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POSSIBILITIES FOR THE INTRODUCTION AND BREEDING OF CHIA (*SALVIA HISPANICA* L.) IN THE SOUTHERN FOREST-STEPPE OF WESTERN SIBERIA

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Each area of a country, due to its specific soil and climatic conditions, requires the elaboration of a biological grounding for the introduction of useful plants which might be lead to the best practical effect when cultivated both under production conditions and on garden plots. In this respect, the introduction of new species is of crucial importance.

Research regarding chia (Salvia hispanica L.) has been conducted at Omsk State Agrarian University since 2017. This crop has been cultivated in Mexico since ancient times, while in Russia it has not been grown yet. The present article shows the scientific results of the research on chia as a new, versatile crop to be cultivated under the conditions of the southern forest-steppe of Western Siberia. Varietal studies were conducted on samples from different countries, including Mexico, France, Israel and Thailand.

The sample assessment was carried on at the breeding nursery according to the following parameters: duration of the growing period, productivity and sucrose content in their leaves. In order to increase the efficiency of the breeding process when creating new chia varieties, the samples 3/18 and 0/18 can be recommended as sources due to their parameter set.

Keywords: *Salvia Hispanica; chia; introduction; duration of the growing period; yield; sucrose*

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ВОЗМОЖНОСТЬ ИНТРОДУКЦИИ И СЕЛЕКЦИИ ЧИА (*SALVIA HISPANICA* L.) В УСЛОВИЯХ ЮЖНОЙ ЛЕСОСТЕПИ ЗАПАДНОЙ СИБИРИ

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Для каждой зоны страны, в связи с их отличительными почвенно-климатическими условиями, должны быть разработаны биологические основы интродукции тех видов полезных растений, которые могут дать наибольший практический эффект при выращивании их как в производственных условиях, так и на приусадебных участках. Особое значение в этой связи приобретает интродукция новых видов. Омский ГАУ с 2017 года ведет научные исследования по чиа (Salvia hispanica L.). Культура имеет древнюю историю выращивания в Мексике, однако в России нет опыта выращивания данной культуры.

В статье приведены научные результаты изучения новой культуры разнообразного использования – чиа, в условиях южной лесостепи Западной Сибири. Образцы на сортоизучении получены из стран: Мексики, Франции, Израиля, Таиланда. В коллекционном питомнике образцы оценивались по ряду показателей: продолжительность вегетационного периода, продуктивность и содержание сахарозы в листьях.

Для повышения эффективности селекционного процесса при создании новых сортов чиа целесообразно использовать в качестве источников по комплексу признаков образцы: 3/18 и 0/18.

Ключевые слова: *шалфей испанский; чиа; интродукция; продолжительность вегетационного периода; урожайность; сахароза*

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Introduction

The history of the cultivation of chia is quite interesting. Despite being the third most important crop culture in Mexico over a period of 5,500 years, it has become an almost unknown species over the last 260 years. In order to be reintroduced in the human diet, it had to be adapted to conditions under which other crops were not likely to survive [19].

Chia is an ancient crop culture which was domesticated around 3500 BCE. Until the arrival of the Spanish, it was a key ingredient in the diet of more than 11 million of Aztecs together with maize, beans and amaranth [18]. After the Spanish colonisation, the production of chia was forbidden in Mexico on the pretext of being a potential competitor of plant and animal species imported from Spain. The main cause, however, is that this crop was widely revered and used in the Aztec religious ceremonies. Chia was preserved thanks to the fact that the indigenous Nahua people, living in the mountains of Puebla, Guerrero, Morelos and Jalisco in Mexico, continued to secretly grow this crop [2, 3].

Chia seeds played a crucial role in the diet of the Mesoamerican people in the Pre-Columbian era. They were undoubtedly important as a source of high-quality nutritional substances. At the present time, their nutritional value and beneficial effect on human health are widely known. However, this information is sometimes derived from well-grounded scientific data, sometimes from statements based on popular traditions and beliefs [14].

Chia has entered the 21st century without undergoing the necessary changes for the adaptation to nowadays production requirements. This is due to the fact that chia has not gone along the same path as other ancient cultures like maize, beans and tomatoes. Therefore, while the aforementioned crops have found their own place in the present-day diet, chia has not. As a result, chia has remained unknown in other countries and its use was limited to those region where this crop was consumed before the arrival of the Spanish [2].

Nonetheless, the role of chia as a commodity started to change at the beginning of the 1990s thanks to scientific research regarding the high content of polyunsaturated omega-3 fatty acids, proteins and fibres in its seeds. At the same time, a research group composed of US and Argentinian scientists visited the city of Acatic in Jalisco, Mexico, in order to study the bases of chia cultivation. Later, they launched a long-term research programme called the “Western Argentina Regional Project”. Its main aim was studying the nutritional value of chia, researching its adaptability and crop breeding, as well as the feature of the cultivation and production of chia in different regions of Argentina, Peru, Colombia, Bolivia and Ecuador [1, 14]. The scientific results of the research have been published by Ricardo Ayerza, Wayne Coates and other researchers over the last 22 years. They have become the key for promoting the use, production and marketing of chia all over the world. As a results, chia is currently cultivated in 14 different countries [19].

Several Russian and foreign mass media promote chia seeds as a new generation food product or "superfood", so rich in vitamins and minerals that it can prevent or even cure many illnesses [6]. At the present time, scientist are facing two main tasks: not only re-discovering the advantages of this crop for the whole world, but also debunking some myths regarding it.

Chia, also called Mexican chia or salba chia (*Salvia hispanica* L.), is an annual plant from the mint family (*Lamiaceae*) cultivated on an industrial scale in order to obtain its seeds, which are rich in omega-3 fatty acids. Chia seeds are also an excellent source of digestible fibre and antioxidants [4].

The *Salvia hispanica* L. plant can produce a great amount of leaves, which can be used as a source of bioactive substances. However, as opposed to its seeds, the chemical composition, pharmacological and nutritional values of chia leaves have not been fully researched yet [16].

Chia seeds contain about 21% of proteins and are far superior to other edible grains such as wheat (14%), maize (14%), rice (8.5%), rye (15.3%), barley (9.2%) and amaranth (14.8%). About one third of the seed mass is composed of fats (oil), 60% of which is represented by α-Linoleic acid, thus making it a source of polyunsaturated omega-3 fatty acids. When extracting the oil, the residual oil cake contains up to 50-60% dietary fibres. The seeds themselves contain about 5% of digestible fibre. They are also sources of vitamin B complex, phosphore, calcium, zinc, copper and natural antioxidants [7].

In 2009 the European Union, where this plant is not well-known, acknowledged chia as a promising food type [9].

Until recently, the production of chia seeds was possible only at tropical and subtropical latitudes due to the long growing period necessary for the complete development of the seeds. Even though chia plants grow well also in a moderate climate, they require a short photoperiod for the efflorescence and usually the plants die when ground frost begins before the seeds reach their full maturity. Scientists from the University of Kentucky, USA, are conducting innovative research on chia breeding. This led to the creation of patented lines which blossom under the conditions of a long photoperiod and can produce seeds in the North-West (Virginia, Kentucky, Massachussets and Pennsylvania) and Midwest of the USA [4].

At the present time chia plants are cultivated on a commercial basis over 370,000 hectares in different agricultural areas of the world, mainly in Bolivia, Paraguay, Argentina, Mexico, Australia, Central America, Peru, Ecuador and Colombia [19].

This culture crops is so important that several countries such as the USA, Chile, Argentina and Italy, where the climatic conditions make the cultivation of chia difficult, are evaluating different agronomic methods in order to adapt the crop to their agricultural zones. The main problem faced by these countries is that chia is a tropical short-day species which grows well in regions located between 20° 55' N and 25° 05' S [19].

Chia is considered a short-day plant [10], sensible to the photoperiod, characterised by the absence of long-day varieties, which limited its commercial use to tropical and subtropical latitudes until 2012 [5].

However, lines bred by local inhabitants are currently wildly grown or cultivated in the moderate climate of the high latitudes of the United States [10, 8]. In order to blossom and bear fruit, chia requires a nightime superior to 12-13 hours [10]. Thus, in the northern hemisphere chia begins to blossom in October, in the southern hemisphere in April [14].

Chia is the only Mesoamerican plant crop that has not been introduced yet. The main cause is represented by the short photoperiod and inadaptability to cold temperatures [10]. The introduction of cultivation in high-latitude regions such as Spain has proved that chia plants do not blossom in time during summer and die early on after shoots die to the early ground frost in autumn [10].

At the present time the introduced cultivation of this crop is quickly widening its area from the traditional Mesoamerican belt to numerous regions all over the globe (Sosa et al., 2016; Orona-Tamayo et al., 2017), e.g. in Argentina (Busilacchi et al., 2013), Chile (Baginsky et al., 2016), Brazil (De Freitas et al., 2016; Da Silva et al., 2017), Bolivia (Ayerza, 2016), the USA (Jamboonsri et al. al., 2012), Australia (Timilsena et al., 2017), India (Sreedhar et al., 2015), Ghana (Yeboah et al., 2014), South Italy (Bochicchio et al., 2015) and others [21]

The review of open access scientific publications has shown that this crop is still underexplored, yet it definitely has a great potential.

Since there have not been trials for the introduction of chia in Russia yet, the present research can become a useful instrument for the cultivation of this crop in non-traditional areas of the country. The geographical coordinates are as follows: city of Omsk, Omsk Region, Russia; latitude 54° 59' 32" N; longitude 73° 22' 06" E; altitude 90 m a.s.l.

Thus, the assessment of certain parameters of the collection sample, including the duration of the growing period, productivity and sucrose content in the leaves, represents a concrete research interest and is of considerable practical importance.

The objectives of the current research are the introduction of a new agricultural crop and the selection of breeding source material for the creation of adaptive varieties for the agroecological conditions of the southern forest-steppe of Western Siberia.

Materials and methods

The research was conducted in 2018–2020 on the fields of the Educational Experimental Farm of the Omsk State Agrarian University, located in the southern forest-steppe zone of the Omsk Region.

The southern forest-steppe zone is characterized by a warm, moderately humid climate. The sum of average daily temperatures over a period with a temperature above 10° is 100–130 days average. The frost-free period in this region averages 110–120 days, the period with a temperature above 0 °C – 185, above 5 °C – 157, above 10 °C – 123 days. Night frosts in the air in springtime are stop on May 21–22 and appear in the autumn of September 10–22. The abundance of sun and heat largely compensates the short duration of the frost-free period and ensures vegetation of plants. The southern forest-steppe of the Omsk region belongs to the zone of unstable hydration. The average long-term annual precipitation is 300–350 mm, for a period with a stable average daily air temperature above 10° precipitation, 190–220 mm falls out. Provision of plants with moisture in the area is characterized by a hydrothermal coefficient of 1.0–1.2, which indicates a satisfactory average moisture supply in the period of active vegetation. By the time of sowing, moisture reserves in the soil are usually sufficient. The soil of the field is ordinary black chernozem, medium humus.

Object of the research were 5 samples of chia (*Salvia hispanica L.*):

- 0/18 (Introduced);
- 1/18(Israel);
- 2/18 (Thailand);
- 3/18 (France);
- 4/18 (Mexico).

The forecrop was wheat. The trials were sown following the Methodology for field trials in vegetable growing [21]. The chia samples were sown in a four-fold repetition (according to the scientific plan) with a seed depth of 0.5 cm. The sowing date on the field was included between the 20^{th} and 25^{th} May. The row spacing amounted to 60 cm. The plot area amounted to 15.5 m^2. The rows were arranged from north to south.

Crop tending included manual weeding and hilling, performed when necessary, side-shoot removal and pruning. The seeds were harvested manually, involving 5 plants per repetition in order to determine the structural analysis, the overall number of plants amounted to 20.

The sowing characteristics of the sowing material were determined according to the National Standard: Germination Power and Viability (National Standard 12038-84) [17]

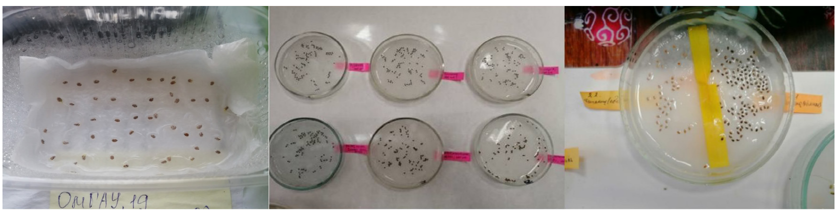
The chemical analysis of the green leaves and seedlings for sucrose content was executed using a pocket refractometer device Refracto 30P.

The meteorological conditions of the growing period were evaluated in line with the data of the Omsk Meteorological Station. Over the trial period, they reflected the peculiarities of the climate of the southern forest-steppe of Western Siberia in a fairly complete manner.

The statistical processing of the experimental data (mean, standard deviation, variance analysis, etc.) was carried out according to the method described in the manual of B.A. Dospekhov (1985) [20].

Results

The quality of the sowing material determines the future yield of an agricultural crop. For this reason, the range of agrotechnical measures aimed at obtaining a high and stable yield should pay particular attention to high-quality sowing material. The lab-based viability of the chia seeds was determined before sowing on 15th March 2018, 10th October 2019 and 28th April 2020 at the Laboratory for Plant Breeding and Seed Production of Field Crops named after S.I. Leontyev (Fig. 1).



a. b. c.

Fig. 1. Determining the energy of germination and viability of the chia seed samples, 2018-2020. The enenge of germination on day: a) 4 – 15th March 2018; b) germinating power on day 4 – 10th October 2019; c) germinating power on day 4 – 28th April 2020.

The trial, depending on the crop samples, showed significant differences in the energy of germination, as well as lab- and field-based viability of the seeds (Tab. 1).

When analysing the parameters of the lab-based viability of the seeds, it should be noted that over the research period the seeds of the 1/18, 4/18 and 0/18 samples showed a high energy of germination: 81% and 83% in 2018; 86%, 89% and 100% in 2019; 69% and 100% in 2020. The 2/18 and 3/18 samples show a low energy of germination: 7% and 21% in 2018; 1% and 11% in 2019, 5%; 24% in 2020. A high percentage in seed viability was shown by the seeds of the 1/18, 4/18 and 0/18 samples (70-100% in 2018, 76-100% in 2019, 81-100% in 2020). These samples also distinguished themselves for their high field-based viability, ranging between 72% (1/18) and 88% (0/18). The survival capacity of all the samples at study amounted to 99%.

Table 1.

Parameters of lab- and field-based viability of the seeds of the collection samples of chia, %

Sample	2018			2019			2020		
	energy of germination	viability	field-based viability	energy of germination	viability	field-based viability	energy of germination	viability	field-based viability
0/18 (introduced)	-	-	-	100	100	72	100	100	88
1/18 Israel	81	99	50	86	99	54	69	81	72
2/18 Thailand	7	38	17	1	32	14	5	12	7
3/18 France	21	70	49	11	76	47	24	63	39
4/18 Mexico	83	100	58	89	100	66	-	-	-

The duration of the growing period of chia varies depending on the habitat and is determined by their height [19, 20]. The review of literature has shown that for production areas located in different ecosystems of Bolivia, Argentina and Ecuador the growing period amounts to 100-150 days [15].

The duration of the growing period and its structure determine the capacity of the variety to adapt to the conditions of a specific climatic area. The duration of the growing period can be related to different commercial and biological traits and properties of a variety [11].

The plants were harvested and exfoliated manually. In order to determine the structural analysis, 5 plants were harvested in each repetition, for an overall amount of 20 pcs. The plants were then bound in bunches and hung in a closed space to desiccate. The seeds of the remaining plants were harvested for further use as sowing material in the following year.

During the vegetation period phenological observations and recording were carried out following the methodology for varietal testing [13] as shown in Tab. 2.

In 2019 crop seeds were obtained for the first time on the field. In August 2019 favourable meteorological conditions for the flowering and ripening of the chia seeds were observed, which cannot be said as regards 2018.

Table 2.

Duration of the vegetation period of chia samples, 2019 (days)

Sample	Shoots	Flowering	Seed formation in the greenhouse	Vegetation period
0/18 (introduced)	07/06	14/11	-	-
1/18 Israel	09/06	-	-	-
2/18 Thailand	09/06	-	-	-
3/18 France	07/06	25/08	05/10	120
4/18 Mexico	09/06	-	-	-

Among the five collection samples at study, seeds grew ripe only in the 3/18 sample with a duration of the vegetation period of 120 days. For the cultivation of seeds in the southern forest-steppe of Western Siberia the use of mid-ripening samples (95-120 days) is recommended. The trial findings showed that the 3/18 sample is recommended as a source in the breeding process scheme.

Chia seeds are an excellent source of digestible fibres and antioxidants [4]. The crop plants can produce a large amount of leaves, which can be used as a source of bioactive substances. However, as opposed to the seeds, the chemical composition, pharmacological and nutritional values of chia leaves have not been sufficiently studied and research on this topic is currently being conducted [16].

In the assessment of the collection samples, the sucrose content in the leaves was determined. Sucrose plays a crucial role in the plant, since it can be found in the plant cells as a form of reserve, especially in the cell sap, or it can be directly consumed by the plant as a nutritional and energetic material [11]. The sucrose content in the green leaves and seedlings of chia is not stable, it changes depending on the sample origin and varies depending of the cultivation conditions . The analysis of the sucrose content in the leaves of the chia samples is presented in Tab. 3.

The research findings have shown that the sucrose content in the chia leaves varied over the years between 6.2% and 14.3%. The highest content was observed in the 3/18 sample (14.3%).

The germination of cereals and plant seeds is a popular trend of the current healthy lifestyle, possessing its atmosphere and exotic. It should be noted that germination the seeds of chia and its analogues is in fact purposeful. Both the grains and their sprouts have a composition which has a positive effect on human health [6, 11].

The shoots, due to their high sucrose content, can be used in food industry as an additive or as an ingredient for different dishes (Tab. 4).

Table 3.

Sucrose content in the green leaves of the collection samples of chia, %

Sample	2019			Average	2020			Average
	repetition				repetition			
	1	2	3		1	2	3	
0/18 (introduced)	10.1	9.7	10.0	9.9	11.0	10.1	10.5	10.5
1/18 Israel	11.4	11.8	11.6	11.6	12.4	12.1	12.1	12.2
2/18 Thailand	7.1	6.7	6.3	6.7	-	-	-	-
3/18 France	6.2	6.7	7.2	6.7	14.3	14.2	12.9	13.8
4/18 Mexico	9.1	8.5	8.9	8.8	-	-	-	-
LSD_{05}	0.8	0.9	0.8	0.8	1.2	1.1	1.1	1.2

Table 4.

Sucrose content in the shoots of seeds of the collection samples of chia (average value in 2019-2020), %

Sample	Index
0/18 (introduced)	17.2
Israel 1/18	25.4
Thailand 2/18	15.9
France 3/18	22.3
Mexico 4/18	23.6
LSD_{05}	2.6

The research has shown that the sucrose content in the seed shoots varied between 17.2% in the 0/18 sample and 25.4% in the 1/18 sample. All the other samples showed an intermediate value among these two indices.

Yield is the main economic trait obtained from the productivity of a single plant and the number of plants per surface unit. In 2020, among the collection samples at study, seeds were obtained from the 3/18 sample (France). The research findings are shown in Tab. 5.

The number of inflorescences per plant in the 3/18 sample varied between 25 and 34 pcs. The number of seeds per plant ranged from 575 to 2,133 pcs. The highest seed weight was observed in a bush that had 25 inflorescences (1.973 g) against other trial plants (0.791 g and 1.047 g). It should be noted that the inflorescences of the aforementioned plant were twice as long as the inflorescences of the other trial plants. This plant should be considered as a model for future chia varieties as regards productivity.

During the study of chia samples, crop-specific pests and diseases were not observed under the ecological conditions of the southern forest-steppe of Western Siberia.

Table 5.

Yield of the 3/18 chia collection sample as of 2020

Plant (repetition)	Inflorescence (repetition)	Seed weight, g	Seed number, pcs	Inflorescence number per plant, pcs	Seed weight per plant, pcs	Thousand seeds weight, g	Weight per square meter, g
1	1	0.391	542	33	1.047	1.351	4.188
	2	0.072	170				
	3	0.036	63				
	Average	0.166	Total: 775				
2	1	0.231	286	34	0.791	0.806	3.164
	2	0.195	242				
	3	0.365	453				
	Average	0.264	Total: 981				
3	1	0.608	575	25	1.973	0.925	7.892
	2	0.655	725				
	3	0.710	806				
	Average	0.658	Total: 2,133				

Thus, the collection samples of this crop have been studied according to several economically valuable traits such as lab-based viability, the energy of germination, duration of the vegetattion period, sucrose content and productivity. Such traits have a significant impact on the potential success of the introduction of chia and on the further breeding for the conditions of the southern forest-steppe of Western Siberia. New seeds of the introduced collection samples have been obtained.

Conclusions

Experimental research on the collection samples of chia under the conditions of the southern forest-steppe of Western Siberia allowed identifying the sources of specific economically valuable traits (duration of the growing period, sugar content, productivity) which are of crucial interest for breeders. Based on the field- and lab-based trials, the following conclusions can be drawn:

1. Among the five collection samples at study, seed ripening was observed in the 3/18 sample with a duration of the growing period amounting to 120 days.
2. The research findings have shown that the sucrose content in the green leaves of chia varied from 6.2% to 14.3%, while in the seed shoots it ranged between 17.2% and 25.4%. The highest sucrose content in the leaves and seed shoots was observed in the 1/18 sample.

3. The number of inflorescences in the 3/18 sample varied between 25 and 34 pcs, while the number of seed per plant ranged from 575 to 2,133 pcs [12].

In order to increase the efficiency of the breeding process while creating new chia varieties, the 3/18 and 0/18 samples should be used as breeding sources [12].

One priority area in chia breeding remains the reduction of the duration of the vegetation period for the conditions of the southern forest-steppe of Western Siberia.

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