PHYSICAL PRINCIPLES OF PROCESSING OFF-GRADE BUCKWHEAT

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Abstract: Currently, there is deterioration of the quality of incoming buckwheat supply. Intensification of harvesting processes, due to application of new combine harvesters aimed at expanding the moisture range of harvested grain, leads to a grain increase at farms and this bulk is kept under unregulated conditions on large open areas. The lack of centralized storage, conditioning and grain drying leads to the fact that producers have to deal with post-harvest handling and storage, though they do not have grain drying units, cleaning equipment and the required number of granaries. In addition, grain storage requires considerable financial costs; therefore not every producer can meet the necessary technological requirements of grain receiving and post-harvest processing. The incoming grain has another moisture content, hard-separable impurities, filmness and content of germinated grains. Processing of such grains using standard practice is costly or this grain is used for feeding purposes. Off-grade grain batches (which don't conform to the requirements of regulatory documents) collected in the foothills of the Altai Territory were chosen for research. The research was carried out for the most common grain parties: with moisture of 17.0–22.0%, with hard-separable impurities above 2.0%, with filmness not more than 19.0%, and buckwheat containing germinated grains. The results of the research allowed offering technology, the distinguishing feature of which is the absence of preparation grains phase before processing. The proposed technology allows to process off-grade buckwheat in order to produce peeled buckwheat and guarantee profitability. The obtained data prove significant advantage of the proposed technology. Economic efficiency of grain processing with four defects is calculated. It is stated that the cost of processing off-grade grain on the proposed technology is much lower than the standard technology of producing buckwheat according to the requirements.

Keywords: buckwheat, humidity, hard-separable impurities, filmness, germinated grains, off-grade grain, spoiled kernel, drying, steaming

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INTRODUCTION

Among cereal crops buckwheat has a special place [1]. Due to its high nutritional and biological value [2–5], the products produced from buckwheat are widely used not only in public catering, but also in baby and healthy foods [6]. Peeled buckwheat, crushed buckwheat and buckwheat flour are produced from buckwheat grains (steamed or not steamed). Peeled buckwheat is the main and most valuable product of processing. However, the quality of peeled buckwheat does not always meet the requirements. Processing efficiency is determined by the characteristics of process, physical, mechanical and technological properties of grain. Quality of processing grain is controlled by the requirements of regulatory documents. Analysis of the enterprise JSC "Biysk elevator" in the foothills of the Altai Territory demonstrated that the proportion of off-grade buckwheat, grain which don't meet the requirements, supplied to the processing for the period from 2000 to 2013 in some years was up to 50%.

To meet the regulatory requirements in the process of preparing this grain to the processing is quite difficult and is not always worthwhile. Processing of such grains leads to the production of substandard buckwheat groats or low grade buckwheat and reduces its nutritional value and eating qualities. The key to the success in the first place is the high quality of products.

Adverse effects on the grain may occur:

– during its cultivation (resulting from edaphoclimatic conditions, affected grains, dead-ripe stage or overwintering in the field);

– during the harvest (as a result of mechanical damage, prolonged storage in heaps, waiting for post-harvest treatment);

– during post-harvest handling or storage because of pests and microorganisms.

Extraneous impurities and high humidity greatly reduces grain value, deteriorates its technological advantages and physical properties. In order to achieve high efficiency of processing buckwheat it is necessary to improve its initial properties to the specified requirements. Such preparation provides the stabilization of the grains quality produced in accordance with normative documents.

The technological process of buckwheat production currently consists of the following steps: removal of impurities, hydrothermal treatment, sorting into factions, flaking, peeling, separation of peeled products according to the requirements.

This technology allows processing the grain in accordance with the requirements of regulatory documents, however, the use of off-grade grain leads to the production of defective products and unprofitable production.

The aim of this work is to determine basic principles of processing off-grade buckwheat providing obtaining of peeled buckwheat according to the requirements and effectiveness of the proposed technologies.

OBJECTS AND METHODS OF STUDY

Standard methods were used in this research. For test samples we selected a batch of buckwheat grown in the foothills of the Altai Territory in 2012–2014 and a batch imported from China. Both batches did not meet the established requirements according to its characteristics.

The objects of research were:

– batches of grain with moisture content 17.0–22.0%;

– batches of grain containing hard-separable impurities more than 2.0%;

– batches of grain with filmness of not more than 19.0%;

– batches of grain containing germinated grains of buckwheat.

All experimental researches were carried out under factory conditions at the buckwheat producing factory JSC “Biysk elevator” (the Altai region, Russia) with capacity of 100 tons / day.

RESULTS AND DISCUSSION

Buckwheat groats quality indicators are directly dependent on quality indicators of produced grain. Technology analysis enables us to assert that the existing grain processing technology are based on its preliminary preparation to the specified requirements. A distinctive feature of the proposed technologies is the absence of preparation phase before processing. Implementation of the proposed technology allows using off-grade grain to produce peeled buckwheat and guarantee profitability in the processing of defected grain.

Processing of grain with a moisture content of more than 17%

During the processing of grain from JSC “Biysk elevator” with a moisture content of over 17%, buckwheat grain had a high concentration of spoiled and vitreous grain, resulting in the production of low grade buckwheat or substandard products. Separate batches had up to 10% of spoiled grain [7]. Such concentration of spoiled grain does not allow using standard technology for the grain processing, as according to the regulatory documents the amount of spoiled grain mustn’t be higher than 0.2 for 1st grade; 0.4 for the 2d grade and 1.2% for the third grade.

Some grain batches are kept by manufacturers under floor storage on various reasons and the moisture content is up to 22.0%. In such conditions active growth of microorganisms on grains leads to a color change. The initial period is characterized by appearance of "pigmented grains". These grains are not spoiled but the processing leads to the production of buckwheat with high content of spoiled core.

Researches on improving the technology of processing buckwheat with high humidity allowed us to try a new method [8]. It is based on the reduction of the duration of grain preparation for processing. Batches entering the elevator with humidity over 17% and the range of differences not more than 1.0% were distinguished. These batches without pre-drying preparation were sent to a factory for processing. Grain drying up to moisture content 13.5–14.5% was replaced by steaming in this method.

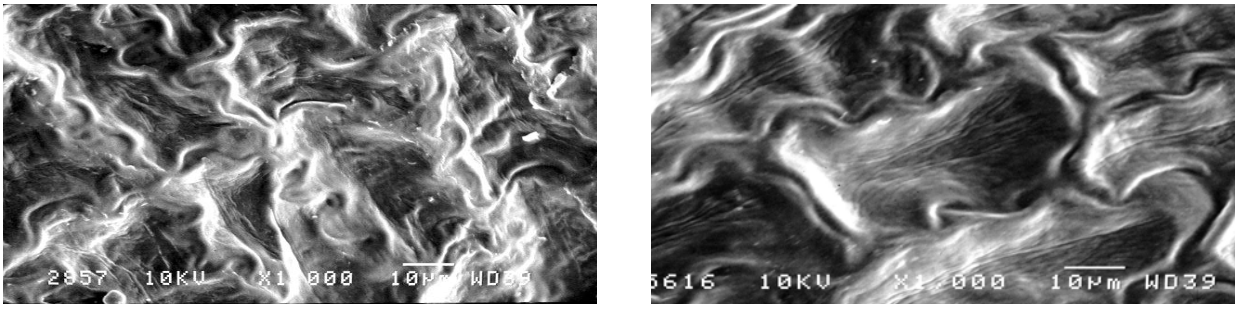
Grain drying is an important step in processing, It provides a quick preparation of grain for necessary conditions, helps equalize the humidity of separate grain components, improves the look and color of the grain, leads to stable storage condition. However, it should be noted that grain drying is costly and energy consuming process. This is due to the fact that convective grain dryers used for drying use liquid fuel for fresh air heating and supply to a drier requires significant power consumption. Moreover, in cases where incoming batches with humidity 17.0–22.0% are processed these direct-flow dryers mustn’t reduce moisture more than 2.0–3.0% per pass of grain.

According to the requirements for drying grain of this quality it is necessary to have a few drying passes until moisture content is 14.0%. Such drying leads to increased fuel consumption and an increase in the cost of grain drying up to necessary moisture content.

The problem of quality and safety of grain is very important in recent years and it is associated primarily with a significant depreciation of existing equipment and increasing of the incoming grain which needs drying.

At the same time a significant damage to grain and the deterioration of its quality happen while passing through the grain elevator equipment, preparation of grain for drying and transporting it. The technological line for acceptance and post-harvest grain processing has more than 30 places of grain damage [9]. Grain damage adversely affect its durability during storage, technological properties and reduces the yield of the end product. Quantitative losses happen due to peeling of buckwheat grain with numerous bumps in the process of transportation and spray of crushed and hulled grains.

A distinctive feature of the wet grain is increasing its size and the surface of deformation respectively. The microstructure of dry and sodden grain surface was examined by photomicrographs obtained on JSM-840 scanning electron microscope (Fig. 1).



(a) (b)

Fig. 1. The surface morphology of buckwheat grain with a moisture content of (a) 14.2%, and (b) 17.8%.

As it can be seen from Fig. 1, the outer surface has a honeycomb structure, in the dry core cell sizes are 10 × 30 microns, in sodden – 70 × 40 mm. This difference is due to the fact that sodden grains are bigger in size.

The proposed method of processing buckwheat with high humidity have optimal conditions for the destruction of microflora from grain surface. Grain, consistently passing through the stages of grain cleaning, was delivered to the steamer of periodic action A9-BIS. Preheating before steaming for 35 minutes up to 20–30°C accelerates the process of hydrothermal grain processing. Steaming is carried out during 6 min at a pressure of 0.55 MPa. The steaming duration is determined by the time from the beginning of steam delivering into the steamer until delivering stops. When grain is taken out from the steamer, it is delivered to the shaft type dryer, and dried by air of 60°C for 20 min until the moisture content is 16.0–18.0%.

Then, the grain goes to the second shaft-type dryer, and dried by air at a temperature of 120–140°C for 50 min. After steaming and drying up to moisture content is 13.5–14.5%, the grain goes to peeling, followed by groats grader and buckwheat production. The proposed technology was applied to research on using grain with following quality indicators (Table 1).

As it is shown in Table 1, for research we used non pre-dried grain before peeling with humidity more than 17.0% for the proposed technology and with a humidity of no more than 14.5% on the recommended technology. The results of comparative tests are given in Table 2.

From the obtained data we can assume that if grain with high moisture content is dried using the recommended technology the Penicillium begins to develop without visible signs of grain damage. Prolonged and repeated drying process stimulates its development and leads to spoiled grains. Temperature steaming mode prevents the Penicillium development thereby reducing the cause of having spoiled grain.

Table 1. The quality of grain used for processing on the recommended and proposed technology

Grain quality indicators	Grain quality according to standard documentation requirements	Actual quality according to recommended technologies	Actual quality according to proposed technologies
Moisture content, %	14.5	13.5–14.0	17.0–22.0
Weight fraction of core, %	73.0	73.0–73.9	73.3–74.1
Weight fraction of hull, %	–	22.3–22.7	22.1–22.6
Weight fraction of impurity, %	2.0	3.4–4.0	3.8–4.1
Weight fraction of grain dockage, %	2.0	1.2–1.5	1.4–1.6

Table 2. Mass fraction of spoiled grain, % in the processing of grain with moisture content more than 17%

Batch of peeled buckwheat	Grain with moisture content more than 17%	
	Recommended technology	Proposed technology
1/03 150 t	0.44–0.78	0.12–0.20
1/05 160 t	0.34–0.64	0.10–0.18
1/05 100 t	0.30–0.38	0.12–0.20
1/07 270 t	0.36–0.52	0.08–0.16
1/09 250 t	0.36–0.42	0.12–0.20

In addition, the temperature and time changes in the proposed method provides a homogeneous core color of six tones [10].

In the proposed technology replacement of grain drying to steaming in a given mode does not increase the cost of peeled buckwheat. According to technological scheme the line capacity is 90 tons / day.

Thus, the processing of grain with high moisture content is possible when steaming is used instead of drying. Obtained products meet the requirements of regulatory documents.

Processing of grain containing hard-separable impurities more than 2.0%

Grain mass except full-value buckwheat contains various impurities, including hard-separable impurities.

Therefore, parent batches of grain are a mixture of grains of various crops, weeds, impurities of mineral and organic origin.

Prior to processing impurities must be removed in order to exclude it from the end product.

However, the presence of impurities especially hard-separable ones (wheat, joint charlock, Tatar buckwheat, field peas and others) complicates greatly the cleaning process and leads to a complex and multi-grain cleaning process. To separate such impurities passes through the grain-cleaning machines are repeated, special grain-cleaning machines are used, the yield of the main grain to waste is increased. Processing of this grain is not always effective. It leads to significant losses in the main grain, producing of substandard groats or off-grade grain and reduces its nutritional value and taste.

In the process of such grain-cleaning and preparation for subsequent processing the content of main grain in wastes is from 10.0% to 70.0% [11].

Recommended equipment does not provide separation of hard-separable impurities without significant loss of main grains and leads to significant economic losses.

Batches of grain with hard-separable impurities up to 10% were subjected to processing.

Traditional grain cleaning method allows to process grains containing hard-separable impurities not more than 2.0%.

Processing of grain containing hard-separable content exceeding 2.0% is not effective.

Loss of normal grain predetermined number of actions connected with a particular monitoring and control of incoming batches.

For the processing of grain containing hard-separable impurities from 2.0% to 10.0% we suggested technological scheme of grain processing, when every fraction of grain and end products are cleaned in two streams 1–3 fr. and 4–6 fr. in addition to traditional cleaning process. To study the work of grain-cleaning line we used grain with quality indicators presented in Table 3.

Installation of frequency converters brand E1-8001 company Vesper on grain cleaners allows to adjust smoothly the frequency and amplitude of oscillation. Changing these settings allows to achieve optimum operating modes of grain cleaning equipment for grain batches of different quality. Test results are summarized in Table 4.

Table 3. Indicators of quality of the processed grain

Grain quality indicators	Grain quality according to standard documentation requirements	Actual grain quality
Moisture content, %	14.5	14.0–14.6
Weight fraction of core, %	73.0	71.8–75.5
Weight fraction of hull, %	–	21.6–23.2
Weight fraction of impurity, including hard-separable, %	2.0 2.0	3.4–5.6 1.8–3.2
Weight fraction of grain dockage, %	2.0	0.8–1.5

Table 4. Comparative analysis of the recommended and proposed grain cleaning

Grain cleaners	Weight fraction of weed impurities in grains on the recommended technology, %	Weight fraction of weed impurities in grains on the proposed technology, %
Two separators BIS-100, gravel separator P3-BCT-100, Trieur Petkus K236	3.4–5.6% (including hard-separable impurities 1.8–3.2%)	3.4–5.6% (including hard-separable impurities 1.8–3.2%)
Impurity contents after recommended machines	1.6–2.4	1.6–2.4
Control of fraction 1 before cleaning After cleaning	no control	0.7–1.8 0.4–0.5
Control of fraction 2 before cleaning After cleaning	no control	0.4–3.6 0.2–0.4
Control of fraction 3 before cleaning After cleaning Control of fractions 4-5-6 before cleaning After cleaning Control of fraction 4 before cleaning After cleaning Control of fraction 5 before cleaning After cleaning Control of fraction 6 before cleaning After cleaning	no control 1.8–3.1 1.0–1.4 no control no control no control 	1.7–2.8 0.3–0.4 1.8–3.1 1.0–1.4 1.2–1.5 0.7–0.9 1.5–1.9 0.6–0.9 2.9–4.1 1.7–2.8
Control of peeled buckwheat 1-3 before cleaning After cleaning	no control	0.5–0.7 0.1–0.3
Control of peeled buckwheat 4-6 before cleaning After cleaning	no control	0.7–1.1 0.3–0.5
Content of weed impurities in the end product	1.1–2.3	0.1–0.3
Content of weed impurities according to GOST 5550-74 not more	0.4	0.4

The sequence of grain cleaning with cleaning of every fraction and additional cleaning of grain of 1-2-3 fractions on separator on WLAN-12, 4-5-6 fractions on paddy-machine PM-0.5 allowed to achieve stable results of processing grain containing hard-separable impurities above statutory requirements.

Thus, changing the mode of the equipment and installation of additional equipment allowed to process grain containing weed impurities. At the same time using the proposed technology the content of weed impurities does not exceed the requirements of regulatory documents.

Processing of grain with filmness up to 19.0%

Natural grain features suggest the development of such methods and processing modes, which would guarantee high technological efficiency of a plant.

One of the most important indicators in the processing grains is its geometrical dimensions, namely the degree of development of bran covering. Depending on edges development, buckwheat can be divided into cruise (with a strongly developed edges, while the core does not fully cover the coat, leaving a hollow top) and wingless with rounded edges (rounded grain shape).

Grains having a wingless form of bran covering are characterized by a high degree of plumpness, bran coverings tightly cover the core, edges have a convex shape. It can be described as of medium size, the content of large fractions (1 and 2 fractions) is on average not more than 55%. The weight of 1000 grains varies between 22 and 25 g. This grain has low technological properties which are determined by wingless form of grain, low uniformity, complexity of separation of coverings from the core with its high content of 78 to 82% [12].

The paper studied the processing of wingless buckwheat. An example of this grain is grain grown in the northern provinces of China.

Comparative qualitative parameters of grain processed by JSC "Biysk" obtained from farmers of the Altai Territory and imported from China (Shanxi, Shaanxi and Gansu) are presented in Table 5.

As it is seen from Table 5, qualitative indicators of Chinese and Altai grain differ significantly. For some indicators (total amount of weed impurities, moisture content, weight fraction of the core, filmness) Chinese grain is much greater than qualitative indicators of Altai buckwheat, which will undoubtedly have a positive impact on technological efficiency of the processing and on increasing the output.

However, there is a flip side of Chinese buckwheat processing, namely it is a low uniformity of grain, low content of large fractions, the high content of small fractions (Table 6). Lack of a distinct grain shape of a tetrahedron (more round shape), a firm adherence of bran covering to the core complicates cleaning, fraction division and the process of peeling grains.

Table 5. Quality indicators of Chinese and Altai buckwheat, %

Grain quality indicators	Chinese grain	Altai grain
Moisture content, %	12.6–13.6	13.6–21.0
Weight fraction of core, %	78.2–80.5	72.0–76.5
Weight fraction of hull, %	16.8–19.0	20.0–23.8
Weight fraction of weed impurity, %	0.6–2.9	1.0–5.6
Weight fraction of grain dockage, %	0.2–1.2	0.4–2.8

Table 6. Fraction composition of Chinese and Altai buckwheat

Fraction number	Chinese grain	Altai grain
1	18.0–25.0	25.0–39.0
2	24.0–35.0	47.0–50.0
3	23.0–25.0	12.0–15.0
4	12.0–15.0	5.0–6.0
5	6.0–9.0	1.0–2.0
6	3.0–4.0	0.5–1.0

Identified features of qualitative composition and morphological structure of Chinese grain defined a number of actions which are connected with technological grain processing:

– Selection and changing of cell of screening surface with a simultaneous change in the kinematic parameters of the screening process equipment;

– Changes in the screening surface at stages of grain separation into fractions.

a) *Cleaning of buckwheat grain from weeds and grain impurities*

Recommended technological scheme of processing buckwheat at JSC "Biysk elevator" identified a number of shortcomings in Chinese grain processing. Features of processing are determined by the difference in quality parameters of grain.

Cleaning buckwheat of Chinese production from weed and grain impurities on the recommended technology led to a loss in grain up to 25% of main grains. The low percentage of grain uniformity up to 55%, a high percentage of small fractions significantly reduces the efficiency of the grain cleaners. Therefore, to separate impurities from Chinese grain is necessary to apply the sieves with larger sizes. Thus, separation needs sieves whose dimensions are comparable to or larger than the sixth grain fraction. This leads to the fact that a considerable amount of grain goes into waste. The content of the sixth fraction is up to 5%, so loss of the end product output can be up to 3.5%. To study the work of grain-cleaning line we use grain with following quality indicators (Table 7).

Table 7. Quality indicators of processed Altai and Chinese buckwheat

Grain quality indicators	Established requirements	Actual quality of Altai grain	Actual quality of Chinese grain
Moisture content, %	14.5	13.9–14.8	13.0–13.8
Weight fraction of core, %	73.0	73.1–74.4	79.4–80.1
Weight fraction of hull, %	–	21.8–22.6	18.8–19.2
Weight fraction of weed impurity, %	2.0	3.4–4.7	1.1–1.6
Weight fraction of grain dockage, %	2.0	1.1–1.6	0.3–0.5

According to requirements grain was cleaned from impurities sequentially on two air-sieve separator. It was suggested to change the specifications of separators, namely the frequency range of vibrations and sieve inclination angle for the cleaning of grain with a high content of fines in the separators BIS-100. Therefore, actuators were fitted with frequency converters of brand E1-8001 company Vesper. It allows to smoothly change modes and separators to determine the optimum operating conditions for a given batch.

Optimal sorting sizes and sieve to separate the elongated, short and shallow impurities are determined empirically for each batch of buckwheat (Table 8).

Table 8. Specifications of BIS-100 separators

Characteristics	Recommended for Altai buckwheat	Recommended for Chinese buckwheat
Frequency of circular field oscillations, min	360	230–280
Radius of the circular oscillations, mm	11	7–9
Number of cleaners in the frame, pieces	32	48
Sorting sieve Cleaning sieve	Triangular 7.5:7.0 2.8x20:2.6x20	Triangular 9.0:8.0 2.6x20:2.6x20
Inclination angle of sieve frames to the horizon, gr.	7	5
Content of normal grain in grain wastes, %	25.7–28.4	8.0–10.1

Thus, changes in the kinematic parameters of sieve oscillation and angle of tip increased the efficiency of impurities separation and helped to determine the optimal performance of sieve separators LSI 100 It led to a decrease in the content of normal corn in grain wastes from 25.4 to 10.1%.

b) *Sorting the grain into six fractions*

A distinctive feature of buckwheat processing is its sorting into six fractions before peeling. When this process before peeling is not accurate enough in the subsequent process of sorting grain products (peeled buckwheat, unscoured grains, crushed grains, buckwheat meal, hull) peeled buckwheat groats can have unscoured grain, which have the similar size. It results in substandard production. According to the requirements peeled buckwheat of 1 st, 2 nd, 3 rd grades can have 0.3, 0.5, 0.7% of unscoured grains respectively.

In the recommended production line the process of sorting by size before peeling has two stages. In the process of pre-screening three grain streams of 1, 2 fraction, 3 and 4, 5, 6 fractions are obtained. The final sorting of buckwheat has six factions.

Chinese buckwheat has a more rounded shape and a low uniformity compared with buckwheat grown in Altai. When the recommended technology is used 1 and 2 fractions contain 15% of fine grains due to the high percentage of 3, 4, 5, 6 fractions.

Grain processing using this scheme leads to an increased content of unscoured grains and increased content of crushed core in peeled buckwheat.

For efficiency of fractionating it was necessary to increase the sieve surface to improve the sorting grain size and product quality in the subsequent processing of the grain.

To solve this problem an integrated approach was used, which consisted in changing the kinematic sieving parameters (amplitude and oscillations frequency) (Table 9) and redistribution of sieving surface.

Table 9. Specifications of plansifters RHA-4M on grain sorting

Characteristics	Recommended characteristics for plansifter ЗРШ-4М	Proposed characteristics
Frequency of circular field oscillations, min	220	140–180
Radius of the circular oscillations, mm	41	20–26
Number of cleaners in the frame, pieces	12	16

Sorting of grain by size was carried out in three stages, preliminary it was divided into four fractions fr. 1, fr. 2, fr. 3 and 4, 5, 6 fractions and finally it was divided into six fractions twice.

Grain divided into 6 fractions according to grain size and passed through sorting steps is delivered separately to buckwheat scourers according to fractions.

Recycling of wingless buckwheat on the proposed technology made it possible to change the efficiency of sorting schemes and to get products which meet the requirements of regulatory documents.

Thus, changes in product movement scheme made it possible to separate grain at the preliminary sieving step not into three, but into four flows and to increase the sieving surface for final sorting of fractions twice.

These changes helped to find the optimal conditions for the subsequent effective peeling of grains.

Batches of buckwheat containing germinated grains

If there is sufficient amount of moisture grain rapidly increases in volume and starts germination. Defects of such grain batches depend on the number of germinated grain and germination time which is connected with the length of the germ. These grains have improved energy, active physiological state and it leads to a change and deterioration of food processing properties.

As there is no data on processing of germinated grain in the literature, there is a need to prove experimentally the value of the maximum permissible content of germinated grains in the incoming batches.

For the research batches of buckwheat containing up to 3% of germinated grain were selected. The sprout length was 3 mm or more. However, during transportation of grain from the producer to the consumer up to 60% of germs were broken, as well as because of technological machines during grain processing (Fig. 2). The absence of sprout made it difficult to sort out germinated grains according to the degree and duration of germination. Therefore, the sprout length in our research was not considered. Batches for research were formed only on the quantitative content of germinated grains; medium samples were taken in seed-preparation facility.

Fig. 2a shows that grain germination leads to visible damage on surface such as cracks sized 3–5 micron, which are arranged along the formed sprout. On Fig. 2b there is no upper part of the edge with the sprout, and there are crack sized 10–15 microns.

We studied the content of spoiled grain in peeled buckwheat depending on the content of germinated grains (spoiled grains and non-germinated grains were not taken into account).

Grain batches were roughly divided into three groups:

(1) with the content of germinated grains up to 1.0%;
(2) containing 1.1–2.0% of germinated grains;
(3) with the content of germinated grains 2.1–3.0%.

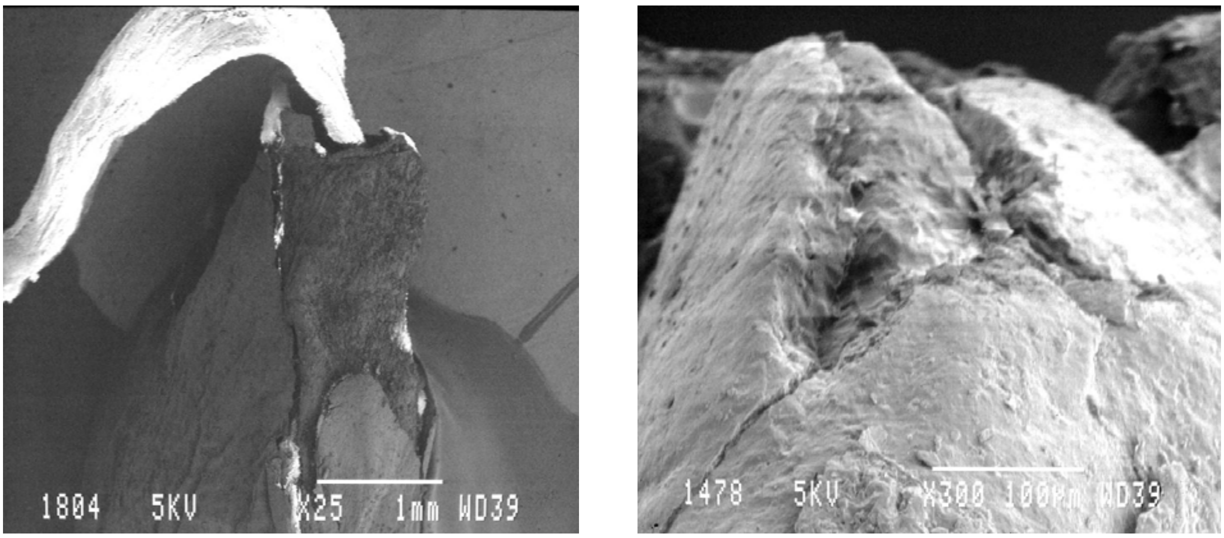
Above divided grain batches were processed, and the contents of spoiled grain was determined according to the requirements. All studies were repeated 3–10 times and processed statistically.

Studies based on the specified requirements demonstrated that peeled buckwheat of first group in terms of spoiled grain belongs to the first class (no more than 0.2%), the second group corresponds to only Class II with the content of spoiled grain of no more that 0.4%, the third group is the third grade (no more than 1.2%).

Non-linear dependence of mass fraction of spoiled grain on the content of germinated grains, is possibly connected with varietal characteristics, long-term keeping of grain in adverse storage conditions, possible sorting of grain producer to the content of germinated grains up to 3%. Grains with more than 3% were not processed. During research it was impossible to trace the length of keeping grain in unfavorable conditions. Moreover, batches were received from the manufacturer and directly from the field.

In order to characterize the quality of germinated grain [13] we determined physical and chemical properties and safety performance. It was shown that the main indicators of normal and germinated grains are comparable. However, germinated grain has an increased content of fat due to possible enzymatic hydrolysis.

To reaserch further the characteristics of the studied group we determined grain indicators fat, fat acid number (KCHZH) and acidity according to conventional techniques. For comparison we used the similar indicators of normal, spoiled and germinated grains. The results are summarized in Table 10.



(a) (b)

Fig. 2. Micrograph: (a) part of surface of unsteamed core with the sprout (from germinated grains) ×25, and (b) part of surface of unsteamed core with the broken sprout (from germinated grains) ×300.

Table 10. Indicators of fat acid number, fat and acidity of the studied groups: normal, spoiled and germinated grains

Sample	Weight fraction		
	Fat acid number, mg KOH/g	Fat, %	Acidity, gr.
Normal grain*	4.1–7.2	1.7–2.0	2.1–2.8
Grain of 1st group	5.0–7.6	1.8–2.2	2.1–2.7
Grain of 2d group	5.1–7.8	1.9–2.1	2.4–2.9
Grain of 3d group	5.4–7.8	1.8–2.0	2.6–3.4
Spoiled grain**	26.4–35.8	1.4–2.0	7.8–12.6
Germinated grain***	28.3–36.4	2.1–2.4	9.8–12.4

Note. * – grain, which has no germinated grains; ** – grain, consisting of spoiled grain; *** – grain, consisting of geminated grains.

Grain of studied groups is comparable to the normal grain, it can be used for the production of peeled buckwheat.

As it is shown in Table 10, the high content of fat acid number and acidity in spoiled and germinated grains is probably due to hydrolysis of fats that occur under the influence of the enzyme lipase forming free fatty acids, decompounding organic phosphorus compounds (phosphatides, phytin, phytosterols), releasing acidic phosphate salts, resolving protein and other substances, increasing amount of acid active compounds.

The increase in the fat content in germinated grain can be associated with the enzymatic hydrolysis, its reduction in spoiled grain, perhaps due to the decomposition of fats by grain microflora.

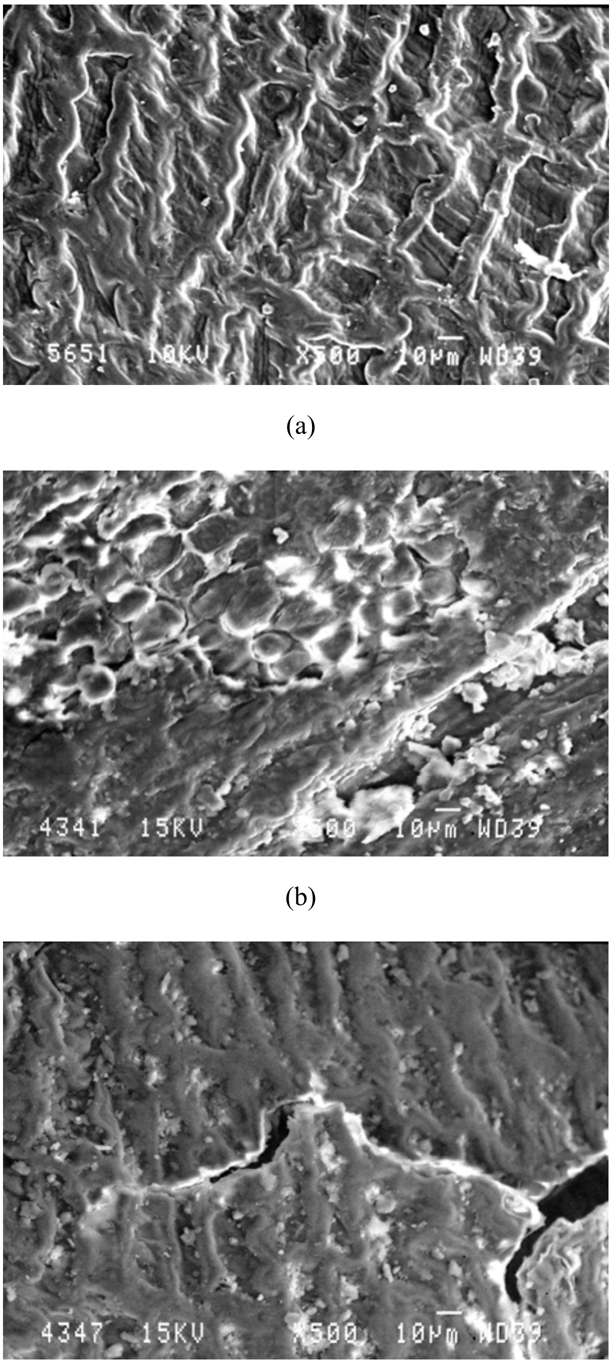
Additionally, we investigated the microstructure of peeled buckwheat surface obtained from normal, spoiled and germinated grains.

The microstructure of the surface of peeled buckwheat surface from normal, spoiled and germinated grains was examined on micrographs obtained from a scanning electron microscope JSM-840. The surface morphology of the samples is shown in micrographs (Fig. 3).

As we can see from figure 3, the microstructure of the outer surface of steamed grain from normal grain has dense cellular structure without damage with uneven distribution of fiber of diameter 5–10 microns. The structure has a polyhedral shape with a mesh size of 10–20 microns up to 70–40 microns. This indicates that steamed grain has surface starch gelatinization and its hardening by heat treatment [14].

The surface of steamed grain produced from spoiled grain has microstructure of discernible densely packed rounded grains of starch sized 5–15 microns. Starch grains are arranged in rows and are connected to the protein matrix, which is consistent with previous studies [15]. The absence of seed coat and the aleurone layer on the core surface is probably due to prolonged exposure to moisture and heat resulting in swelling and deformation of the core and a complete destruction of the structure.

The surface of spoiled grain produced from germinated grain has also a very distinct honeycomb structure with an uneven distribution of fibers of diameter 7–20 microns. The structure has a polyhedral shape with a mesh size of 10–20 microns up to 20–50 microns. This change in the structure of the core surface from germinated grains indicates a higher degree of starch gelatinization in comparison with the normal grain at the same mode of hydrothermal treatment. The entire surface of the core is covered with a grid of cracks having a width of 3–20 mm and length up to 500 mm. Probably, the presence of developed cracks on the core surface lead to a significant increase of the specific surface of the core, contributes to overheating of such grains during heat treatment, greater gelatinization of surface and darkening of core endosperm.



(a)

(b)

(c)

Fig. 3. The surface morphology of buckwheat samples from (a) normal, (b) spoiled, and (c) germinated grains.

The total surface area of germinated and normal grain was determined by BET method at initial step of adsorption isotherm [16]. Measurement of nitrogen adsorption isotherms was carried out on an automatic volumetric vacuum setting "ASAR-2000" at 77.5K (samples were prepared, evacuated in vacuo at 493K before the complete cessation of gas evolution). The results are shown in Table 11.

As it is shown in Table 11, the specific surface area increases 3 times due to germination process.

Analysis of the research results of germinated grain showed that in the process of hydrothermal treatment germinated grains with a developed grid of cracks on the surface are characterized by darkening of the endosperm and considered to be spoiled. The more germinated grain is after the hydrothermal treatment, the more spoiled grain appears.

For the processing of grain containing germinated grains, it is necessary to use a weaker TRP modes to obtain peeled buckwheat of lighter color.

The calculation of the cost of off-grade grain processing was made on the basis of value set in the current period of grains and groats in the standard output of peeled buckwheat 69% and 74% for the Chinese grain. Standard grain was used to compare. Calculation of cost of off-grade grain processing is presented in Table 12.

Table 11. The specific surface of normal and germinated grain

Sample	Specific surface of buckwheat, cm^2/g
Normal grain	1100 +/- 30
Germinated grain	3290 +/- 150

Table 12. Cost of off-grade grain processing

Defect of grain	Cost, 1 ton/ruble	Cost reduction, %	Cost effectiveness, %	Grain price for 1 ton with VAT (ruble)	Groat price of 1 ton with VAT (ruble)
Standard grain	11957	–	10.0	8000	14468
Wet st.*	12332	–	6.7	8000	14468
Wet prep.**	11997	2.9	9.6	8000	14468
With hard-separable imp. st.	12438	–	5.7	8000	14468
With hard-separable imp. prep.	12312	3.7	6.8	8000	14468
With filmness up to 19 % st.	11997	–	9.6	8000	14468
With filmness 19 % prep.	11285	6.3	16.5	8000	14468
Containing germinated grain st.	11997	–	9.6	8000	14468
Containing germinated grain prep.	11734	2.4	12.1	7800	14468

Note. * st. – standard technology; ** prep. – proposed technology.

The presented data suggest that a comprehensive approach to the modernization of Russian equipment allow processing off-grade grain with obtaining end products in accordance with the requirements, reducing the cost to 6.3%. Thus, changing drying rate mode and fractionation methods make it possible to increase the efficiency of processing off-grade buckwheat grain.

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