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CHANGES IN QUALITY OF AMARANTH GRAIN IN THE COURSE OF POSTHARVEST HANDLING AND STORAGE

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Abstract. One of the solutions to the problem of people's health deterioration is the wide use of plant products. The most valuable of them are vegetable oils, including amaranth oil. The latter contains a complex of vitamins, macroelements and trace elements, unsaturated fatty acids and essential amino acids, and the unique natural bioactive substance squalene, which performs a number of key functions in the human body. However, postharvest treatment of amaranth grain, in particular, drying and subsequent storage under different conditions, can significantly impair its valuable natural properties. The research presents the findings on how the chemical composition and microbiological characteristics of amaranth grain change in the course of its drying and storage under different conditions, which can ensure its high quality during storage. It has been studied how drying amaranth to the moisture content 9% at 50°C and 60°C effects on the total amount of saponified substances and on the content of squalene, linolenic, linoleic, oleic, palmitic, and stearic acids (determined by gas–liquid chromatography). It has been found that after amaranth grain is dried, it loses 10% of saponified substances and 14% of squalene, as compared with freshly harvested grain, while the content of free fatty acids in the unsaponified fraction does not change. It has been determined how storing amaranth throughout a year at +5°C, +15°C, and +25°C, at the relative humidity 55% and 75%, changes such basic grain quality parameters as the content of protein, starch, fibre, fat, and ash, the acid value, and the acidity of fat. The biggest were the changes after a year's storage at 25°C and the relative atmospheric humidity 75%: protein decreased by 13.5%, starch by 8.7%, fat by 29.0%. There was almost no change in the contents of fibre and ash. Besides, these storage conditions resulted in a significant deterioration of the fat quality: its acid value increased by 6.9 times, and the alcohol extract acidity by 2.9 times. When amaranth was stored at +5°C and the relative humidity was 55%, the decrease in the content of the main components was appreciably smaller: 8.1% for protein, 2.9% for starch, and 4.2% for fat. Under the same conditions, the activity of microorganisms is significantly lower. All this allows recommending these storage conditions for industrial use.

Keywords: amaranth grain, postharvest grain handling, grain drying, grain storage, squalene, chemical composition of amaranth grain, grain microflora.

Introduction. Formulation of the problem

In recent years, people's health in our country has deteriorated. A solution to this problem can be the wide use of safe high-quality food with a guaranteed content of bioactive compounds vital for the human body. One of these valuable and promising cereals is amaranth. Its grain contains a complex of vitamins, macronutrients and trace elements, unsaturated fatty acids and essential amino acids, and a unique natural bioactive substance, squalene, which performs a number of key functions in the human body. Using amaranth grain is becoming more and more popular nowadays. It is an item of increasing demand with producers who are primarily interested in the quality of the raw materials and their compliance with all necessary requirements.

Domestic and foreign studies, though numerous, still have not fully revealed how the quality of amaranth grain changes during postharvest treatment and storage. After harvesting, grain is not immediately processed and used in production: first, it undergoes a

range of technological operations, primarily cleaning and drying. They are supposed not only to ensure long-term storage, but also to preserve all the valuable natural properties of amaranth which are important for further processing. This article focuses on how to solve these problems.

Analysis of recent research and publications

Amaranth has been known and used in the world since ancient times. This is evidenced by archaeological finds in the territory of the ancient American civilisations, the Incas and the Aztecs. In modern times, this crop first attracted scientists' and manufacturers' attention in the early 1970s, after the Australian plant physiologist D.Downton established that it belonged to a group of plants with high-intensity C_4 photosynthesis and could form quite a lot of protein rich in lysine, methionine, and tryptophan [1-11].

Compared with cereals and oil crops traditionally grown in Ukraine, the main feature of amaranth grain is its chemical composition that includes quite a number of substances having a high calorific and biological value. Of these, amaranth oil is of special interest. Besides being high in unsaturated fatty acids (65% to 75% according to various authors), this oil contains squalene. Squalene actively normalises microcirculatory processes, being a source of oxygen. According to domestic and foreign studies, amaranth is significantly higher in protein and fat than the most common crops, wheat and corn. It has the most balanced amino acid composition, and the ratio of amino acids makes amaranth protein close to the ideal protein [9,12-14].

Amaranth grain's unique properties allow an extremely wide range of its applications. The amaranth grain variety *Ultra* yields very valuable oil containing about 15–18% of squalene and up to 1% of tocopherol (vitamin E). Amaranth oil is considered an immunostimulant and can be used to correct immunodeficiency when treating diseases of various aetiologies, from cardiovascular disorders, erosions and ulcers to cancer. Besides, scientists have confirmed that drugs obtained from amaranth grain, as well as those from its stems and leaves, can significantly reduce blood cholesterol and protect the human body from the effects of radiation. This makes it applicable in traditional medicine [1,13-15].

Processing this crop's grain can yield up to 67% of high-protein flour, which can be used to manufacture functional products. Due to its low gluten content, amaranth can be an extremely useful product for people with allergy. But so far, the consumer market is not adequately saturated with amaranth-based products and is comprised mainly of dietetic foods [3,4,15,17].

Concentrate from amaranth grain can be used to make mixed milk drinks and as special food for people hypersensitive to cow's milk proteins. [5,7,11].

The herbage of amaranth and by-products of its processing prove quite useful to manufacture animal feed high in protein, pectin, dietary fibre, vitamins, macronutrients, and trace elements [1,2,6,13].

Another important fact in favour of amaranth cultivation is this crop's significant adaptive potential, which ensures high productivity at minimum expenditure of energy and has a positive biogeocoenotic effect on the soil fertility [1,2]. That is why a lot of studies are devoted to the technology of cultivation and selection of amaranth. The researchers who focused and still focus on these issues include D. Brenner, D. Early, C. Kauffman, T. Goptsiy, V. Shcherbakov, I. Kohut, G. Zharkov, S. Kadirov, S. Miroshnichenko, and others. They have developed in detail the agrotechnology of growing different amaranth species and varieties in different climatic zones. Much attention is also paid to the selective breeding of amaranth [1-3,7,8,14,18].

R. Bressani, L. Garcia-Vela, G. Vysochyna, A. Yegorova, G. Yevdokimova, L. Ovsyannikova, T. Chirkova, and others considered in their works the chemical composition of amaranth grain. They studied in detail the amino acid composition of protein, starch, lipids, trace elements, and macronutrients of different amaranth species, and considered the possibility of isolating certain substances from grains and from leaves and stems [6,9,13].

Methods of processing amaranth and its applications in various sectors of the economy were studied by A. Zheleznov, A. Kazumyan, E. Ofitserov, Y. Roslyakov, S. Smirnov, S. Sobolev, A. Sturua, R. Uazhanova, A. Iztaev, T. Schneider, E.Petrova, and others. In this sphere, a number of technologies were developed. They allow grinding amaranth grain and groats, enriching bakery, confectionery, pasta, and fermented dairy food with amaranth processing products, obtaining puffed grains, oil, etc. [3,4,13,15-17].

R. Abalone, A. Cassinera, J. Roberts, E. Ronoh, I. Chernousov, T. Yanyuk, and others focused on postharvest handling of amaranth grain. They investigated the technological, aerodynamic, and hygroscopic properties of amaranth grain, developed a method of drying amaranth grain in the device with the suspended-twisted layer, studied the kinetics of drying in open air-and-sunshine drying stands and the effect of long storage on the grain quality [5,19,20-23].

S. Smirnov suggested a technology of cleaning amaranth grain before grinding. It involves, first, using a vibratory separator SPV-06 to isolate large, small, and light impurities that have width different from that of the crop, and then using a pneumatic aspirator UPS-06 to separate those that differ in their aerodynamic properties [24].

I. Chernousov pointed out that to dry amaranth seeds, one needs a drying method that would allow developing higher speeds of the drying agent relative to the amaranth seeds, would ensure the maximum contact area of the drying agent with the surface of amaranth seeds, a gentle drying mode, and the

maximum intensity to cost ratio. That is why he suggested drying amaranth grain in an apparatus with a suspended-twisted layer. This method would allow obtaining dry grain and spending less energy on the drying process. However, these devices are not manufactured industrially yet [5].

R. Abalone and E. Ronoh compared the kinetics of drying a thin layer of amaranth grain under the open sun with drying it in an air-and-sunshine convective dryer [22,23]. These drying methods are constructionally simple and energy-efficient. Still, when used in Ukrainian climatic conditions, they will not allow obtaining amaranth grain dry enough: in our country, this crop ripens quite late (September and October), in the period characterised by high humidity, fogs, clouds, and rain.

L. Miroshnychenko considers the maximum shelf life of amaranth grain and suggests limiting it to 2 years, because longer storage significantly increases the grain's fat acidity, peroxide, and iodine values, which affects the grain quality [25].

Wet and damp amaranth grain should be cleaned of impurities and dried before storage to prevent deterioration. For reliable storage, amaranth grain must meet the following requirements: humidity not more than 9%, contamination with impurities not more than 2% [4,5,19].

Thus, due to many advantages, amaranth grain is becoming more and more popular nowadays. It is an item of increasing demand with producers who are primarily interested in the quality of the raw materials and their compliance with all necessary requirements. However, most research works are devoted to the selective breeding of amaranth, its cultivation, and processing. Only few studies consider the problems of its postharvest handling, in particular, drying and storage of amaranth grain. Besides, even in this area of research, works, for example, on the drying of amaranth grain mainly focus on heat and moisture transfer during drying and on their intensification, rather than on how they affect the quality of dried grain. The dependence of the quality characteristics of amaranth grain on the temperature and relative humidity during its storage has been analysed but insufficiently, too. This determined the purpose and the objectives of our research.

The purpose of the research is studying the changes in the chemical composition and microbiological characteristics of amaranth grain during its drying and storage under different conditions, which will ensure its quality and reliable storage. The research **objectives**:

– to study the effect of drying amaranth on the content of squalene and fatty acids;

– to study the effect of the storage conditions on the chemical composition and microbiological characteristics of amaranth.

Research materials and methods

The amaranth grain variety *Ultra* of domestic selection grown in the Odessa Region in 2014 was used for the research. The grain contained 9% of moisture and 1.7% of impurities. This early-ripening grain variety (its originator was V. Dokuchaev Kharkiv National Agrarian University) was included in the Register of Plant Varieties of Ukraine in 1998.

The convective drying of amaranth grain was studied using a laboratory dryer at the Grain Storage Technology Department, ONAFT. This dryer simulates the conditions of drying created by industrial grain dryers [26]. The quality characteristics of the dried amaranth grain were inspected using a grain dryer *Astra-Ingul-Mini* in the production conditions of the farm *Elena*.

Amaranth is processed primarily to obtain amaranth oil, and its squalene content is considered an important characteristic. So, after the convective drying, the total amount of saponified substances and the contents of squalene, linolenic, linoleic, oleic, palmitic, and stearic acids were determined in the dried amaranth grain. The results of the studies were expressed as a percentage in dry matter (DM).

The fatty acids and squalene content was determined in the Odessa Research Forensic Centre of the Ministry of Internal Affairs of Ukraine using chromatography–mass spectrometry as follows.

To quantify the saponified and unsaponified substances, the weighed amaranth grain samples (10g each) were homogenised with quartz sand and extracted with hexane for 2 hours three times. The combined extracts were evaporated to dryness. Then 20ml of methanol and 10ml of aqueous 20% NaOH were added. The esterification was performed for 4 hours in a glycerol bath. The resulting solutions were extracted three times with hexane. Then 10% HCl solution was added till pH=3 and extracted with hexane, too. The hexane extracts were evaporated to a constant weight and weighed on analytical balances.

Squalene was determined by gas–liquid chromatography using a chromatography–mass spectrometer Agilent 6890 N/5975 Inert GC/MS System. The conditions were as follows: capillary column HP-35MS, length 30m, diameter 0.25mm, phase 0.25 μm, steady flow 1.0ml/min, carrier gas helium, auto-injector Split 20:1, evaporator temperature $T_{initial}$ 2000°C, time 2min, heating 100°C/min, T_{final} 3000°C, electron-impact ionisation, ionisation energy 70eV, ion source temperature T 2399°C, detector interface temperature T 2500°C, sample volume 1μl. The resulting chromatograms were processed using the software MSD ChemStation D.03.00.611 Agilent Technologies. Spectrum analysis was performed using the software AMDIS 2.64, NIST Mass Spectral Search Program Ver/2/0 Dec 2005 with the basic library.

The quantitative composition of squalene, linoleic, linolenic, oleic, and palmitic acids were determined by the internal standard method using calibration curves.

The amaranth grain was stored in an ONAFT laboratory. The 0.5kg samples of shelled dried amaranth grain with the initial moisture content 9% were kept in jute bags for a year. The bags were placed

in desiccators with controlled air parameters: air temperature t=+5, +15, and +25°C, relative humidity φ=55 and 75%. The required relative humidity in the desiccators was created by the appropriate concentration of sulphuric acid solution, and refrigerators and thermostats provided the right temperature.

Prior to putting the amaranth in storage, and every three months during the storage period, the grain's quality parameters were determined: protein, starch, fat and its acid value and acidity in terms of dry matter, and the composition of the microflora (QMAFAnM – quantity of mesophilic aerobic and facultative anaerobic microorganisms).

The generally accepted quality characteristics of amaranth grain were studied at ONAFT departments by standard methods [27]. The moisture content was determined by the accelerated thermogravimetric method (according to ISO712-85) in a drying chamber SESH-3ME; protein by the Kjeldahl method (ISO5983:2005) using a device Kjeltec8100 made by FOSS Tekator (Sweden); starch by polarimetry (ISO6493:2000); crude fat by defatting with ethyl ether in a Soxhlet apparatus (ISO6492:2000); fibre by acid and alkaline hydrolysis (ISO6865:2000); ash by ashing in a muffle furnace (ISO5984:2000). The fat quality parameters, such as the acid value of fat and the acidity of alcohol extracts, were established by the traditional titrimetric method [28,29].

The microflora of amaranth grain was analysed by traditional methods [30]. The quantitative and qualitative composition of the microflora was determined by taking wipe samples of microorganisms from the surface of amaranth grain, followed by its tenfold dilution and inoculation on meat-and-peptone agar (MPA) and wort agar (WA). The inoculated cultures were grown at +37°C and +28°C respectively. The total bacterial count was determined on the MPA after 48 hours, and micromycetes on the WA after 7 days. Spore forms of bacteria were determined in pasteurised wipe samples from amaranth grain which were inoculated on a combined growth medium MPA+WA (1:1). The generic assignment was established by cultural and morphological characteristics.

After a year of storage (from November 2014 to October 2015), the quality parameters of amaranth grain were tested in a production environment at the farming enterprise *Tumanove*.

Results of the research and their discussion

At the first stage of the research, the amaranth grain was dried. The most common convective drying was performed on a test bench installation in a dense layer with the initial moisture level 16.4% at 50°C and 60°C. The amaranth grain layer was 0.1m thick, and the drying agent velocity was 0.6m/s, which simulates the drying conditions in industrial grain dryers. Amaranth was dried to the standard moisture content 9%.

The results of the study have shown that using a drying agent with the temperatures 50°C and 60°C allowed reducing the moisture content of amaranth grain to the standard acceptable values during drying. With these temperatures of drying, the grain was never heated above 50°C. The drying process lasted 36 and 24 minutes at the temperatures of the drying agent 50°C and 60°C respectively.

Table 1 – Content of squalene and fatty acids in the amaranth grain of the variety *Ultra* before and after drying, % on a DM basis (n=3, p≥0.95)

Parameters		Before drying	After drying
Content of saponified substances		6.15	5.59
Content of squalene		1.04	0.91
Content of free acids in the unsaponified fraction, %	Linoleic acid	1.6	1.6
	Linolenic acid	49.2	49.2
	Oleic acid	14.6	14.6
	Palmitic acid	6.2	6.2
	Stearic acid	2.0	2.0
	Undefined substances	26.4	26.4

Drying the samples of amaranth grain at 50°C and 60°C has allowed determining such important parameters of its quality as the total amount of saponified substances, the content of squalene, of linolenic, linoleic, oleic, palmitic, and stearic acids. The averaged results obtained (% on a dry matter basis) are given in Table 1.

Despite the moderate drying agent temperatures (50-60°C), the content of saponified substances in amaranth grain decreased by an average of 10.0%, and that of squalene by 14.3%, compared with similar parameters in freshly harvested grain before drying (Table 1). The content of free fatty acids in the unsaponified fraction remains unchanged.

The next stage of the research focused on the changes in the amaranth grain quality depending on the duration and conditions of storage (temperature and relative humidity).

On studying the changes in the chemical composition of amaranth grain during storage, it has been found that after 12 months of storage at the temperature +25°C and relative humidity 75%, the initial total nitrogen content (2.55%) remained about the same (2.53%). However, there was a gradual decrease in protein nitrogen (from 1.59% at the beginning of the research to 1.44% after 12 months of storage under the above conditions) and in protein (from 9.93% to 9.00%). This was accompanied by a corresponding increase in non-protein nitrogen compounds: from 0.96% to 1.10% (Fig. 1).

The histograms make it clear that this decrease in the protein content results from longer storage time and increased storage temperature and relative humidity. The protein changes the least when amaranth is stored at the temperature +5°C and relative humidity 55% (from 9.93% to 9.19%, i.e. by 8.1%).

The changes in the protein content observed during storage of amaranth grain can be explained by natural ageing processes in grain as a living organism. Their intensity increases with the increasing temperature and relative humidity.

In the course of storage, the starch content gradually decreases at all temperatures and relative humidites (Fig. 2). It should be noted that when amaranth is stored at a low temperature (+5°C) and relative humidity (55%), the starch content decreases more slowly (from 61.4% to 59.7%) than at higher temperatures and humidity (from 61.4% to 56.5%). The decrease in the mass fraction of starch can be explained by the fact that an increase in the temperature and humidity intensifies grain's aerobic respiration, which accelerates the consumption of carbohydrates this process requires. Besides, longer storage intensifies the natural aging processes in grain.

Most parameters of the chemical composition of amaranth grain vary with different storage conditions, and its fat content changes, too: not only the amount of fat (Fig. 3), but its quality as well (Fig. 4, 5). So, after 12 months of storage at +25°C and at the relative humidity φ = 55%, the amaranth grain contained 6.0% of fat (with 6.5% in the original sample), and after 12 months' storage at +25°C and φ=75%, the amount of fat decreased to 5.0%.

It should be noted that according to N. Kozmina, a famous grain biochemist [28], grain storage leads to the greatest changes in the composition and properties of the lipid fractions of grain, as they are most susceptible to oxidative and hydrolytic processes. Various enzymatic processes take place in the lipid complex: phospholipids and glycolipids are cleaved, and free fatty acids accumulate. Unsaturated fatty acids, especially the free ones, are oxidised by oxygen from the air and by the enzyme lipoxygenase. Peroxides, hydroperoxides, and other oxidation products accumulate and can form complexes with proteins and carbohydrates. All this affects the quality of fats during storage.

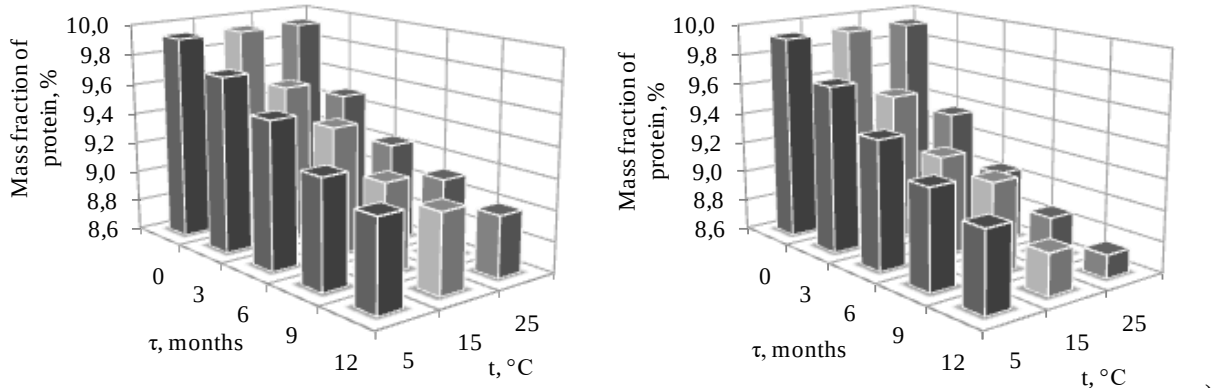


Fig. 1. Change in the protein content of amaranth grain on a DM basis during storage under different conditions: a) φ=55%; b) φ=75%

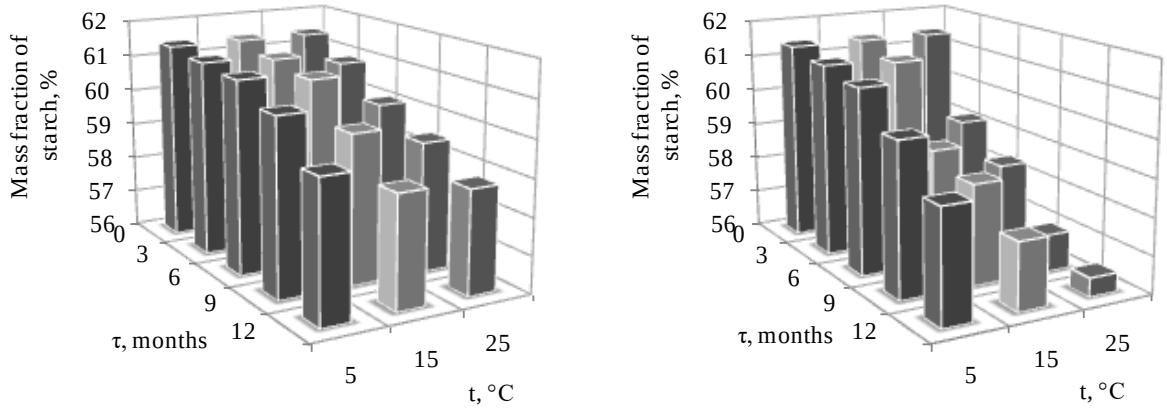


Fig. 2. Change in the starch content of amaranth grain on a DM basis during storage under different conditions: a) φ=55%; b) φ=75%

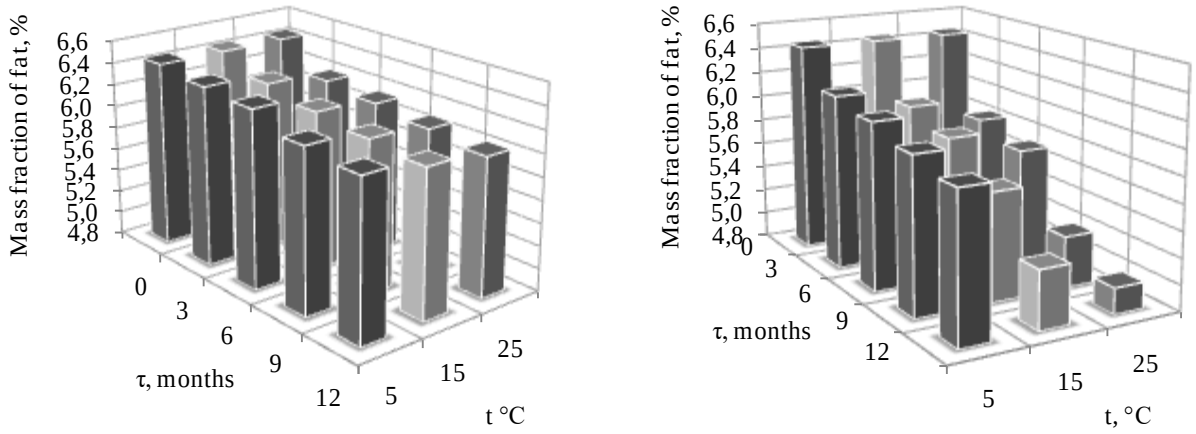


Fig. 3. Change in the fat content of amaranth grain on a DM basis during storage under different conditions: a) φ=55%; b) φ=75%

The simplest way of controlling the changes in the quality of fat in grain is monitoring the acid value and acidity of fat. Fig. 4 and 5 show how these parameters of fat quality change when amaranth grain is stored for 12 months under different conditions.

After 12 months of storing the amaranth grain at +5°C and φ=55%, there was almost a threefold increase (2.9times) in the acid value of fat (Fig. 4). At the relative humidity of the air φ=75%, with the temperature and storage duration being the same, the acid value of fat increased 3.5 times. At +25°C and the relative humidity 75%, the acid value increased even more significantly – 6.9 times.

The acidity of amaranth grain stored under different conditions typically increases, too (Fig. 5). It should be noted that it is the storage temperature, rather than the relative humidity, that determines the changes in the acidity of alcohol extract. A higher increase in the acidity is observed at the storage temperature +25°C and relative humidity of the air 75%. Thus, after 12 months' storage at +5°C and relative humidity 55-75%, the acidity of the alcohol extract of the grain increased from 2.4° to 3.3–3.8°, and at +15°C, it increased from 2.4° to 4.3-4.4°.

If amaranth is stored at +15°C and relative humidity 55%, the acid value of fat increases by 3.6 times, and the acidity of the alcohol extract by 1.8 times.

The studies of how different storage conditions change the quality of amaranth have also shown that regardless of the temperature, relative humidity, and duration of storage, the fibre content was 4.40-4.47%, and that of minerals 3.85–3.90%. Thus, throughout the year of storage, they remained almost at the same level as in the control (i. e. these parameters had the same values as at the beginning of storage): 4.41% and 3.85% respectively.

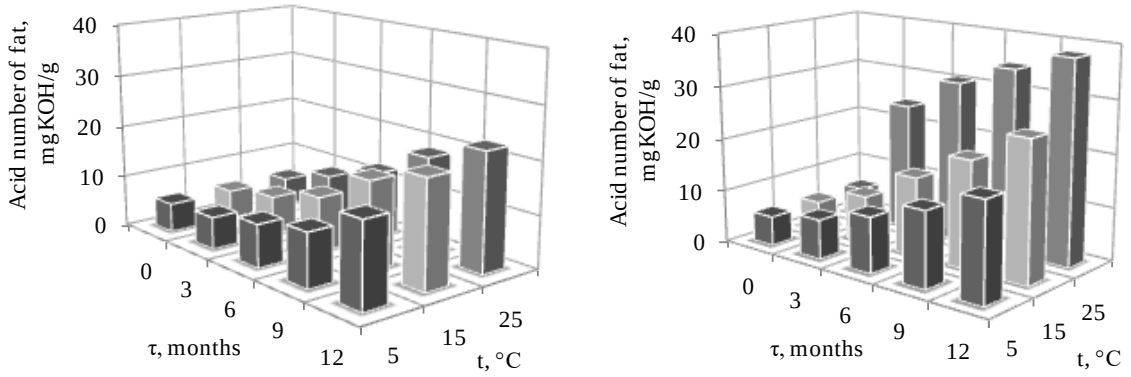
The microbiological parameters of any product are very important characteristics of its quality. The most common microbiological parameter is the quantity of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM). Used in the food industry, it indicates the sanitary condition of production.

The predominant component of the original bacterial microflora of amaranth grain (Fig. 6), and of most cereals, too, is the nonsporiferous bacillus *Erwinia herbicola*. This representative of epiphytic microflora is a normal companion of grain when it is stored under standard conditions, and does not cause grain spoilage. However, in large amounts and in the active state, *Erwinia herbicola* intensively emits heat and promotes the process of self-heating. About a third of the microflora is made up by other fungi, and the smallest share is that of coliform bacteria.

At φ=55%, no growth of microorganisms was detected on the amaranth grain during storage (Fig. 7). On the contrary, the initial number of bacteria and micromycetes decreased in the course of 12 months of storage by 74.4–88.9% and 78.0–85.0% respectively. Storage at the relative humidity 75% resulted in less intense reduction in microorganisms: after 12 months, the initial number of bacteria and micromycetes decreased by 60.4–80.7% and 66.1–68.5% respectively. Their largest reduction occurred during storage at +5°C, and the smallest at +25°C. The decrease in the number of bacteria was mainly due to the death of those of the species *Erwinia herbicola.* Almost no micromycete development took place at this relative humidity, but a change in their species composition was observed.

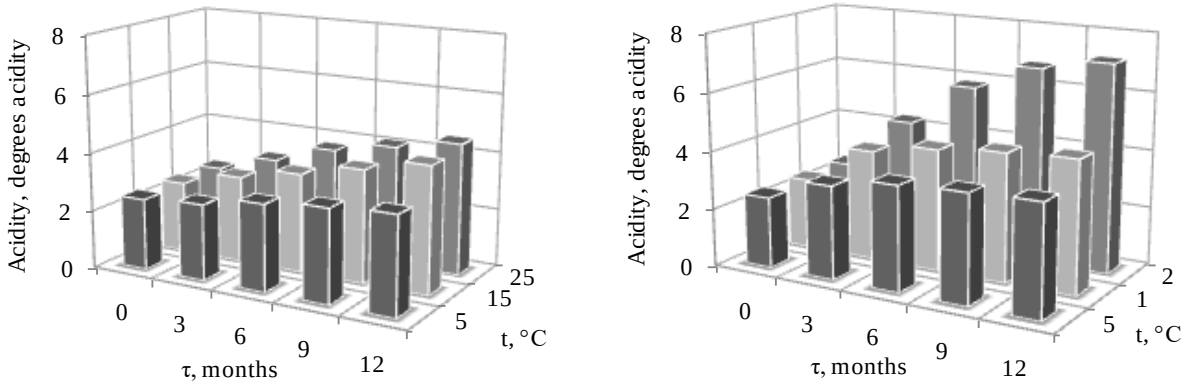
During storage, changes were also observed in the composition of the fungal flora of amaranth grain. It has been noticed that the fungi *Alternaria*, *Cladosporium*, *Mucor*, and other unidentified field fungi decrease in number, compared with the beginning of storage. However, there is an increase in moulds of the genera *Penicillium* and *Aspergillus*, which become permanent components. Almost all fungi developing during storage at +5°C and +15°C belonged to the genus *Penicillium*, and at +25°C, fungi of the genus *Aspergillus* were observed to develop, too.

It should be noted that pathogenic microorganisms that could cause accumulation of dangerous toxins in amaranth grain were not detected.



a) b)

Fig. 4. Change in the acid value of fat in amaranth grain during storage under different conditions: a) φ=55%; b) φ=75%



a) b)

Fig. 5. Change in the acidity of amaranth grain during storage under different conditions: a) φ=55%; b) φ=75%

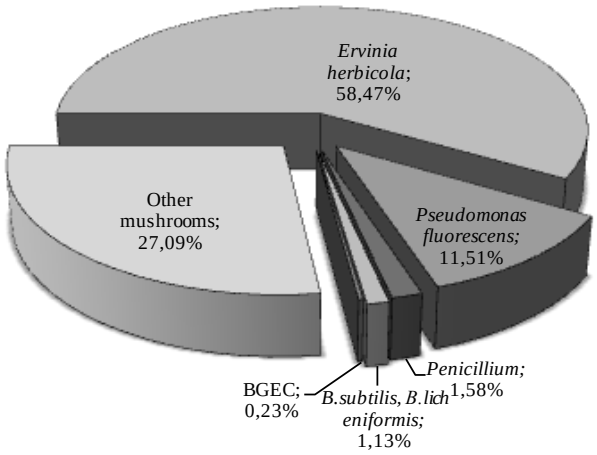


Fig. 6. Characteristics of the original composition of the amaranth grain microflora

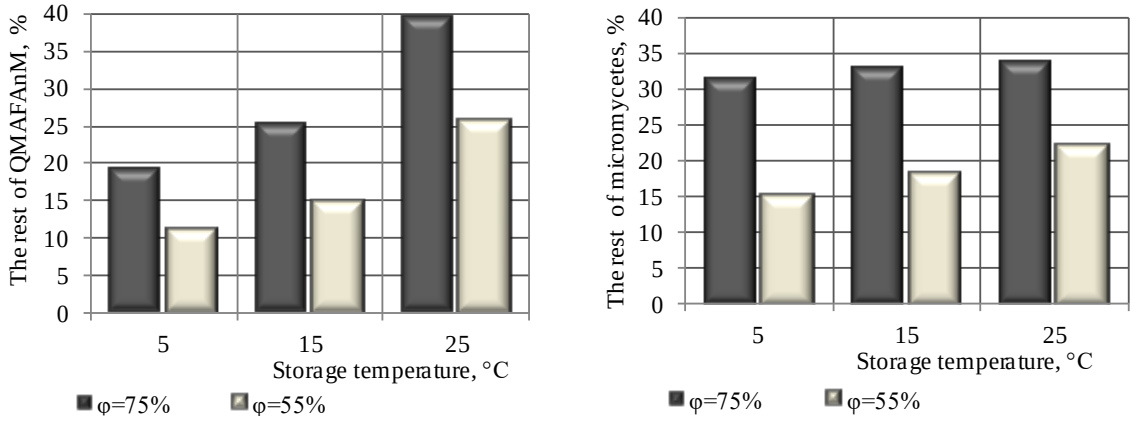


Fig. 7. Change in the QMAFAnM (a) and micromycetes (b) after 12 months of storage under different conditions

In the production environment of the farm *Olena*, a grain dryer Astra-Ingul-Mini was used to dry a batch of amaranth grain with the initial moisture content 16.2% and contamination 1.1%. The drying agent velocity was 0.6-0.8m/s, the drying agent temperature was 58–60°C, and that of the ambient air was 15°C. The maximum temperature of heating the amaranth grain during drying did not exceed 48–50°C. Cold pressing allowed obtaining 6.4% of amaranth oil from dried amaranth grain with the moisture content 9.4–9.6%. The oil's squalene content was 6.9%, and the acid value of fat was 3.12mg KOH/g. Thus, drying amaranth grain with the drying agent temperatures up to 60°C ensures the acceptable moisture content and the required quality of the resulting dried grain**.**

The quality parameters of the amaranth grain after a year of storage (from November 2014 to October 2015) were tested in a production environment at the farm *Tumanove*. Grain with the moisture content 9.5–10.0% and the acid value 3.51% was stored in a floor-type warehouse under uncontrolled conditions in three-layer paper bags, each containing 50kg, stacked on the wooden floor. During the year of storage, the air temperature in the warehouse fluctuated within 5–20°C, and the relative humidity within 55–80%. The initial acid value of fat was 3.51mg KOH/g. In October 2015, after a year of storage of the amaranth, its quality parameters were determined: the grain's moisture content 8.5–9.6%, the acid value 4.86mg KOH/g, which complies with those prescribed for amaranth food grain. No damage or undesirable changes in the quality of amaranth grain during storage were found. The amaranth grain was not stored further, because the enterprise sold it.

The successful preservation of the amaranth grain's quality in a production environment can be explained by the fact that the average annual air temperature in the warehouse was maintained at the level of 12.5°C, and the relative humidity was 67.5%. The grain was stored in the cold season, which helped to reduce its temperature to values of about +5°C. Grain storage practice shows that chilled grain, due to its poor thermal conductivity, retains its low temperature for a long time. This prevents loss of its quality, in particular, an increase in its acid value. Besides, three-layer bags protect the grain from the negative effects of the ambient air humidity.

Conclusions

1. It has been established how convective drying of amaranth in a dense layer effects on the total amount of saponified substances, on the content of squalene, linolenic, linoleic, oleic, palmitic, and stearic acids. It has been shown that after amaranth grain is dried at 50°C and 60°C to the humidity 9%, the content of saponified substances decreases by 10.0% and that of squalene by 14.3%, compared with freshly-harvested grain, and the content of free fatty acids in the unsaponified fraction remains unchanged. Field testing has confirmed that convective drying of amaranth grain, with the drying agent temperatures up to 60°C, guarantees the acceptable humidity and proper quality of the dried amaranth grain obtained.

2. It has been established that there are regular features in the changes in such basic quality characteristics of amaranth grain as protein, starch, cellulose, fat, ash, as well as the acid value and acidity of fat, when grain is stored for a year at +5°C, +15°C, and +25°C and at the relative humidity 55% and 75%. The biggest changes have been found to occur after a year of storing grain at 25°C and the relative humidity 75%. With this storage mode, the protein content decreased by 13.5%, starch by 8.7%, fat by 29.0%. The content of fibre and ash remained almost unchanged. Besides, these storage conditions resulted in significant deterioration in the quality of fat: the acid value increased by 6.9 times, and the acidity of the alcohol extract by 2.9 times. When storing amaranth at the temperature +5°C and the relative humidity 55%, the decrease in the content of the main components was significantly smaller: 8.1% for protein, 2.9% for starch, and 4.2% for fat.

3. It has been shown that after 12 months' storage of amaranth grain in the temperature range +5...+25°C at the relative humidity φ=55%, the initial number of bacteria

and micromycetes decreased by 74.4–88.9% and 78.0–85.0% respectively. The decrease in the number of bacteria was mainly due to the death of those of the species *Erwinia herbicola.* Almost no micromycete development took place at this relative humidity, but a change in their species composition was observed.

Thus, to guarantee good preservation of dry amaranth grain, with the humidity not exceeding 9%, for up to one year, the following storage conditions can be recommended: temperature + 5...+15°C and relative humidity up to 55%.

References:

1. Hoptsii TI, Voronkov MF, Bobro MA. Amarant: selektsiia, henetyka ta perspektyvy vyroshchuvannia: monohrafiia. Kharkiv: KhNAU; 2018.
2. Bressani R. The proteins of grain amaranth. Food Rev. Int. 1989;5(1):13-38. https://doi.org/10.1080/87559128909540843
3. Connor JK, Gartner RJW, Runge RM. Amos RN. Amaranthus edulis: an ancient food source re-examined. Australian Journal of Experimental Agriculture and Animal Husbandry. 1980;20(103):156-161. https://doi.org/10.1071/EA9800156
4. Igbokwe PE, Tiwari SC, Collins JB, Tartt JB, Russell LC. Amaranth--a potential crop for southwestern Mississippi. Research report-Mississippi Agricultural and Forestry Experiment Station. 1988;13(10):1-4.
5. Chernousov IM. Razrabotka i nauchnoe obosnovaniye sposoba sushki semyan amaranta v apparate so vzveshenno-zakruchennym sloem [dissertation on the Internet]. Voronezh: GOUVPO VGTA; 2010.
6. Berger A, Gremaud G, Baumgartner M, Rein D, Monnard I, Kratky E, Lambelet P, et al. Cholesterol-lowering properties of amaranth grain and oil in hamsters. Int. J Vitam. Nutr. Res. 2003;73(1):39-47. https://doi.org/10.1024/0300-9831.73.1.39
7. Gimplinger DM, Dobos G, Schönlechner R, Kaul H-P. Yield and quality of grain amaranth (Amaranthus sp.) in Eastern Austria. J Plant soil environ. 2007; 53(3):105-112 https://doi.org/10.17221/2224-PSE.
8. Brenner DM. Non-shattering grain amaranth populations. Trends in new crops and new uses. ASHS Press, Alexandria, VA. 2002:104-106.
9. Bressani R, Garcia-Vela LA. Protein Fractions in Amaranth Grain and Their Chemical Characterization. Journal of Agricultural and Food Chemistry. 1990;38(5):1205-1209. https://doi.org/10.1021/jf00095a010
10. Bressani R. Amaranth: The nutritive value and potential uses of the grain and by-products. Food and Nutrition Bulletin. 1988;10(2):1-11. https://doi.org/10.1177%2F156482658801000219
11. Paredes-Lopez O. Amaranth, Biology, Chemistry and Technology. Boca Raton: CRC Press; 1994.
12. He HP, Cai Y, Sun M, Gorke H. Extraction and purification of squalene from amaranthus grain. J Agric. Food Chem. 2002;50(2):368-372. https://doi.org/10.1021/jf010918p
13. Becker R, Wheeler EL, Lorenz K, Stafford AE, Grosjean OK, Betschart AA, et al. A compositional study of amaranth grain. J of Food Science. 1981;46(4):1175-1180. https://doi.org/10.1111/j.1365-2621.1981.tb03018.x
14. Miroshnichenko LA, Zharkova IM, Kulakova SN, Kadirov CV, Eprintsev AT, Kalinicheva MV. Amaranth: A few aspects of cultivation, processing, studies of pharmaceutical properties. Functional Foods for Cardiovascular Diseases. New York: D&A Inc, 2005.
15. Peter K, Gandhi P. Rediscovering the therapeutic potential of Amaranthus species: A review. Egyptian Journal of Basic and Applied Sciences. 2017;4(3):196-205. https://doi.org/10.1016/j.ejbas.2017.05.001
16. Mburu MW, Gikonyo NK, Kenji GM, Mwasaru AM. Nutritional and functional properties of a complementary food based on Kenyan amaranth grain (Amaranthus cruentus). African Jornal of food, agricultural, nutrition and development. 2012; 12(2):5959-5977
17. Chavez-Jáuregui RN, Silva ME, Arêas JA. Extrusion cooking process for amaranth (Amaranthus caudatus L.). J. of Food Science. 2000;65(6):1009-1015. https://doi.org/10.1111/j.1365-2621.2000.tb09408.x
18. Early DK. Amaranth production in Mexico and Peru. In: Janick J, Simon JE (eds), Advances in new crops. Timber Press, Portland, OR. 1990:140-142.
19. Valentiuk NO. Udoskonalennia tekhnolohii pisliazbyralnoi obrobky zerna amarantu [dyssertaciia]. Odesa; ONAKhT; 2019.
20. Stankevych HM, Valentiuk NO. Problemy ta perspektyvy pisliazbyralnoi obrobky nasinnia amarantu. Rekonstruktyvnyi typ adaptuvannia realnoho sektoru ekonomiky ta haluzevoi nauky Ukrainy do umov postindustrialnoho suspilstva. Odesa: KP «Odeska miska drukarnia»; 2017:373-390.
21. Abalone R, Cassinera A, Gastón A, Lara MA. Some physical properties of amaranth seeds. Biosystems Engineering. 2004;89(1):109-117. https://doi.org/10.1016/j.biosystemseng.2004.06.012
22. Abalone R, Cassinera A, Gastón A, Lara MA. Thin layer drying of amaranth seeds. Biosystems Engineering. 2006**;**93(2):179-188. https://doi.org/10.1016/j.biosystemseng.2005.11.010
23. Ronoh EK., Kanali CL, Mailutha JT, Shitanda D. Modeling Thin layer drying of amaranth seeds under open sun and natural convection solar tent dryer. Agricultural Engineering International. [Internet]. 2009 Nov;11: [cited 2020 Sep 14]:[about 3pp.]. Available from: http://www.cigrjournal. org/index.php/Ejounral/ article/viewFile/1420/1276.
24. Smirnov S. Tekhnologiya ochistki zerna amaranta pered pomolom. Khleboprodukty. 2006;2:50-52.
25. Miroshnichenko LA Khraneniye zerna amaranta i produktov ego pererabotki. Khraneniye i pererabotka selkhozsyria. 2006;4:20-21.
26. Stankevych GM, Strakhova TV, Shuvalov SYe, Shmagin LM. Sushinnya zerna: Laboratorni roboti. Libid. 1997.
27. Skuzikhina IM, Tuteliana VA, editor. Rukovodstvo po metodam analiza kachestva i bezopasnosti pishchevykh produktov. M: Brandes. Meditsina; 1998.
28. Kozmina NP. Biokhimiya zerna i produktov ego pererabotki. M: Kolrs; 1976.
29. Vladimirova EG, Ushakova GI, Kushnareva OP. Biokhimiya zerna. biokhimiya khlebopecheniya; biokhimiya brodilnykh proizvodstv: Metodicheskiye ukazaniya k laboratornomu praktikumu. Orenburg: OGU; 2004.
30. Kapreliants LV, editor. Tekhnichna mikrobiolohiia. Odesa: Druk; 2006.

ДОСЛІДЖЕННЯ ЯКОСТІ ЗЕРНА АМАРАНТУ В ПРОЦЕСІ ПІСЛЯЗБИРАЛЬНОЇ ОБРОБКИ ТА ЗБЕРІГАННЯ

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Анотація. Одним із шляхів вирішення проблеми погіршення стану здоров'я людей може бути широке використання рослинних продуктів, серед яких найбільш цінними вважаються рослинні олії, зокрема олія амаранту. Вона містить комплекс вітамінів, мікро- і макроелементів, ненасичені жирні кислоти та незамінні амінокислоти та унікальну природну біологічно активну речовину, сквален, який виконує низку ключових функцій в організмі людини. Однак післязбиральна обробка зерна амаранту, зокрема сушіння, та його наступне зберігання у різних умовах можуть значно погіршити його цінні природні властивості. У роботі наведено результати досліджень змін хімічного складу та мікробіологічних характеристик зерна амаранту в процесі його сушіння та зберігання у різних умовах, що дозволить забезпечити його гарантовану якість при зберіганні. Вивчено вплив сушіння амаранту до вологості 9% за температур 50°С та 60°С на загальну кількість обмилених речовин, вміст сквалену, ліноленової, лінолевої, олеїнової, пальмітинової і стеаринової кислот, які визначали методом газорідинної хроматографії. Встановлено, що після сушіння зерна амаранту відбувається зниження вмісту обмилених речовин на 10% та сквалену на 14% у порівнянні зі свіжозібраним зерном, а вміст вільних жирних кислот в необмиленій фракції залишається без змін. При зберіганні амаранту впродовж року за температур +5°С, +15°С та +25°С та відносній вологості повітря 55% та 75%. визначено зміни вмісту таких основних показників якості зерна як білок, крохмаль, клітковина, жир, зола, а також кислотне число та кислотність жиру, Показано, що найбільші зміни відбулися через рік при зберіганні зерна за температури 25°С та відносної вологості повітря 75%. При цьому вміст білка зменшився на 13,5%, крохмалю на 8,7%, жиру на 29,0%. Вміст клітковини та золи практично не змінилися. За цих же умов зберігання відмічено також значне погіршення якості жиру – кислотне число зросло у 6,9 разів, кислотність спиртової витяжки у 2,9 разів. При зберіганні амаранту за температури +5°С та відносної вологості 55% зниження вмісту основних складових було суттєво меншим та склало для білка 8,1%, крохмалю 2,9%, жиру 4,2%. За цих же умов значно знижується життєдіяльність мікроорганізмів, що дозволило рекомендувати вказані умови зберігання для промислового використання .

Ключові слова: амарант, післязбиральна обробка зерна, сушіння зерна, зберігання зерна, сквален, хімічний склад зерна амаранту, мікрофлора зерна.

Список літератури:

1. Амарант: селекція, генетика та перспективи вирощування: монографія / Т.І. Гопцій, М.Ф. Воронков, М.А. Бобро та ін. Харків: ХНАУ, 2018. 362 с.
2. Bressani R. The proteins of grain amaranth // Food Rev. Int. 1989. Vol. 5, Issue 1. P.13-38. https://doi.org/10.1080/87559128909540843
3. Amaranthus edulis: an ancient food source re-examined / Connor J.K. et al // Australian Journal of Experimental Agriculture and Animal Husbandry. 1980. Vol.20, Issue 103. P.156-161. https://doi.org/10.1071/EA9800156
4. Amaranth--a potential crop for southwestern Mississippi / Igbokwe P.E., et al // *Research report-Mississippi Agricultural and Forestry Experiment Station*. 1988. Vol. 13, Issue 10. P.1-4.
5. Черноусов И.М. Разработка и научное обоснование способа сушки семян амаранта в аппарате со взвешенно-закрученным слоем: дис. канд. техн. наук: 05.18.12. защита 8.04.2010 / науч. руков. С.Т. Антипов. Воронеж: ГОУВПО ВГТА, 2010. 231 с.
6. Cholesterol-lowering properties of amaranth grain and oil in hamsters / Berger A et al // Int. J Vitam. Nutr. Res. 2003. Vol. 73, Issue 1. P. 39-47. https://doi.org/10.1024/0300-9831.73.1.39
7. Yield and quality of grain amaranth (Amaranthus sp.) in Eastern Austria / Gimplinger D.M. et al // J Plant soil environ. 2007. Vol. 53, Issue 3. P.105-112. https://doi.org/10.17221/2224-PSE
8. Brenner D.M. et al Non-shattering grain amaranth populations // Trends in new crops and new uses. ASHS Press, Alexandria, VA. 2002. P. 104-106.
9. Bressani R., Garcia-Vela L. A. Protein Fractions in Amaranth Grain and Their Chemical Characterization // Journal of Agricultural and Food Chemistry. 1990. Vol. 38, Issue 5. P.1205-1209. https://doi.org/10.1021/jf00095a010
10. Bressani R. Amaranth: The nutritive value and potential uses of the grain and by-products // Food and Nutrition Bulletin. 1988. Vol. 10, Issue 2. P.1-11. https://doi.org/10.1177%2F156482658801000219
11. Paredes-Lopez O. Amaranth, Biology, Chemistry and Technology. Chapter 10. CRC Press. 1994. P.185-205.
12. Extraction and purification of squalene from amaranthus grain / He H.P. et al // J Agric. Food Chem. 2002. Vol.50, Issue 2. P. 368-372. https://doi.org/10.1021/jf010918p
13. A compositional study of amaranth grain / Becker R. et al // J of Food Science. 1981. Vol.46, Issue 4. P. 1175-1180. https://doi.org/10.1111/j.1365-2621.1981.tb03018.x
14. Amaranth: A few aspects of cultivation, processing, studies of pharmaceutical properties / Miroshnichenko L.A. et al // Functional Foods for Cardiovascular Diseases: Functional foods can help reduce the risks of cardiovascular diseases (New York: D&A Inc). 2005. P. 228-234.
15. Peter K., Gandhi P. Rediscovering the therapeutic potential of Amaranthus species: A review // Egyptian Journal of Basic and Applied Sciences. 2017. Vol.4, Issue 3. P. 196-205. https://doi.org/10.1016/j.ejbas.2017.05.001
16. Nutritional and functional properties of a complementary food based on Kenyan amaranth grain (Amaranthus cruentus) / Mburu M.W. et al // African Jornal of food, agricultural, nutrition and development. 2012. Vol. 12, Issue 2. P.5959-5977.

17. Chavez-Jáuregui R.N., Silva M.E., Arêas J.A. Extrusion cooking process for amaranth (Amaranthus caudatus L.) // J. of Food Science. 2000. Vol.65, Issue 6. P.1009-1015. https://doi.org/10.1111/j.1365-2621.2000.tb09408.x
18. Early D.K. Amaranth production in Mexico and Peru. In: Janick J., Simon J.E. (eds.). Advances in new crops. Timber Press, Portland, OR. 1990. p. 140-142. URL: http://www.hort.purdue.edu/newcrop/ proceedings1990/V1-140.html (viewed on 14.08.2020)
19. Валентюк Н.О. Удосконалення технології післязбиральної обробки зерна амаранту: дис. канд. техн. наук: 05.18.02: захист 28.11.2019 / наук. кер. Станкевич Г.М.. Одеса: ОНАХТ, 2019. 187 с.
20. Станкевич Г.М., Валентюк Н.О. Проблеми та перспективи післязбиральної обробки насіння амаранту // Реконструктивний тип адаптування реального сектору економіки та галузевої науки України до умов постіндустріального суспільства: Монографія. / за ред. Савенка І.І., Станкевича Г.М., Седікової І.О. Одеса: КП «Одеська міська друкарня», 2017. С. 373-390.
21. Some physical properties of amaranth seeds /Abalone R. et al // Biosystems Engineering. 2004. Vol. 89, Issue 1. P. 109-117. https://doi.org/10.1016/j.biosystemseng.2004.06.012
22. Thin layer drying of amaranth seeds / Abalone R. et al // Biosystems Engineering. 2006. Vol. 93, Issue 2. P.179-188. https://doi.org/10.1016/j.biosystemseng.2005.11.010
23. Modeling Thin Layer Drying of Amaranth Seeds under Open Sun and Natural Convection Solar Tent Dryer / Ronoh E.K.et al // Agricultural Engineering International: the CIGR Ejournal. 2009. Vol. XI. 11 p. URL: http://www.cigrjournal. org/index.php/Ejounral/ article/viewFile/1420/1276 (Last accessed: 141.09. 2020).
24. Смирнов С. Технология очистки зерна амаранта перед помолом // Хлебопродукты. 2006. №2. С.50-52.
25. Хранение зерна амаранта и продуктов его переработки / Мирошниченко Л.А и др. // Хранение и переработка сельхозсырья. 2006. № 4. С.20-21.
26. Сушіння зерна: Лабораторні роботи: Навч. посібник / Станкевич Г.М, та ін. К: Либідь, 1997. 136 с.
27. Руководство по методам анализа качества и безопасности пищевых продуктов / Под ред. Скурихина И.М., Тутельяна В.А. М.: Брандес, Медицина, 1998. 340 с.
28. Козьмина Н.П. Биохимия зерна и продуктов его переработки. М.: Колос, 1976. 375 с.
29. Владимирова Е.Г., Ушакова Г.И., Кушнарева О.П. Биохимия зерна, биохимия хлебопечения; биохимия бродильных производств: Методические указания к лабораторному практикуму. Оренбург: ОГУ, 2004. 61 с.
30. Технічна мікробіологія / Капрельянц Л.В. та ін.; за ред. Л.В. Капрельянца. Одеса: Друк, 2006. 308 с.