерии, которая, при попадании в организм человека, вызывает острую кишечную инфекцию. Это особенно важно при потреблении в пищу сырой продукции – мидии, молюски, сырья рыба. В настоящее время для борьбы с патогенными микроорганизмами используют антибиотики, негативное влияние который доказано во всем мире. В связи с чем, существует острая необходимость в поиске эффективных решений, направленных на борьбу с негативным влиянием патогенных микроорганизмов на объекты аквакультуры. Перспективным считается использование бактериоцинов, вызывающих подавление роста и гибель патогенных микроорганизмов. Эффективность пробиоитческих препаратов и бактериоцинов можно повысить за счет использования полезных штаммов бактерий, присутствующих в естественной среде обитания животных. Такой подход позволит создавать специализированные линейки пробиотических препаратов разного спектра действия (антиоксидантные, антимутагенные, ферментативные и прочие), которые будут способствовать развитию животноводства и минимизировать использование антибиотиков для лечения заболеваний бактериального характера. Для создания эффективной кормовой добавки на основе бактериоцинов в борьбе с сальмонеллой необходимо подобрать оптимальные условия культивирования новых штаммов-продуцентов для максимального выхода бактериоцинов.

Цель. Обзор и выявление потенциальных питательных сред для выращивания штаммов бактерий, присутствующих в естественной среде обитания животных, продуцирующие бактериоцины направленного действия.

Материалы и методы. В ходе исследования был применен сравнительно-аналитический метод. Информационная база сформирована на основе анализа данных, представленных в открытых научных публикациях. Поиск литературных источников проводился в реферативных и информационных базах данных, включая eLibrary, Российскую государственную библиотеку, ScienceDirect, ResearchGate, Google Scholar, National MedLine, онлайн-библиотеку Wiley и другие. В качестве поисковых запросов использовались следующие ключевые термины: «Salmonella», «сальмонелла», «бактериоцин», «bacteriocin», «субстрат», «subiectum», «штамм бактерии», «bacterial iactatio», «пробиотик», «probiotic», «пребиотик», «prebiotic», «сальмонеллез», «salmonellosis» – как в отдельности, так и в различных комбинациях. Временные ограничения при поиске не устанавливались с целью охвата максимально репрезентативного массива публикаций.

Результаты. Универсальными добавками в питательные среды для выделения бактериоцинов являются дрожжевой экстракт, пептон и глюкоза. Эти компоненты встречаются практически во всех вышеперечисленных питательных средах, что указывает на их вероятную высокую эффективность в качестве источников углерода и азота. Применение патоки, соевого жмыха, пшеничных отрубей, ферментативный раствор из лигноцеллюлозных отходов показали себя достойными субстратами с точки зрения не только производительности самих бактериоцинов, но и с точки зрения экономической эффективности субстратов. Пшеничные отруби, лигноцеллюлозные отходы, соевый шрот, патока являются вторичным сырьем. Применение вторичных продуктов и продуктов растительного происхождения, имеющих пребиотические свойства (например, зерновой ворох пшеницы ранних фаз спелости), в качестве субстратов для выделения бактериоцинов является эффективным и направлен на ресурсосбережение.

Заключение. Применение новых штаммов бактерий, выделенных из естественных сред обитания, с целью получения бактериоцинов, в аквакультуре будут способствовать развитию животноводства и минимизировать использование антибиотиков для лечения заболеваний бактериального характера.

Ключевые слова: аквакультура; микроорганизмы; бактерии; антибиотики; бактериоцины; субстраты; антагонистическая активность

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Scientific Reviews

SUBSTRATES FOR THE ISOLATION OF BACTERIOCINS: REVIEW

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Abstract

Background. Due to the increasing demand for fish products, the stock of wild fish is continuously being depleted. This leads to a high level of aquaculture development in the world. The high content of microorganisms in the water, including pathogenic ones, can negatively affect its quality and safety. Salmonella is a particular danger to aquaculture facilities. Hydrobionts can be carriers of this bacterium, which, when ingested, causes acute intestinal infection. This is especially important when eating raw products such as mussels, mollusks, and fresh fish. Currently, antibiotics are used to combat pathogenic microorganisms, the negative effects of which have been proven all over the world. In this regard, there is an urgent need to find effective solutions aimed at combating the negative impact of pathogenic microorganisms on aquaculture facilities. The use of bacteriocins, which cause the suppression of growth and death of pathogenic microorganisms, is considered promising. The effectiveness of probiotic drugs and bacteriocins can be improved by using beneficial bacterial strains present in the natural habitat of animals. This approach will make it possible to create specialized lines of probiotic drugs of different spectrum of action (antioxidant, antimutagenic, enzymatic, and others) that will promote the development of animal husbandry and minimize the use of antibiotics for the treatment of bacterial diseases. To create an effective feed additive based on bacteriocins in the fight against salmonella, it is necessary to select optimal conditions for the cultivation of new producing strains for maximum bacteriocin yield.

Purpose. Review and identification of potential culture media for growing bacterial strains present in the natural habitat of animals producing targeted bacteriocins.

Materials and methods. In the course of the study, a comparative analytical method was applied. The information base is based on the analysis of data presented in open scientific publications. Literary sources were searched in abstract and information databases, including eLibrary, the Russian State Library, ScienceDirect, ResearchGate, Google Scholar, National MedLine, the Wiley online Library and others. The following key terms were used as search queries: “Salmonella”, “bacteriocin”, “subiectum”, “bacterial iactatio”, “probiotic”, “prebiotic”, “salmonellosis” – both individually and in various combinations. No time limits were set for the search in order to cover the most representative array of publications.

Results. Yeast extract, peptone and glucose are universal additives in nutrient media for the isolation of bacteriocins. These components are found in almost all of the above-mentioned nutrient media, which indicates their likely high efficiency as sources of carbon and nitrogen. The use of molasses, soybean meal, wheat bran, and an enzymatic solution from lignocellulose waste proved to be worthy substrates not only in terms of the productivity of the bacteriocins themselves, but also in terms of the economic efficiency of the substrates. Wheat bran, lignocellulose waste, soybean meal, molasses are secondary raw materials. The use of secondary products and products of plant origin having prebiotic properties (for instance, a grain pile of wheat in the early stages of ripeness) as substrates for the isolation of bacteriocins is effective and is aimed at resource conservation.

Conclusion. The use of new bacterial strains isolated from natural habitats in order to produce bacteriocins in aquaculture will contribute to the development of animal husbandry and minimize the use of antibiotics for the treatment of bacterial diseases.

Keywords: aquaculture; microorganisms; bacteria; antibiotics; bacteriocins; substrates; antagonistic activity

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Введение

Аквакультура является самой быстроразвивающейся отраслью пищевой промышленности. На нее приходится практически 50% рыбы, которая производится в мире. В результате глобального увеличения спроса на рыбную продукцию, запас дикой рыбы истощается, что приводит к высокому уровню развития аквакультуры в мире. По данным FAO [1], общий объем вылова рыбы в мире на 2024 год составил около 223,2 млн. тонн, при этом производство аквакультуры составило 130,9 млн. тонн.

По данным Росстата [2], потребление рыбы в России увеличивается и за 2024 год оно составило порядка 23 кг на человека в год. Это объясняется тем, что рост населения и изменение предпочтений в сторону рыбной продукции неуклонно увеличивается. Люди стали уделять больше внимания своему здоровью, в связи с чем современные тренды по питанию предлагают сбалансированные рационы, в которые и входит рыбная продукция и другие объекты аквакультуры – ракообразные, моллюски, мидии и прочее.

Продукция аквакультуры является высокобелковым продуктом. В ее состав входят насыщенные жирные кислоты Омега-3 и Омега-6, которые нужны для укрепления иммунитета, улучшения состояния сердечно-сосудистой системы и общего состояния организма, а также витамины А, Е и D, макро- и микроэлементы - К, Se, Fe и др., необходимые для нормализации артериального давления, укрепления костей и хрящей, улучшение мозговой активности [3].

Бактериальная нагрузка сырой рыбы зависит от состояния окружающей среды и микробиологического качества воды, температуры, общей минерализации, удаленности от территорий, загрязненности фекалиями человека и животных, способа вылова и условий охлаждения. Одной из распространённых и опасных бактерий является сальмонелла. Водная среда является основным резервуаром сальмонеллы, способствует ее передаче среди гидробионтов, а также длительному персистированию в рыбном хозяйстве.

Заражение рыбных хозяйств сальмонеллой несёт опасность заражения продуктов питания и экономических убытков. В большей степени опасность представляют продукты аквакультуры, не подвергающиеся термической обработке: сырья рыба, моллюски, мидии и прочее. Несмотря на высокую осведомленность и большое количество мер, предпринимаемых в борьбе с распространением сальмонеллы в пищевой сфере, экономические убытки остаются достаточно высокими. По данным [38], ежегодно по всему миру ущерб от сальмонеллёза составляет от 1 до 3 млрд. долларов. Поэтому поиск решений для снижения распространённости сальмонеллой является актуальным как с экологической, так и с экономической точки зрения.

Для борьбы с сальмонеллой повсеместно используют антибиотики. Поэтому, помимо прямой опасности попадания бактерий сальмонеллы и других микроорганизмов в рыбу, существует косвенная опасность попадания в продукты питания антибиотиков, применяемых для борьбы с сальмонеллой. Кроме того, некоторые штаммы сальмонеллы, как и другие патогенные микроорганизмы, например, *Vibrio* spp., *Aeromonas* spp. и *Pseudomonas* spp., которые заражают представителей аквакультуры, имеют устойчивый иммунитет к антибиотикам [4-6].

Поиск решения вышеуказанных проблем требует современного и комплексного подхода. Перспективным считается использование бактериоцинов, представляющих собой специфические белки и белковые соединения, вырабатываемые бактериями и вызывающие подавление роста и гибель других бактерий. По данным исследования Червоткиной Д.Р. [7], бактериоцины и их продуценты способны стать профилактическим препаратом против заболеваний объектов аквакультуры, и выступить в качестве микробиологического контроля загрязненности сальмонеллой и снизить риски попадания сальмонеллы в продукты питания.

Эффективность пробиоитческих препаратов и бактериоцинов можно повысить за счет использования полезных штаммов бактерий, присутствующих в естественной среде обитания животных [39]. Ученые [39] разработали способ выявления перспективных штаммов бактерий из естественных сред обитания. Такой подход позволит создавать специализированные линейки пробиотических препаратов разного спектра действия (антиоксидантные, антимутагенные, ферментативные и прочие), которые будут способствовать развитию животноводства и минимизировать использование антибиотиков для лечения заболеваний бактериального характера.

Применение новых бактериоцинов, их продуцентов и инновационных способов их доставки будет способствовать профилактике заболеваний и заражения объектов аквакультуры и значительной экономии средств, необходимых для их лечения. Для создания эффективной кормовой добавки на основе бактериоцинов в борьбе с сальмонеллой необходимо подобрать оптимальные условия культивирования новых штаммов-продуцентов для максимального выхода бактериоцинов. В связи с этим, возникает острая необходимость поиска и создания универсальной питательной среды (субстрата), которая будет отличаться не только экономической, но и производительной эффективностью, а также позволит создать бактериоцины, позволяющие активно применять их в аквакультуре при борьбе с патогенными микроорганизмами, в том числе с сальмонеллой.

Цель исследования – обзор и выявление потенциальных питательных сред для выращивания штаммов бактерий, присутствующих в естественной среде обитания животных, продуцирующие бактериоцины направленного действия.

Материалы и методы

В ходе исследования был применен сравнительно-аналитический метод. Информационная база сформирована на основе анализа данных, представленных в открытых научных публикациях. Поиск литературных источников проводился в реферативных и информационных базах данных, включая eLibrary, Российскую государственную библиотеку, ScienceDirect, ResearchGate, Google Scholar, National MedLine, онлайн-библиотеку Wiley и другие. В качестве поисковых запросов использовались следующие ключевые термины: *«Salmonella*», «сальмонелла», «бактериоцин», «bacteriocin», «субстрат», «subiectum», «штамм бактерии», «bacterial iactatio», «пробиотик», «probiotic», «пребиотик», «prebiotic», «сальмонеллез», «salmonellosis» – как в отдельности, так и в различных комбинациях. Временные ограничения при поиске не устанавливались с целью охвата максимально репрезентативного массива публикаций.

1. Бактерии, способные синтезировать бактериоцины.

Бактреиоцины синтезируются грамположительными и грамотрицательными микроорганизмами, например, такими микроорганизмами, как: бактерии родов *Bacillus, Clostridium, Streptococcus, Leuconostoc, Lactobacillus, Staphylococcus, Micrococcus, Corynebacterium, Mycobacterium, Streptomyces*. Они являются грамположительными бактериями. Касаемо грамотрицательных бактерий – это бактерии рода *Rhizobium, Leguminosarum, Klebsiella* и *Pseudomonas*. Наиболее безопасными являются грамположительные бактерии, а именно молочнокислые, так как они наиболее изучены и имеют наиболее широкий спектр применения, нежели грамотрицательные.

2. Бактериоцины.

Бактериоцины - это пептиды, синтезируемые на поверхности бактериальных рибосом микроорганизмов. Бактериоцины обладают антибактериальным действием, направленного действия против штаммов микроорганизмов, являющиеся близкородственными, либо того же вида.

Существует огромное количество различных видов бактериоцинов, но не все бактериоцины возможно применять в аквакультуре. На данный момент для аквакультуры в мире используются такие бактериоцины, как [8; 9]: Лихеницидин А1, Субтилин и коагулин (*Bacillus*), Низин А, *Lactacin 481*, *Lactocin 27, Plantaricin A, Plantacin B, Helveticin*, Лейкоцин, Сакацин, Педиоцин PAl/AcH, Энтероцины AS-48, А, В и другие.

Например, по данным некоторых исследований [10; 11], бактериоцины штамма *Bacillus* известны своей способностью подавлять широкий спектр основных патогенов рыб, включая бактерии и вирусы. Штамм этих бактерий способен синтезировать субпептин, турицин, мерсацидин, субтилин, субтилозин и сублансцин, которые способны подавлять патогены рыб. Также известно из этого источника, что молочнокислые бактерии из кишечника раков эффективно справлялись с подавлением инфекции *A. Hydrophila* у ракообразных. Стоит отметить, что бактериоцины выделенные из *L. Acidophilus*, которые были получены из творога, по данным [12], отлично защищают от патогенов *V. parahaemolyticus, V. cholerae, V. alginolyticus*. По данных других ученых [13], бактериоцин Сурфактин, который является противовирусным соединением и вырабатывается *P. aeruginosa, A. Calcoaceticus* и *B. Subtilis*, уже используется для борьбы с бактериальными и вирусными заболеваниями в аквакультуре. Также ряд ученых предполагают [14-17], что молочнокислые бактерии являются важным средством против сальмонеллы, а также отмечают, что, например, штамм *L. Paracasei* за счет выделения бактериоцинов позволяет снизить pH окружающей среды. Это снижает рост сальмонеллы, но не останавливает его.

3. Питательные среды (субстраты)

Для каждого вида бактериоцина необходим субстрат определенного качества, так как от условий культивирования зависит количество выделяемых бактериоцинов микроорганизмами. Если среда недостаточно полна питательными веществами, плотность клеток может не достичь необходимого уровня и низкая биомасса бактерий приведет к минимальной выработке бактериоцинов. Необходимо тщательно подходить к выбору среды не только из-за возможной непроизводительности микроорганизмами бактериоцинов, но и в целях качественного отбора бактерий из их естественной среды в лабораторную, так как, если не соблюсти вышеуказанные условия, возможны потери в колонии бактерий [18].

Существует ряд традиционных питательных сред:

- Основа из отфильтрованной морской воды. В неё добавляют 1,0-2,5% агара и солевые добавки: хлорид аммония, хлористый натрий, нитрат натрия, сернокислую медь, фосфорнокислый калий, нитрат аммония (10 ммоль/л), казеин (10 мг/мл);
- ГРМ-агар («Питательные среды», Оболенск, Россия);
- Крахмальный агар (Starch agar, Ref.1-283, Scharlau, EU);
- Среда №1 (г/л): бактопептон («Difco», США) — 20, глюкоза («Maize products», Индия) — 2,5, NaCl — 5, K2HPO4 («Реатэкс», г. Москва) — 2,5 (pH 7,2±0,2);
- Среда №2 (г/л): бактопептон («Difco», США) — 20, глюкоза («Maize products», Индия) — 2,5, NaCl — 5, K2HP04 («Реатэкс», г. Москва) — 2,5, триптон соевый («Difco», США) — 3 (pH 7,2±0,2);
- Питательный агар (Nutrient Agar M001, HiMedia, Индия);
- АГВ (НПО «Питательные среды», г. Махачкала);
- Мюллера-Хинтона («HiMedia», Индия) [19,20].

С целью эффективного применения бактериоцинов, требуется улучшать старые и создавать новые субстраты для их выделения. Это обуславливается тем, что мир нуждается в новых видах бактериоцинов, которые будут применимы, в том числе для различных объектов аквакультуры.

В работе [21-23] представлены результаты исследования выращивания 475 штаммов *Enterococcus*, применяя 3 вида питательных сред:

среда 1: пептон, дрожжевой экстракт, кукурузный экстракт, сахароза;

среда 2: пептон, дрожжевой экстракт, кукурузный экстракт, патока из сахарной свеклы. У сред 1 и 2 концентрация составляла 1,00%, 0,05%, 0,25%, 2,00%.

среда 3: В составе третьей среды были внесены изменения, а именно, убрали патоку из сахарной свеклы и скорректировали концентрацию других компонентов. Состав среды 3: пептон (1,00%), дрожжевой экстракт (0,05%) и кукурузный экстракт (0,25%);

среда 4 содержала в себе только патоку из сахарной свеклы (2,00%).

По результатам исследования [21-23], авторы отмечают, что с помощью питательной среды 1 (кукурузный экстракт, пептон, дрожжевой экстракт, сахароза), которая отличалась своей экономичностью, обнаружены следы энтероцинов entA, entP и entB у 5 штаммов *Enterococcus*. Штаммы бактерий *E. faecalis* 58, *Enterococcus* sp. 423 и *Enterococcus* sp. 226 являются отличными кандидатами в качестве продуцентов бактериоцинов против *P. Aeruginosa, E. coli, S. Aureus* и *L. Monocytogenes*. Антагонистическая активность CFS составила 51200 МЕ/мл против штамма *L. Monocytogenes* и 1600-3200 МЕ/мл против штамма *E. faecalis* 888. Применение патоки и кукурузного сиропа может позволить увеличить экономическую эффективность производства бактериоцинов в промышленном сегменте.

Патока и кукурузный сироп действительно являются хорошими компонентами питательной среды для *Enterococcus*, однако найден не менее эффективный и доступный компонент в качестве субстрата для выделения бактериоцинов из *Enterococcus*. Об этом пишут в своих исследованиях ученые [24,25,26], где сообщают об высокой эффективности соевого шрота в качестве субстрата для выделения энтероцинов из *Enterococcus durans*. Положительные результаты были получены для энтероцинов A, B, P и X. Антагонистическая активность энтероцинов составляла практически 6400 АЕ/мл$^{-1}$. Такие результаты были получены из двух питательных сред, которые имели следующий состав (г/л):

среда 1: соевый шрот (10), декстроза (20), твин 80 (2), фосфат калия (2);

среда 2: соевый шрот (16), декстроза (20), твин 80 (1), фосфат калия (2).

Питательная среда с добавлением соевой муки является многообещающим субстратом для выделения бактериоцинов.

В других исследованиях [27,28,29] ученые отмечают высокую эффективность недорогих питательных сред: среда Лурия-Бертани, питательный бульон, триптический соевый бульон, мозгово-сердечный бульон и среды, содержащие только пептон и глюкозу, могут стать хорошими субстратами для культивирования бактериоцинов из рода *Bacillus*, а также отмечается, что добавление дрожжевого экстракта и NaCl, щелочной pH в совокупности с повышенной температурой и интенсивным перемешиванием повышают производительность бактериоцинов *Thuringiensis* и *Subtilis* P34 [30-32].

Пептон, дрожжевой экстракт и глюкоза являются хорошими вспомогательными веществами в составе питательной среды не только для вышеуказанных субстратов, но и для других основ. Например, более высокую производительность культивирования бактериоцинов обеспечили пшеничные отруби. Культивирование проводилось с помощью метода твердой ферментации. Применение пшеничных отрубей в выделении бактериоцинов из *Lactobacillus plantarum* (582,86 ± 0,87 ЕД/мл), из которых получаются плантарицины, исследовали ученые [33; 34]. Наиболее высокие показатели отмечены в среде на основе пшеничных отрубей (5-150 г) с добавлением пептона (1,13%), дрожжевого экстракта (1,13%), глюкозы (1,56%) и цитрата триаммония (0,50%) при температуре 37 °C в течение 24 часов. Стоимость среды оказалась ниже на 25%, чем стоимость коммерческой среды, а выработка бактериоцина выше в полтора раза. В исследовании [35] ученые предложили в качестве субстрата для выращивания пробиотиков зерновой ворох пшеницы ранних фаз спелости. Такое сырье обладает низкой стоимостью и является перспективным пребиотиком для сельского хозяйства. Поэтому, зерновой ворох пшеницы ранних фаз спелости может стать потенциальной основой питательной среды для выделения бактериоцинов.

В работе [36] ученые предложили использовать лигноцеллюлозные отходы в качестве субстрата для *Lactobacillus plantarum*, что также оказалось достаточно эффективным способом для культивирования бактериоцинов (плантарицонов). Был использован ферметативный раствор (цитратный буфер pH 6,0). Концентрация бактериоцинов составила 9,21 BU/мл.

В таблице 1 приведены бактериоцины и субстраты, необходимые для их выделения.

Таблица 1.

Бактериоцины и субстраты для их выделения [21-36]

Штамм бактерий	Субстрат	Бактериоцины
Enterococcus: E. *faecalis* 58, *Enterococcus* sp. 423, *Enterococcus* sp. 226 *Enterococcus durans*	1) Патока и кукурузный сироп 2) Соевая мука	Энтероцины P, A, B, X.
Bacillus	1) среда Лурии-Бертани 2) питательный бульон 3) триптический соевый бульон 4) мозгово-сердечный бульон 5) среды, содержащие только пептон и глюкозу	Thuringiensis, Subtilis P34
Lactobacillus: *Lactobacillus plantarum* *Lactobacillus lactis*	1) Пшеничные отруби с добавлением дрожжевого экстракта, пептона и глюкозы 2) лигноцеллюлозные отходы	Plantaricin A, Plantacin B и Helveticin, Низин.

Данные субстраты являются потенциально применимыми при получении бактериоцинов для борьбы с сальмонеллой. Бактериоцины имеют узкий спектр действия, так как они поражают родственных или близкородственных бактерий. Об этом указано в работе [37], где авторы говорят о необходимости создания препаратов, которые будут содержать несколько видов бактериоцинов для более эффективной борьбы с патогенными микроорганизмами, в том числе с сальмонеллой.

Выводы

Универсальными добавками в питательные среды для выделения бактериоцинов являются дрожжевой экстракт, пептон и глюкоза. Эти компоненты встречаются практически во всех вышеперечисленных питательных средах, что указывает на их вероятную высокую эффективность в качестве источников углерода и азота. Применение патоки, соевого жмыха, пшеничных отрубей, ферментативный раствор из лигноцеллюлозных отходов показали себя достойными субстратами с точки зрения не только производительности самих бактериоцинов, но и с точки зрения экономической эффективности субстратов. Пшеничные отруби, лигноцеллюлозные отходы, соевый шрот, патока являются вторичным сырьем. Применение вторичных продуктов и продуктов растительного происхождения, имеющих пребиотические свойства (например, зерновой ворох пшеницы ранних фаз спелости), в качестве субстратов для выделения бактериоцинов является эффективным и направлен на ресурсосбережение. Применяя вторичные продукты в качестве основы для питательных сред для выделения бактериоцинов, существует возможность не только добиться создания универсальной питательной среды, отличающаяся своей доступностью, но и уменьшить количество отходов, что, будет благоприятно сказываться на экологической ситуации в мире.

Информация о конфликте интересов. Авторы заявляют об отсутствии конфликта интересов.

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Научно-практический рецензируемый журнал **Siberian Journal of Life Sciences and Agriculture** издается с целью пропаганды фундаментальных и фундаментально-прикладных региональных достижений в области медицины, биологии, сельского хозяйства и смежных дисциплин на территории Российской Федерации и за рубежом.

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