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Original article

AMARANTH GRAIN PROCESSING PRODUCTS AS SOURCES OF PLANT PROTEIN, STARCH, FAT, AND ANTIOXIDANT

R.Kh. Kandrokov, K.S. Bekshokov, P.A. Bekshokova

Background. *One of the principal ways to enhance the food products quality and improve the nutritional structure of the population is the introduction of non-traditional types of plant raw materials containing a balanced complex of proteins, lipids, minerals, vitamins, macro- and microelements into the diet.*

Methods. *As an object of research, we used amaranth grain of the "Voronezhsky" variety. The processing of amaranth grain into various products was carried out on MLP-4 laboratory grinding mills with fluted and smooth microrough rollers.*

Results. *As a result of mechanical amaranth grain processing using stock-produced technological equipment, the following amaranth processing products were derived as a raw material for the production of various bakery, confectionery and food-concentrate products: whole grain amaranth flour, low-fat amaranth flour, starchy amaranth flour, protein amaranth flour, amaranth flakes and amaranth bran. Technological scheme for producing whole grain amaranth flour consisting of third break systems has been developed.*

Conclusion. *The yield of whole-ground amaranth flour was 97.2%, the yield of amaranth bran was 2.8%. Technological scheme for processing amaranth meal and consisting of one milling and three vibrating systems has been developed. The yield of whole-ground amaranth flour was 92%, the yield of amaranth bran was 8%. The optimum parameters of the amaranth grain hydrothermal treatment by cold conditioning were determined - in the production of amaranth flakes, the original amaranth grain are to have a moisture content of 12-13% and be binned* *for 2 hours. Established optimum roller space at which the yield of amaranth flakes reaches 88.9% per one pass through the roller mill is 0.1 mm.*

Keyword: *amaranth; processing; flour; grain; flakes; bran; protein*

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Научная статья

ПРОДУКТЫ ПЕРЕРАБОТКИ ЗЕРНА АМАРАНТА КАК ИСТОЧНИКИ РАСТИТЕЛЬНОГО БЕЛКА, КРАХМАЛА, ЖИРА И АНТИОКСИДАНТА

Р.Х. Кандроков, К.С. Бекшоков, П.А. Бекшокова

Обоснование. *Одним из основных путей повышения качества пищевых продуктов и улучшения структуры питания населения является внедрение в рацион нетрадиционных видов растительного сырья, содержащих сбалансированный комплекс белков, липидов, минеральных веществ, витаминов, макро- и микроэлементов. диета.*

Методы. *В качестве объекта исследования использовали зерно амаранта сорта «Воронежский». Переработку зерна амаранта в различную продукцию осуществляли на лабораторных мельницах МЛП-4 с рифлеными и гладкими микрошероховатыми вальцами.*

Полученные результаты. *В результате механической переработки зерна амаранта с использованием серийного технологического оборудования получены следующие продукты переработки амаранта как сырье для производства различных хлебобулочных, кондитерских и пищеконцентратных изделий: мука амарантовая цельнозерновая, мука амарантовая обезжиренная, крахмалистая амарантовая мука, белковая амарантовая мука, амарантовые хлопья и амарантовые отруби. Разработана технологическая схема производства цельнозерновой амарантовой муки, состоящей из систем третьего дробления.*

Заключение. *Выход цельномолотой амарантовой муки составил 97,2%, выход амарантовых отрубей - 2,8%. Разработана технологическая схема переработки амарантового шрота, состоящая из одной фрезерной и трех вибрационных систем. Выход цельномолотой амарантовой муки составил 92%, выход амарантовых отрубей - 8%. Определены оптимальные* *параметры гидротермической обработки зерна амаранта холодным кондиционированием - при производстве амарантовых хлопьев исходное зерно амаранта должно иметь влажность 12-13% и находиться в консервированном состоянии в течение 2 часов. Установленный оптимальный шаг валков, при котором выход амарантовых хлопьев достигает 88,9% за один проход через вальцовую мельницу, составляет 0,1 мм.*

Ключевые слова: *амарант; переработка; мука; зерно; хлопья; отруби; белок*

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Introduction

The nutritional structure of the population for Russian Federation has undergone an adverse change over the last 30 years, which resulted into decrease of animal proteins consumption by 25% (incl. complete protein by 50%), total of dietary calories by 15%, animal fat consumption by 70% and plant protein by 30% [1].

Traditional types of plant-based raw materials in Russian include wheat, rye, barley, buckwheat, corn, rice, millet. One of the principal ways to enhance the food products quality and improve the nutritional structure of the population is to introduce into the diet non-traditional types of plant raw materials containing a balanced complex of proteins, lipids, minerals, vitamins, macro- and microelements and being nutrient-rich, preventive and of high palatability [2-7].

Relevant and important direction in the development of the food and processing industry is advancement and implementation of cutting-edge industrial technologies like the production of new types of foodstuff (for general, functional and specialized purposes, of increased nutritional value and with a high content of protein and vitamins) [8-10].

A new source of raw materials for the food industry has appeared on the Russian market - amaranth grain and its processing products that have a valuable chemical composition as well as high nutritional and biological value and contain a wide range of physiologically functional nutrients, which determines the prospects for their use in food technology productions [11-15].

Recently, amaranth grain and its processing products have found wide application in the domestic market as a new plant source of raw materials for the food, oil extraction and pharmaceutical industries. Amaranth grain is one of the most promising non-traditional type for producing various foods as well as nutritional supplements of functional purpose. Amaranth surpasses many traditional cereals in terms of protein, amino acids, vitamins, macro- and microelements, biologically active substances and fat content, incl. wheat and rye. [16-21].

I would especially like to note that all amaranth grain processing products contain a unique substance - squalene, which is a strong natural antioxidant, the content of which reaches up to 8% and vitamin E (1.19 mg/100 g), which is in the tocotrienol form, the antioxidant properties of which higher than that of its tocopherol form. In addition, vitamin E (4.2 mg/100 g) enhances the effectiveness of other antioxidants contained in processed products [21-22].

Comprehensive studies of scientific literature in food systems texture and organoleptic evaluation of yogurts with the addition of amaranth flour, the effect of high hydrostatical pressure on the content of indispensable amino acid, the increase in the protein content in an amaranth drink, the interfacial and emulsifying properties of amaranth (amaranthus hypochondriacus) protein isolates under different acidity conditions, and identification of certain macroelements in the mycelium and broth of medicinal mushrooms grown on amaranth flour, and the mimic composition, texture and organoleptic evaluation of yogurts with the addition of amaranth flour [22-28].

Amaranth grain has a valuable chemical composition, including high content of the most important, essential amino acid - lysine, high nutritional and biological value, and is a promising raw material for various branches of the food and processing industry [29-33].

Amaranth grain pomacepomace is a by-product of the oil extraction industry. After the extraction of oil from the amaranth grain, it is milled to varying degrees of dispersion for the intended use. Amaranth grain processing products contain essential amino acids, insoluble dietary fiber, PP vitamins, minerals balanced in the content of Ca and P macronutrients. Analysis of various literary sources reflects the advisability of using amaranth processed products as an enriching supplement in various food products. The inclusion of amaranth meal flour into the formulation of bakery products will resolve the deficiency problem of essential nutrients in the Russian population diet [34-38].

Table 1 represents a comparative characteristic of the main components content in the grain of amaranth, wheat and rye [1].

Table 1.

Content of the main components in amaranth, wheat and rye

Crop	Protein, %	Fat, %	Carbohydrates, %	Fiber, %	Ash, %	Water, %
Amaranth	17.6	7.4	54.2	6.2	2.6	12
Wheat	12.3	1.7	68.4	2.0	1.6	14
Rye	11.0	1.7	69.6	1.9	1.8	11

Table 2 represents the amino acid composition of various types and varieties of wheat and amaranth flour for the production of bakery and confectionery products compared by three limiting essential amino acids - lysine, methionine and threonine. The common use of wheat flour worldwide determined its' choice in the comparative study of amino acids composition.

Table 2.

Comparative study of amino acids composition of wheat and amaranth flour for the production of bakery and confectionery products (by three limiting essential amino acids) (Zharkova & Trufanova, 2016)

Amino acid	Premium quality wheat flour, g/100 g protein	First grade wheat flour, g/100 g protein	Whole grain amaranth flour, g/100 g protein	Starchy amaranth flour, g/100 g protein	Protein amaranth flour, g/100 g protein
Lysine (L)	0.250	0.265	1.340	0.483	3.692
Methionine (M)	0.153	0.160	0.626	0.250	1.492
Threonine (T)	0.311	0.318	0.644	0.226	1.917
Total: (L+M+T)	0.714	0.743	2.610	0.959	7.101

The tables 1 and 2 represent that plant protein, which is contained in wheat, rye and respectively in wheat and rye flour of various varieties, is biologically incomplete (low content of limiting essential amino acids) compared to amaranth and products of its processing. Consumption of food products based on traditional varieties of wheat and rye bread cannot provide the population with biologically valuable protein and vitamins absorbed with plant foods. The content of limiting amino acids In different varieties of amaranth, that is, lysine, methionine and threonine exceeds traditional wheat and rye flour 1.3 to 10.0 times.

Amaranth flour is a dietary product to tackle obesity. The inclusion of amaranth flour-based foodstuff in the menu allows to reduce calories one consumes, while energy and performance will remain at the appropriate level because of the unique amino acid composition of amaranth [39-44].

This variety of flour became widely used in dietary nutrition as a biological supplment in the production of fermented milk products that do not require heat treatment. Amaranth flour can be added in small quantities (1-2 tablespoons) to cottage cheese, yogurt, and kefir. Foodstuff based on amaranth flour improves health state and prevents cardiovascular, oncological, dermatological, immune, digestive tract, metabolic and other diseases. Amaranth flour is gluten-free and can be eaten by people with celiac disease and gluten enteropathy [45-50].

One of the most valuable products of amaranth grain processing is amaranth oil, produced both by extraction and mechanical pressing, containing not only saturated and unsaturated fatty acids, but also squalene. One of the most important properties of squalene is its ability to accelerate angiogenesis that prevents the formation of cancer cells [51-54].

Squalene is one of the most important bioactive compound that acts as a regulator of lipid and steroid metabolism, is a precursor of various steroid hormones, and is a part of the epidermal lipid layer. It effectively protects the cells and especially the liver from the harmful effects of endogenous and exogenous toxins- Squalene has wound healing properties because of its immunomodulatory effect, which promotes healing and restoration of both damaged tissue architecture and organs. Furthermore, a fairly large number of fats (oils) in flour has an adverse effect on the baking properties of products with whole grain amaranth flour [55-58].

The purpose of this research is the technology of processing amaranth grain into various products as sources of vegetable protein, starch, fat and antioxidant.

The **purpose** of the research is to obtain an assortment of various amaranth grain processing products, including whole-ground amaranth flour, amaranth grains, semi-skimmed amaranth flour, starchy amaranth flour, amaranth flakes and amaranth bran.

Materials and Methods

As an object of research, we used amaranth meal, which results from mechanical pressing, and grain, both are of the "Voronezhsky" variety.

Determination of the quality indicators of the original grain of amaranth and products of its processing was determined according to the standards in force in the Russian Federation. Determination of grain moisture was carried out according to GOST 13586.5-2015 by dehydrating a sample of crushed grain in an air-heating cabinet at fixed parameters: temperature and duration of drying and determining its weight reduction. Determination of starch content in grain and flour was carried out according to GOST 10845-98 Grain and products of its processing; The determination of the mass fraction of protein in grain and flour was carried out according to the Kjeldahl method according to GOST 10846-91; fat content - according to GOST 32749-2014; fiber content - GOST 32040-2012; ash content - according to GOST 10847-74. Chemical and physico-chemical parameters of amaranth flour from amaranth meal are determined by: GOST (National Standard of Russian Federation and CIS countries) 5668-68 "Methods for determination of fat fraction of total mass", GOST 10846-91

"Method for determination of protein", GOST 10845-88 "Method for determination of starch", GOST 31675-2012 "Methods for determination of crude fibre content with intermediate filtration", GOST 27494-87 "Methods for determination of ash content". The chemical and physico-chemical parameters of amaranth grain processing products were assessed on SpectraStar 2500 XL (Unity, USA), an infrared light grain analyzer.

At the first stage, as a result of fractionation on a sieve separator of the initial amaranth grain, three grain fractions of various sizes were obtained for more efficient processing. The amount of the 1st fraction (removed from a 1000 micron woven wire mesh sieves) was 17.7%, the amount of the 2nd fraction (passed through a sieve with a mesh size of 1000 micron and being removed from a sieve of 800 micron) was 76.2% and the amount of the 3rd fraction (passed through a sieve with a mesh size of 800 microns) was 9.1%. Therefore, 82.3% of the original amaranth grain mass as an object of research is less than 1 mm in size.

At the second stage, the processing of the original amaranth grain and the original amaranth meal was conducted with obtaining various products. The processing of amaranth grain into various products was carried out on MLP-4 laboratory grinding mills with fluted and smooth microrough rollers (Sovokrim, Russia). The main mechanical and kinematic indicators of the MLP-4 mill with fluted rollers are as follows: productivity - up to 100 kg/h, speed of the fast-rotating roller - 4.5 m/s, differential - 1.75, groove back-to-back arrangement, the number of grooves on the 1st linear centimeter - 8 pieces, groove slope 8%. Intermediate amaranth grain products were sieved on a separator which consists of 3 polyamide sieves designed according to GOST R (Russian National Standard) 51568-99 (ISO 33 10-1-90), two grits and one flour sieves with 850, 450 and 132 micron mesh size respectively.

Roller space in the laboratory grinding mills MLP-4 of the 1st break system is 0.25 mm, on the second break system is 0.15 mm, on the third break system is 0.10 mm.

Original amaranth meal was grinded on a laboratory hammer mill with a peripheral speed of 70.0 m/s (Sovokrim, Russia).

Research Results and Discussion

One of the common objectives of ongoing research consists in studying the structure and nutritional prices properties of amaranth grain, composition and properties of the main nutrients, as well as in the study of technological properties of grain and products of its processing. It will enable the development of innovative technologies and range of specialized gluten-free grain mixtures from amaranth grain for food de those with gluten intolerance.

It is known that ash content is directly related to mineral content. Carried out research on the study of the mass fraction of ash in whole grain amaranth welt flour, as well as flour enriched with protein from amaranth grain [16-18]. Increasing the protein content in flour (enrichment) was achieved by grinding and dividing flour into fractions with the release of protein parts and extraction of shells. Research data showed that the proportion of ash in enriched amaranth flour was higher (6.9%) than the ash content of whole grains new flour (2.4%) [30]. This indicates that in amaranth grains also contain minerals sharpened in the embryonic part, which makes them available for processing. The content of dietary fiber in amaranth grain corresponds to a value of 11.3% [30, 31]. Other cars report slightly higher values fiber content in amaranth grain - in the range from 14% to 16% [32]. The protein content in amaranth grain varies from 13.1% to 17.4%, which is higher than its content in other cereal crops. This fact is confirmed numerous world studies [21, 23, 26-27, 33]. Current data show the advantage substances of amaranth, from the standpoint of protein digestibility, milk protein similar in digestibility to casein and higher levels of lysine compared to other cereals.

Giving generalized data on the content main nutrients in native amaranth grain it can be noted that amaranth, like all cereals, belongs to the group of starchy raw materials, since digestible carbohydrates are mainly represented by starch. Relative to other traditional grain crops, amaranth is characterized by low content of dietary fiber, but significantly exceeds them in protein content. More In addition, the protein isolated from amaranth grain is close to ideal protein FAO/WHO (1973). By content threonine, phenylalanine, tyrosine and tryptophan equivalent to milk protein [29]. As a result of mechanical amaranth grain processing using stock-produced technological equipment, the following amaranth processing products were derived as a raw material for the production of various bakery, confectionery and food-concentrate products: whole grain amaranth flour, low-fat amaranth flour, starchy amaranth flour, protein amaranth flour, amaranth flakes and amaranth bran.

Whole grain amaranth flour

The easiest way to produce amaranth flour is to mill whole grains on stock-produced milling equipment. When producing whole grain amaranth flour, hydrothermal treatment of the original amaranth grain (moisturizing and binning) is not required. Technological scheme for producing whole grain amaranth flour consists of third break systems, in which case the yield of whole-ground amaranth flour is 97.2% and the yield of amaranth bran is 2.8%. Table 3 represents chemical composition obtained as a result of laboratory grinding of amaranth grain of whole grain amaranth flour (Fig 1) [58-59].

Table 3.

Chemical composition of whole grain amaranth flour

Product	Grams in 100 g of the product					
	protein	fat	starch	fiber	ash	moisture
Whole grain amaranth flour	15.6	7.2	58.2	3.7	3.0	11.5

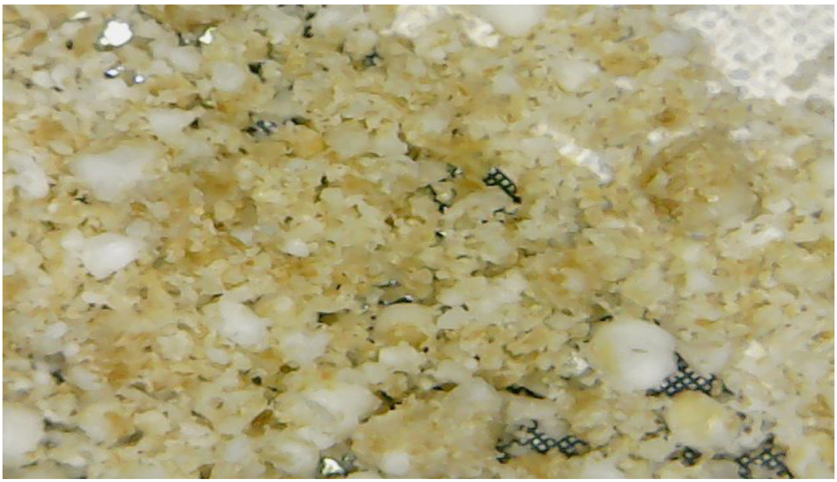

Fig. 1. Whole grain amaranth flour (20x magnification)

Low-fat amaranth flour

Original amaranth meal with the production of 92% amaranth flour and 8% amaranth bran was processed according to the technological scheme, which was developed at the Federal State Budgetary Educational Institution of Higher Education "Moscow State University of Food Production", and includes one milling and three vibrating systems. When milling the original amaranth meal on a laboratory hammer mill, milling system extraction is 25.0%. When milling sieve residue of a hammer mill with roller machine with fluted rollers, 1st reduction system extraction is 65.4%, 2nd is 55.4%, 3rd is 47.0%.

Considering increased value of amaranth oil, it is extracted from grain using the method "cold pressing" on screw presses. Since the grain oil content is low (about 8%), approximately 2-3% of the oil of the amaranth seeds initial mass can be extracted by using this method. The rest is evenly distributed over the contents of the amaranth grain by pressing (Fig. 2).

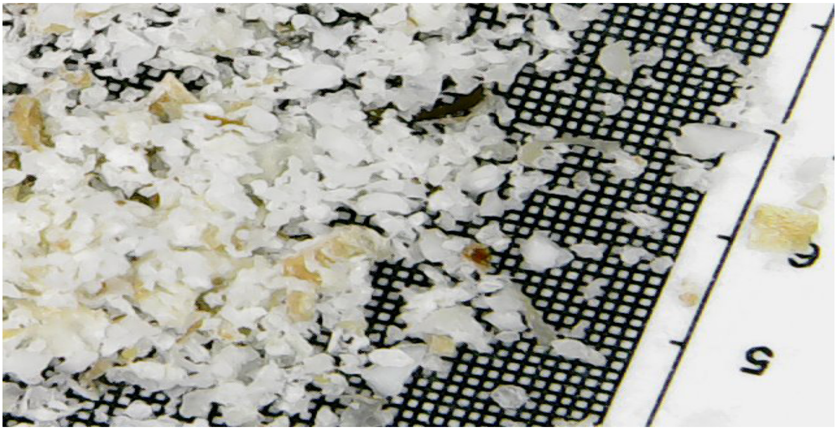

Fig. 2. Low-fat amaranth flour (20x magnification)

When the oil is extracted from the original grain, amaranth millcake is created, which is used to produce low-fat amaranth flour after milling and separating the bran (Table 4).

Table 4.

Content of the main components in low-fat amaranth flour

Product	Grams in 100 g of the product						
	protein	fat	starch	fiber	ash	moisture	energy value, kcal
Low-fat amaranth flour	19.9	2.5	68.9	1.3	2.7	12.0	354

Unlike whole grain amaranth flour, this flour has a significantly higher protein content (19.9 g instead of 15.6 g) and lower fat and starch content.

Starchy amaranth flour

Empirically, it was possible to find technological modes for amaranth grain processing that render possible its division into anatomical parts - the germ, shell and endosperm (starchy part). At the first stage, amaranth flakes derive from the original amaranth grain. At the second stage, after grinding and separation starchy amaranth flour and amaranth bran derive from the amaranth flakes, the endosperm of the grain (Fig 3).

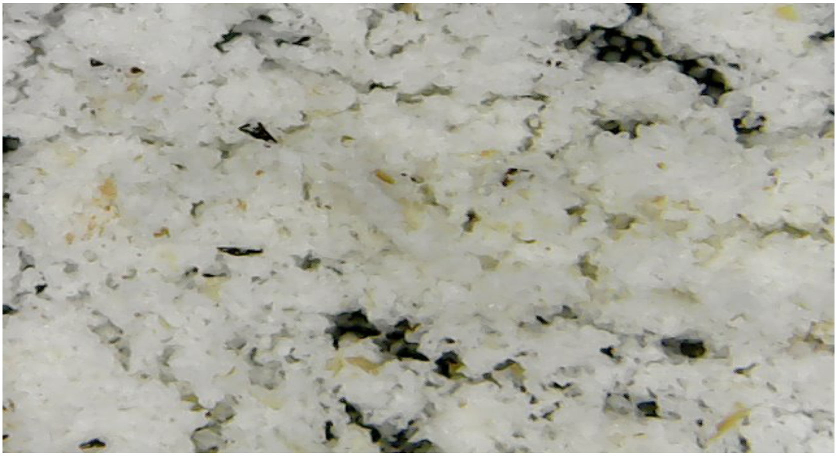

Fig. 3. Starchy amaranth flour (20x magnification)

Unlike the whole grain amaranth flour, this flour has a significantly higher starch content (76.7 g instead of 58.2 g per 100 g of flour) and a lower content of proteins and fats (Table 5).

Table 5.

Content of main components in amaranth starch flour

Product	Grams in 100 g of the product					
	protein	fat	starch	fiber	ash	moisture
Starchy amaranth flour	6.0	1.8	76.7	2.5	3.0	10.0

A great advantage of starchy amaranth flour is its positive impact on the baking quality attributes of both pan and hearth bread. Not all baking conditioners have an ability to significantly increase its shape stability along with significant increase in the volume of bread. At the same time, the organoleptic parameters of bread made of wheat baking flour of premium quality and starchy amaranth flour mixture were representatively rated with the highest score.

Along with the better appearance, the condition of the bread crumb was highly scored. In this regard, the bread had a light, pleasant aftertaste and flavor.

Protein amaranth flour

Studies have shown that virtually all amaranth oil is contained in the germ. When separating the grain into anatomical parts, specifically the germ, shells and endosperm, germ grits can be produced, its oil content reaches 20%. At present, there is no industrial technology for separating amaranth grain into anatomical parts. The total amount of amaranth germ grains is about 20-25% of the initial weight of the grain. Since the concentration of amaranth germ grits oil has increased, it is possible to extract up to 5% of the oil from the seeds total mass by cold pressing (Fig. 4).

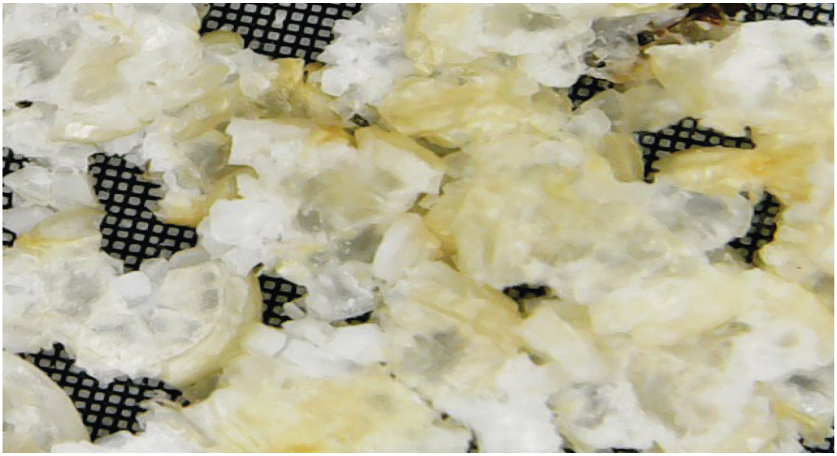

Fig. 4. Amaranth protein flour (20-fold increase)

When the oil is extracted from the original grain, amaranth meal is created, which is used to produce amaranth protein flour and amaranth bran after additional processing (Table 6).

Table 6.

Content of the main components in amaranth protein flour

Product	Grams in 100 g of the product					
	protein	fat	starch	fiber	ash	moisture
Protein amaranth flour	26.0	2.0	65.1	2.9	3.3	11.2

In contrast to whole grain amaranth flour, this flour has a significantly higher protein content (26.0 g instead of 15.6 g) and a lower content of fat and starch.

Under extreme life and work conditions (the Arctic coast, the far north, high mountain region, heavy manual operations), it is necessary to increase the amount of proteins and vitamins consumed with food. Foodstuff containing protein amaranth flour is suitable for these purposes.

Amaranth flakes

Amaranth flakes derive from whole amaranth grains on a flattening or roller mill with smooth microrough rollers. In terms of chemical composition, amaranth flakes are similar to amaranth grains since grains are flattened and not crushed into anatomical parts in the process of their production.

At the first stage, studies were conducted to determine the optimal roller space to derive the maximum yield of amaranth flakes from the original amaranth grain, which underwent hydrothermal treatment (HTT) by cold conditioning with binning for 2 hours in one pass. Cold conditioning was used as the HTT for being the most common method. Table 7 and Figure 5 represent the obtained data.

Table 7.

Roller space influence on the yield of amaranth flakes

Weight of original amaranth grain, g	Space, mm	850 micron sieve residue, %	475 micron sieve residue, %	132 micron sieve residue, %	Passed through 132 micron sieve, %
500	0.4	81.0	5.0	8.0	1.0
500	0.3	82.0	6.0	6.0	1.0
500	0.2	84.0	8.0	6.0	2.0
500	0.15	87.0	9.0	4.5	2.5
500	0.1	88.0	7.0	2.0	3.0

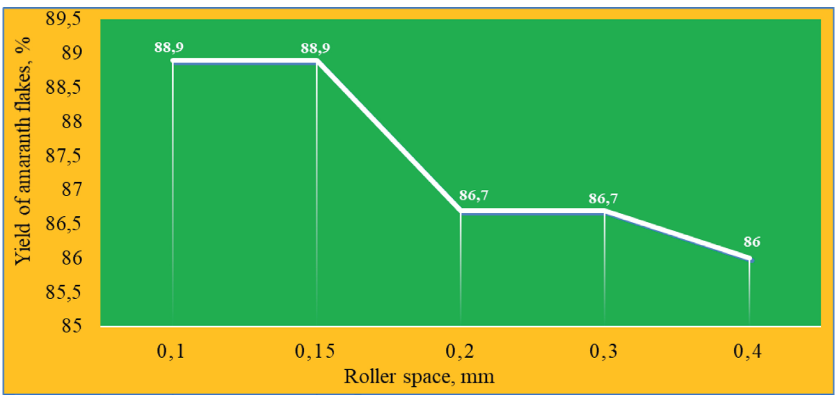

Fig. 5. The dependence of amaranth flakes yield on the size of the roller space

At the second stage, studies were conducted to determine how binning time affects the amaranth flakes yield. For this purpose, the original amaranth grain was moistened to 12-13% and binned for 2.0, 3.0, 4.0, 5.0, and 6.0 hours respectively (Table 8). It has been established that the highest yield of amaranth flakes per one pass through the roller gap is produced by binning for 2-3 hours.

Table 8.

Effect of binning time on the yield of amaranth flakes

Weight of original amaranth grain, g	Binning time, h	850 micron sieve residue, %	475 micron sieve residue, %	132 micron sieve residue, %	Passed through 132 micron sieve, %
450	2.0	88.9	6.8	3.3	1.0
450	3.0	88.9	5.7	4.4	1.0
450	4.0	86.7	5.7	5.6	2.0
450	5.0	86.7	5.7	5.1	2.5
450	6.0	86.0	6.0	4.0	3.0

Figure 6 shows the appearance of experimentally obtained amaranth flakes.

Fig. 6. Appearance of amaranth flakes

Studies conducted at the Federal State Budgetary Educational Institution of Higher Education “Moscow State University of Food Production” showed that with an optimal space gap of 0.1 mm the yield of amaranth flakes can be up to 88.9% per pass through the roller mill.

The implemented industrial technology on stock-produced high-performance domestic equipment makes it possible to produce 20-30% of germ grits, 60-70% of starchy amaranth flour and approximately 10% of amaranth bran from the original amaranth grain.

Conclusions

As a result of the research, a range of various amaranth grain processing products was produced, including whole grain amaranth flour, amaranth grits, Low-fat amaranth flour, starchy amaranth flour, amaranth flakes and amaranth bran. Technological scheme for producing whole grain amaranth flour consisting of third break systems has been developed. The yield of whole-ground amaranth flour was 97.2%, the yield of amaranth bran was 2.8%. Technological scheme for processing amaranth meal and consisting of one milling and three vibrating systems has been developed. The yield of whole-ground amaranth flour was 92%, the yield of amaranth bran was 8%. The optimum parameters of the amaranth grain hydrothermal treatment by cold conditioning were determined - in the production of amaranth flakes, the original amaranth grain are to have a moisture content of 12-13% and be binned for 2 hours. Established optimum roller space at which the yield of amaranth flakes reaches 88.9% per one pass through the roller mill is 0.1 mm. The patent for the invention of the Russian Federation No. 2 761 665 "Method for obtaining amaranth flakes" was received for the developed technology.

The resulting products of processing of amaranth grain can be used for the production of various bakery, flour confectionery and food concentrate products for mass and specialized food.

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DATA ABOUT THE AUTHORS

Roman Kh. Kandrokov, Associate Professor of the Department of Grains, Bakery and Confectionery Technologies
Russian Biotechnological University “ROSBIOTECH

11, Volokolamskoe shosse, Moscow, 125080, Russian Federation
nart132007@mail.ru
SPIN-code: 7081-1209
ORCID: https://orcid.org/0000-0003-2003-2918
Researcher ID: AAX-2106-2020
Scopus Author ID: 57200383950

Kerim S. Bekshokov, Associate Professor, Department of Biochemistry and Biophysics
Dagestan State University
43A, M. Gadzhiev Str., Makhachkala, 367000, Russian Federation
gopher2000@mail.ru
SPIN-code: 2670-5760
ORCID: https://orcid.org/0000-0003-0736-1522
Scopus Author ID: 57194067950

Patimat A. Bekshokova, Associate Professor, Department of Ecology
Dagestan State University
43A, M. Gadzhiev Str., Makhachkala, 367000, Russian Federation
patenka2009@mail.ru
SPIN-code: 3533-6890
ORCID: https://orcid.org/0000-0001-5473-0728
Scopus Author ID: 57204509939

ДАННЫЕ ОБ АВТОРАХ

Кандроков Роман Х., доцент кафедры зерновых, хлебопекарных и кондитерских технологий
Федеральное государственное бюджетное образовательное учреждение высшего образования «Российский биотехнологический университет «РОСБИОТЕХ»
Волоколамское шоссе, 11, г. Москва, 125080, Российская Федерация
nart132007@mail.ru

Бекшоков Керим С., доцент кафедры биохимии и биофизики
Федеральное государственное бюджетное образовательное учреждение высшего образования «Дагестанский государственный университет»

ул. М. Гаджиева, 43 А, г. Махачкала, 367000, Российская Федерация
gopher2000@mail.ru

Бекшокова Патимат А., доцент кафедры экологии
Федеральное государственное бюджетное образовательное учреждение высшего образования «Дагестанский государственный университет»
ул. М. Гаджиева, 43 А, г. Махачкала, 367000, Российская Федерация
patenka2009@mail.ru

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