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MODERNIZED FLOWCHART FOR MILLET PROCESSING INTO POLISHED MILLET GROATS

Abstract

In Ukraine, millet production is characterized by significant fluctuations in sown area and gross yield over the past three decades, with peak values recorded in the 1990s. Currently, the average annual sown area is 70–120 thousand hectares, and production volumes reach 100–200 thousand tons, with cultivation concentrated in the steppe and forest-steppe regions. Ukraine holds leading positions in Europe, accounting for approximately 0.5–0.8% of global millet production. The range of millet-based groats in Ukraine is mainly limited to polished millet groats. Breeding work in Ukraine is systematic and continuous, with constant updates to the varietal composition. As of 2025, 37 varieties are registered in the State Register, among which the most widespread is "Myronivske 51". The production of polished millet groats is a multistage process that includes cleaning, fractionation, dehulling, sorting, polishing, and quality control. Dehulling is carried out on roller-deck machines with one or two decks, with sequential cleaning of the products after each dehulling system. The polishing stage improves kernel quality and extends shelf life. The yield of the finished product is 60–65%, while dehulling losses reach 15.5%; the remaining losses consist of by-products formed due to kernel fragmentation and flour formation. The technology is complex, labor-intensive, and energy-demanding, with high space and equipment requirements, which complicates production at small enterprises. The main limitations include the narrow product assortment and relatively low product yield, as well as the high complexity of the technological flow with numerous sorting and separation stages. To improve efficiency and expand the assortment, technological modernization is needed: improvement of dehulling and polishing machines, optimization of intermediate sorting, implementation of water-heat treatment, and the introduction of modern means of groat quality control. These measures would create conditions for the development of groat production and an increase in millet's market share. During the research, a technological process for millet processing into polished groats was developed by introducing water-heat treatment at the preparation and final stages of production. Preliminary steaming at 0.10–0.15 MPa and subsequent drying to 14% moisture improves the physical and mechanical properties of the grain, reduces hull strength, and facilitates more efficient dehulling. Dehulling is carried out in two stages on roller-deck machines, which enables gradual removal of the hulls and reduces kernel damage. Separation after each processing stage effectively removes husk and flour. Kernel polishing on abrasive dehuller Kaskad ensures gentle abrasion of hull residues and minimizes losses, while aspiration improves quality and shelf-life. The final stage – repeated steaming – enhances the functional properties of the groats, inactivates enzymes, stabilizes fat, and increases microbiological safety of the product.

Keywords: millet, cultivation and processing, groat industry, technological analysis, steaming of grain and polished kernel, application of kernel control on pneumatic sorting table, increase product yield.

Introduction

The history of millet as a groat crop has deep roots that trace back to the earliest stages of agricultural development and the formation of agrarian civilizations. Archaeobotanical and paleoethnographic research indicates that the domestication of millet occurred during the Neolithic period, approximately in the 6th–5th millennium BCE, in the territory of Northern China and Central Asia. Findings of Panicum miliaceum L. seeds in the cultural layers of Yangshao settlements in the Yellow River basin confirm its early use in the diet of Neolithic farmers. This region is considered the center of origin of cultivated millet, from where it spread to other parts of Eurasia. The gradual westward spread of millet occurred through Central Asia to the steppe zones of Eastern Europe, as evidenced by archaeological excavations of Scythian burial mounds, where grain remnants have been discovered. In Europe, the first reliable evidence of millet use dates back to the Bronze Age, specifically the 2nd millennium BCE, particularly in the territory of present-day Hungary, the Czech Republic, and Poland. Among ancient Slavic tribes, millet was one of the key crops ensuring food security, as indicated by archaeological data and written references in the chronicles of Kyivan Rus. At that time, millet was widely used to prepare porridges, bread products, and beverages, reflecting its versatility as a food product. Throughout the Middle Ages, millet became established as an important cereal crop in European agriculture, especially under conditions of poor soils and unstable climates. Its cultivation became widespread in peasant farms due to the crop's unpretentious nature, drought resistance, and short vegetation cycle. In Ukrainian lands, millet played a key role in the population's dietary structure, particularly in the production of millet porridge, which for a long time remained a staple of the daily diet. With the development of the flour and groat industry in the 19th–20th centuries, technologies for millet processing were improved, allowing for the production of groats with a high degree of purification. However, the gradual displacement of millet by wheat, maize, and rice in many regions led to a decline in its share of global production. Nonetheless, in Asian and African countries, millet still remains an important element of food security, especially in regions with high moisture deficit [1–4].

Today, global millet production is characterized by significant regional differences and is shaped by a combination of agroclimatic, socio-economic, and cultural factors that influence the scale of its cultivation. According to the Food and Agriculture Organization of the United Nations (FAO), the average annual global millet production over the past decade has ranged from 28 to 31 million tons, with sown areas fluctuating between 28 and 32 million hectares. The bulk of production is concentrated in regions with arid and semi-arid climates, where crops with a short growing season and high resistance to heat and moisture deficit are traditionally cultivated. India is the largest millet producer globally, accounting for over 40% of the world’s output, or approximately 12–13 million tons per year. In addition to India, significant production volumes are contributed by Niger and Nigeria, each of which cultivates an average of 4.5–5 million tons of millet annually, making them key production centers in West Africa. In this region, millet serves as a strategic food security crop due to its stable yields under drought conditions, where cultivation of other cereals is often unfeasible. Other major producers include Mali, Sudan, Burkina Faso, and Chad, where total production varies between 1 and 2 million tons, and sown areas remain consistently high. Collectively, African countries contribute over 50% of global millet production, underscoring its strategic importance for the continent. In China, production volumes reach 2–2.5 million tons per year, with cultivation primarily concentrated in northern provinces with a continental climate. In Europe and North America, millet holds secondary importance and is cultivated as a niche crop. For example, in the United States, annual gross production amounts to about 0.2–0.3 million tons, making it the largest producer in North America. European countries collectively produce about 0.4–0.6 million tons of millet annually, accounting for approximately 2% of global production. In Central and Eastern European countries (Ukraine, Poland, Hungary, the Czech Republic, and Slovakia), millet maintains the status of a traditional food crop. In contrast, in Western Europe (France, Germany, Austria), production is mostly niche-oriented, targeting the organic sector and the needs of specialized food markets [5–8].

Literary review

The assortment of groat products obtained from millet processing is shaped by both the biological properties of the crop and the technological traditions of different regions of the world. The basic and most widespread product is groats produced by removing the floral and fruit husks, the germ, and partially or fully polishing the endosperm of Panicum miliaceum L. or related millet species. In most countries with established traditions of millet consumption (India, China, Niger, Nigeria, Mali, Ukraine, Poland), millet groats are the primary end product of industrial processing, which necessitates a high degree of purification and polishing to achieve the desired organoleptic properties [9,10].

In global practice, several types of millet groats are distinguished depending on the degree of surface processing of the kernel and the preservation of structural components of the grain. The most widespread is polished groats, which contain a minimal amount of residual husks and are characterized by a uniform light-yellow surface. In Eastern European and Central Asian countries, crushed millet groats are also produced by fragmenting the polished kernel to reduce cooking time. In India and China, products with less intensive polishing are widespread, retaining more bran fractions and the germ, which increases nutritional value but reduces shelf life. In addition to traditional millet groats, industrial-scale production includes auxiliary processed products aimed at expanding the functional uses of millet. In many African countries (Niger, Nigeria, Mali, Sudan), groats with partial preservation of bran fractions are produced for preparing national dishes such as thick porridges and fermented foods. In South Asia, pre-steamed groats are widely produced, involving water-heat treatment of the grain before polishing, which improves cooking properties and increases the solubility of proteins and carbohydrates. In countries with developed food industries (USA, France, Germany), the production of millet-based groat products includes innovative forms tailored to specialized dietary needs. These include instant porridges, flakes, and granules made from millet groats, used as gluten-free ingredients in food products. At the same time, Europe and North America are seeing a growing trend toward whole-grain groats that retain the germ and bran layers, aligning with modern healthy eating trends [11–14].

Formulation of the problem

Millet production in Ukraine is characterized by significant variability. According to statistical data from the State Statistics Service of Ukraine and international databases (FAOSTAT), over the past three decades the sown area of millet in Ukraine has ranged from 40,000 to 300,000 hectares, resulting in substantial fluctuations in total harvest from 50–70 thousand tonnes to 250–300 thousand tonnes during periods of increased domestic demand. The largest millet-growing areas were recorded in the mid-1990s, when millet production held strategic importance for the country’s food security. However, since the early 2000s, a gradual decline in sown area has been observed due to decreasing crop profitability and displacement by more lucrative cereals such as wheat and corn. In the recent period (2015–2023), the average annual millet sown area ranges from 70,000 to 120,000 hectares, ensuring production volumes between 100,000 and 200,000 tonnes. The highest production volumes are traditionally concentrated in the steppe and forest-steppe regions (Dnipropetrovsk, Zaporizhzhia, Mykolaiv, Odesa, Poltava, and Kharkiv regions), which is explained by millet’s adaptability to low moisture and high temperatures during the growing season. In Ukraine, millet is mainly cultivated by small and medium-sized farms. In the context of global production, Ukraine accounts for approximately 0.5–0.8% of the world's total millet harvest, allowing it to remain one of the leading producers in the European region [15–18].

The range of groat products obtained from millet processing in Ukraine is traditionally represented by polished millet groats, which is the only product regulated by the Rules for conducting and organizing the technological process at groat mills [19].

The assortment of millet-based groat products in Ukraine can be described as limited compared to foreign practices, particularly in the EU, the USA, and India, where the production of instant porridges, flakes, and granules based on millet groats is actively developing.

DSTU 5026:2008 "Millet. Technical Specifications" is the current regulatory document that defines quality requirements for millet grain intended for food use. It sets key parameters to ensure compliance with safety standards and technological suitability for processing. The standard applies to cultivated millet grain (Panicum miliaceum L.) supplied to grain processing enterprises and defines its quality based on a set of physicochemical, sanitary-hygienic, and organoleptic indicators. DSTU 5026:2008 also includes a classification of millet based on quality categories depending on the intended use and key parameter levels. The standard establishes moisture content requirements, which must not exceed 13.5%, to ensure proper storage conditions and prevent microbiological spoilage or self-heating. Limits are also set for impurities: foreign matter (no more than 2.0%) and grain admixture (no more than 8.0%). The standard classifies millet by kernel color, which is an important factor in further groat processing. The following types are identified: white, creamy, yellow with shades, red in various shades, and mixed colors. For high-quality food-grade use, preference is given to first- and second-class millet with yellow or white coloration, as these yield groats with desirable organoleptic characteristics after polishing. First-class millet must possess the highest consumer and technological properties: uniform kernel size, moisture content not exceeding 13.5%, minimal amounts of foreign and grain impurities (within 2.0 % and 5.0 %, respectively), no signs of pest damage or mold, and a total of damaged and shriveled kernels not exceeding 3–4%. This grain is considered most suitable for the production of groats with high organoleptic quality. Second-class millet has slightly lower quality indicators: higher permissible levels of impurities (foreign matter up to 2.0%, grain admixture up to 8.0%), and a greater proportion of damaged, shriveled, or sprouted kernels.

As of July 2025, the State register of plant varieties permitted for distribution in Ukraine [20] includes 37 varieties of common millet (Panicum miliaceum L.). The most widespread remains the Myronivske 51 variety, which was included in the Register [20] as early as 1978. In the following decades, the assortment of registered varieties expanded with the inclusion of Kyivske 87 (1991) and Kyivske 96 (1999). During the first two decades of the 21st century, breeding work remained consistent, reflecting the systematic nature of the selection process. However, the most intensive renewal of the varietal composition occurred in 2006, when five new varieties were registered simultaneously: Denvikske, Zolushka, Konstantynivske, Lana, and Tavriiske. Over the past five years, there has been further active replenishment of the varietal resources: in 2020, the varieties Dyvovyzhne, Kazkove Dzherelo, and Kornberger Mittelfrueh were registered; in 2021 – Yardush; in 2022 – Kesha; in 2023 – Peremozhne; and in 2024 – PS Lileya, PS Chysta Krynytsia and Slavetne.

The millet breeding process in Ukraine is continuous and purposeful, ensuring the gradual formation of a modern varietal base of this crop and creating prerequisites for expanding and updating the raw material base necessary for the stable operation and development of groat production.

The low popularity of millet-based products on the modern Ukrainian market is driven by a complex of socio-economic, technological, and cultural factors that interdependently affect consumer preferences. First and foremost, millet is traditionally associated with a limited range of products, primarily represented by millet groats, shaping the perception of this crop as secondary compared to other cereals such as wheat, rice, or buckwheat. This stereotype, rooted in the soviet period, still significantly hampers the development of a millet consumption culture under modern conditions. A key barrier is also technological limitations in production. Millet processing is accompanied by elevated kernel losses due to the complexity of dehulling and the need for multi-stage processing, which directly affects the cost of the final product.

Insufficient modernization of processing equipment and the lack of adapted processing schemes for modern high-yielding varieties limit the potential for product range expansion, resulting in a market dominated by traditional millet groats with few innovative solutions in the field of modern groat products.

An important role is also played by the social aspect, particularly the changing dietary preferences of consumers. The demand structure is dominated by convenience foods and products aligned with current healthy eating trends, while millet, despite its high content of biologically valuable substances, remains underrepresented in the categories of enriched, functional, and premium products. An additional factor is the lack of effective promotion of millet-based products in the domestic market, which prevents consumers from forming clear associations between this crop and modern, high-quality food products.

The technological process for producing polished millet groats, according to the Rules for conducting and organizing the technological process at groat mills [19], is a multi-stage system of operations. It includes initial cleaning of the grain mass from foreign impurities, fractionation by size characteristics, dehulling, separation of dehulling products, polishing, control, and sorting after each processing stage.

The prepared grain is first fractionated using air-screen separators and groat plansifter A1-BRU. The technological scheme of production can be implemented in two ways: single-stream processing without size fractionation or a two-stream scheme with fractionation into coarse and fine fractions. The coarse fraction is formed by passing through a 3,0 mm sieve and descending from 1,7×20 mm sieves; the fine fraction passes through a 1,7×20 mm sieve and descends from 1,5×20 mm sieves. Both fractions are then directed to the dehulling operation.

Dehulling is performed on roller dehullers with one or two decks. The use of single-deck dehullers involves sequential grain processing through four dehulling systems (in the case of fractionation, three systems are used: the first operates separately for each fraction, while the second and third operate jointly). When using double-deck dehullers, sequential dehulling occurs on two systems. After each dehulling system, the products go to sorting to air separators to remove husks, crushed kernel particles, and bran, as their presence significantly reduces the efficiency of subsequent operations. Specifically, products from the first dehulling system are separated three times, while products from the second, third, and fourth systems are separated twice. As a result of these operations, millet kernels with an unhulled grain content not exceeding 1% are formed. This intermediate product is classified as semi-processed polished millet groats (dranets). To improve the commercial appearance, enhance consumer characteristics, and ensure an extended shelf life, a polishing operation is performed, during which the fruit and seed coats, as well as part of the germ, are removed. Polishing is carried out in a single system using machines such as the A1-ZShN type and screw-press polishing units U1-BShP. The polishing products are passed twice through air separators to remove bran, small kernel particles, and remaining hull fragments. The obtained whole polished kernel is directed to a groat sieve for final control: large impurities are removed on sieves with openings Ø 2,3–2,5 mm or sizes of 1.8–1.9×20 mm, while bran residues and crushed particles are removed by passing through sieves with openings Ø 1,6–1,7 mm. The material descending from the 1.6–1.7 mm sieves forms the finished product–polished millet groats–which are additionally cleaned twice in air separators before packaging. The yield of finished product by this technological scheme is 60–65% [19].

Among the main disadvantages of polished millet production is the long duration and multi-stage nature of the technological process, which largely determines its high energy consumption and labor intensity. The need to use four consecutive dehulling systems when employing single-deck roller dehullers or two systems when using double-deck dehullers is explained by the morphological features of millet grain. An additional complexity of the technology is created by the advanced system of separation and sorting: the products of dehulling after each system undergo thorough cleaning using up to nine air separators, which ensure the removal of husks, crushed kernel particles, and bran. The integrity and size composition of the kernel are controlled using groat sieves and additional air separators. The specific features of the technological scheme impose increased requirements on the production area for the placement of corresponding equipment and the transport communications between its units. This creates significant difficulties for implementing the full production cycle of polished millet groats at enterprises with low capacity, often limiting their ability to master millet processing. Analysis of the classical technology reveals a number of key limitations, among which the main ones are the narrow product assortment and relatively low yield of finished groats. The yield of polished millet groats is 60–65 %, while the proportion of husks removed at the dehulling stage reaches 15.5 %. The remaining by-products and waste are formed due to excessive formation of crushed kernel particles and bran, which arise as a result of the intensive mechanical action of the working parts of the dehulling and polishing machines.

The complexity and length of the technological process, increased losses of the valuable part of the grain, and insufficient flexibility of production schemes determine the objective need for further modernization of millet processing technology. Optimization of the designs of dehulling and polishing machines, improvement of the intermediate sorting system, implementation of stages of water-heat treatment of the grain, and equipment for groat quality control are key directions for increasing the efficiency of polished millet production and further expanding its product range.

Materials and methods

The aim of this study is to substantiate and develop a technological scheme for processing millet into polished millet groats with the implementation of two-stage steaming, reduction of the dehulling stage, and introduction of groat quality control using specialized equipment.

The objectives are:

- to analyze the volumes of millet cultivation worldwide and in Ukraine, identifying current trends, challenges in cultivation, and processing;
- to analyze the stages of millet processing into groats according to the existing technology;
- to develop and substantiate a modernized technological process for millet processing into groats by introducing grain steaming before dehulling and steaming of the finished product, shortening the dehulling stage, and implementing groat control on pneumatic sorting table.

Results of the study and their discussion

As part of our research, we developed an improved version of the technological process for processing millet grain into polished groats (Fig. 1). This process increases the yield of whole kernels and improves the quality indicators of the final product by introducing water-heat treatment at the stages of grain preparation and final kernel processing.

According to the developed technological scheme, millet grain cleaned of impurities and with a moisture content not exceeding 14% is directed in a single stream to the first stage of water-heat treatment, which is carried out by hot conditioning in batch-type steamers, such as the "A9-BPB" (manufactured by "OLIS" Ltd,, Odesa [21]). Steaming is carried out under a steam pressure of 0.10–0.15 MPa for 3–5 minutes. The steamed grain is then dried in vertical steam dryers, such as the "VPS-O" (manufactured by "OLIS" Ltd,, Odesa [21]), to a moisture level of no more than 14%.

Water-heat treatment of millet before dehulling is a key technological step that optimizes the grain's physical and mechanical properties and significantly increases the efficiency of subsequent dehulling and polishing operations. Millet kernels are characterized by a dense adhesion of the fruit and seed coats to the endosperm surface, as well as high vitreousness, which necessitates the application of intense mechanical force during dehulling. Such force often leads to the formation of a large number of broken kernel particles and flour dust, increasing unproductive losses. Water-heat treatment alters these properties, creating favorable conditions for more controlled separation of the husks.

During grain steaming, partial plastic deformation and softening of the outer layers occur due to moisture penetration into the intercellular spaces and protein denaturation in the cell walls. This reduces the

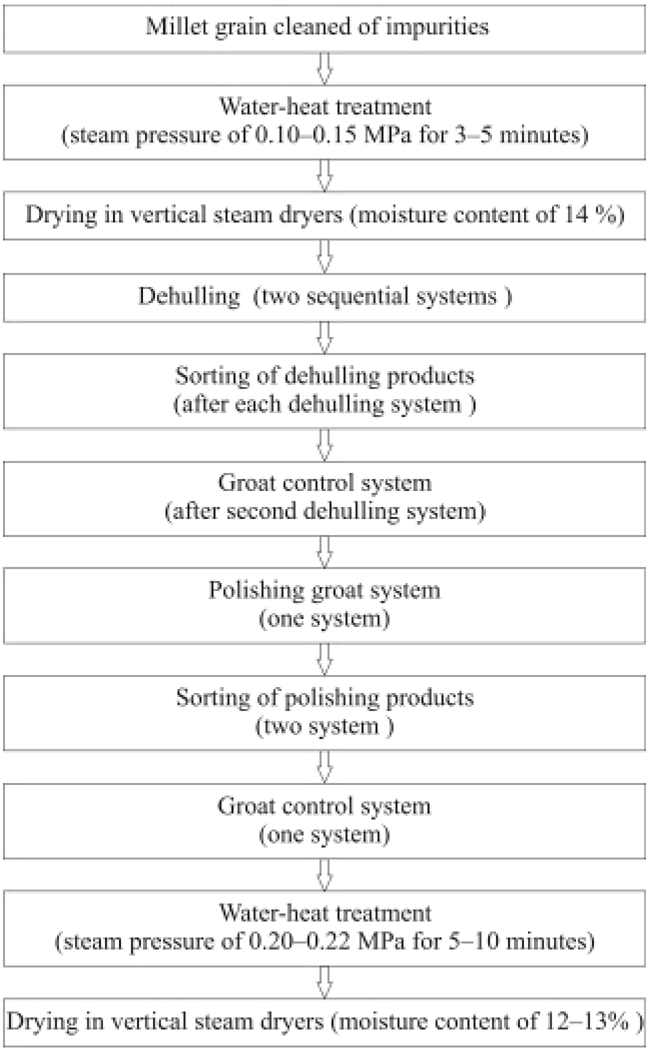

Fig. 1 –The structure scheme of processing millet into groats

strength of the bond between the husks and the outer endosperm layers. Simultaneously, the starch granules in the endosperm swell, and partial breakdown of protein-starch complexes occurs, reducing internal stress within the kernel tissues. As a result, the mechanical force required for dehulling and polishing is reduced, significantly decreasing kernel breakage and the formation of floury particles.

Additionally, steaming inactivates enzymes, which slows down hydrolysis and kernel spoilage during storage of the finished product. The thermal effect also leads to partial gelatinization of the starch in the surface layers, reducing brittleness during mechanical processing.

In the next stage, the grain mass is subjected to dehulling using two sequential systems of roller-deck dehulling machines, such as the millet dehuller “VDSO” (manufactured by "OLIS" Ltd,, Odesa [21]).

Dehulling millet grain after preliminary water-heat treatment using two consecutive systems millet dehuller “VDSO” (manufactured by "OLIS" Ltd,, Odesa [21]) has a number of significant technological and quality advantages, justifying the application of this approach in modern groat production facilities. Performing the dehulling operation after steaming results in a substantial change in the physical and mechanical properties of the kernel, directly influencing the performance of the roller-deck machines. During steam treatment under pressure, the floral hulls soften, protein-polysaccharide bonds partially break, and the adhesion strength of the hulls to the outer layers of the endosperm decreases. This reduces the mechanical effort required for their separation and, accordingly, minimizes kernel damage during dehulling. The use of two sequential dehulling systems millet dehuller “VDSO” allows for a stepwise impact on the kernel with gradual removal of the hulls. This approach ensures more precise processing, reducing the formation of broken particles and flour. The first system primarily separates the floral hulls with partial removal of the fruit coats, while the second completes the cleaning of the kernel by removing residual hulls fragments. Such distribution of mechanical load between the systems prevents excessive pressure on the kernel and reduces the likelihood of microcracks in the endosperm structure, positively affecting the integrity and technological properties of the groat.

The structural features of the millet dehuller "VDSO" allow for the adjustment of the pressure of the working elements and the feed rate of the grain, which, combined with preliminary conditioning, ensures a high level of adaptability of the process to different batches of raw materials. The combined effect of applying steaming and two systems of single-deck roller-deck machines results in an increase in the yield of whole kernels up to 65–70% by reducing unproductive losses in the form of flour dust and broken particles. Additionally, the uniformity of the granulometric composition of the final groats is improved, and their culinary properties are enhanced due to the preservation of the structural integrity of the endosperm.

To improve the efficiency of hulls separation, the dehulling products after each system are subjected to separation in air separators, such as the “ASO” (manufactured by "OLIS" Ltd,, Odesa [21]), which makes it possible to remove hulls, broken kernel particles, and flour dust.

The use of “ASO” air separators (manufactured by "OLIS" Ltd,, Odesa [21]) for sifting millet dehulling products offers a number of significant technological advantages, justifying their integration into modern production lines for polished millet groats. The key task of this equipment is the effective separation of dehulling products based on aerodynamic properties, allowing the removal of light fractions hulls, floral and fruit coat residues, as well as fine particles of flour dust and ensuring a stable granulometric composition of the semi-finished product for further processing. One of the main advantages of the “ASO” separators is the ability to finely adjust the airflow, ensuring a high degree of selectivity in product separation. This is particularly important when working with millet, the kernels of which are low in weight and highly variable in morphological characteristics. As a result, this equipment reduces the number of hulls fragments and flour dust in the whole kernel fraction, which directly improves the quality of subsequent polishing and the final product. Using “ASO” separators after each dehulling system ensures multi-stage cleaning of the products, minimizing the risk of recontaminating the kernel with hulls, increasing the efficiency of the following technological equipment (especially polishing machines), and reducing wear and tear by removing abrasive hulls particles. The design features of the "ASO" separators include a closed air circulation system, which significantly reduces energy consumption for sifting and lowers the dust content of the working environment. This not only cuts operational costs but also improves sanitary and hygienic conditions in the production area.

Before further polishing, a control sorting of products is carried out in a groat plansifter, such as the "RKO" (manufactured by "OLIS" Ltd,, Odesa [21]), where the remaining flour dust and broken kernel particles are removed. Kernels that remain on sieves with a size of 1,4×20 mm are classified as whole dehulled kernels and directed to the next operation, while undersized material is removed as broken kernel particles, flour dust, and residual hulls.

Polishing of whole kernels is performed in a single system using the abrasive dehuller "Kaskad" (manufactured by "OLIS" Ltd,, Odesa [21]) or their structural analogues, which operate based on the principle of intensive abrasion of the remaining hulls.

The main advantages of abrasive dehuller "Kaskad" (manufactured by "OLIS" Ltd,, Odesa [21]) in millet processing lie in their ability to effectively clean the kernel from residual hulls fragments and superficial endosperm layers without significantly damaging its structure. Polishing millet grain is a technologically challenging operation due to the small size of the kernels, their fragility, and their tendency to form flour dust under intensive mechanical action. Abrasive dehuller "Kaskad"implement the polishing process through a controlled abrasion mechanism, which allows for the gradual removal of thin hulls layers in stages, avoiding deep damage to the outer endosperm layers. A key advantage is the ability to regulate the intensity of polishing (rotation speed of working elements, applied pressure, and residence time of the grain in the chamber), which allows adaptation of the process to the specific characteristics of the kernels. As a result, the formation of broken kernel particles and flour dust is reduced, increasing the yield of whole polished kernels. Thanks to their design, which includes intensive aspiration, flour dust and fine hulls particles are removed simultaneously with the polishing process. This prevents their re-adhesion to the kernel surface and improves the hygienic condition of the grain. This approach makes it possible to obtain polished millet with a clean, uniform surface, which positively affects its organoleptic properties and storage stability.

After polishing, the products undergo double air separation in a closed-cycle air separator, such as the "ASO", to effectively remove residual flour dust and hulls particles. The cleaned kernels are then fed to a pneumatic sorting table, such as the gravity separator "SPS" (manufactured by "OLIS" Ltd,, Odesa [21]), where final quality control of the polished kernels is carried out, and unhulled grains are removed and sent back for reprocessing in the second dehulling system.

The use of the gravity separator "SPS" (manufactured by OLIS LLC, Odesa [21]) at the final quality control stage of polished millet groats improves the qualitative characteristics of the final product and reduces the share of unsuitable impurities. The operating principle of this equipment is based on the combination of vibrational impact and a controlled airflow, enabling particle separation based on a complex of physical properties such as density, size, shape, and aerodynamic characteristics. The main advantage of the gravity separator "SPS" (manufactured by OLIS LLC, Odesa [21]) is its ability to effectively separate unhulled or partially hulled grains, hulls fragments, and light impurities from whole polished kernels. This is especially important in millet groats production, where even a small amount of unhulled grains or hulls fragments significantly degrades the commercial appearance and consumer properties of the product. The use of the gravity separator "SPS" ensures a higher degree of uniformity in groats in terms of structure and color. An additional advantage of the gravity separator "SPS" is the ability to precisely regulate process parameters (airflow intensity, vibration frequency, and amplitude), allowing the equipment to be adapted to different product batches with varying granulometric characteristics. This makes it possible to minimize whole kernel losses while maintaining a high yield of finished groats and simultaneously removing foreign impurities and technological defects. The main advantage of the gravity separator "SPS" (manufactured by OLIS LLC, Odesa [21]) over optical sorters at the control stage of polished millet groats lies in its fundamentally different operating principle, which provides superior efficiency in fraction separation based on physical and mechanical properties. Optical sorters operate exclusively on optical principles, identifying and removing kernels that differ in color or shade from the main product mass. However, in the case of millet characterized by small kernels with variable hull and partial germ coloration, as well as a tendency to form small husk fragments after hulling and polishing–optical sorters are unable to differentiate kernels by density or degree of hulling. As a result, they do not fully remove unhulled or partially damaged kernels from the final product. The gravity separator "SPS" performs multiparametric separation of the product based on density, size, shape, and aerodynamic properties not just optical characteristics. This allows for the effective removal of not only kernels with residual hulls but also low-density particles, small kernel fragments, and hulls, improving the uniformity and structural integrity of the final groats. Moreover, the gravity separator "SPS" offers advantages in operational cost and reliability: it does not require complex calibration of optical systems, expensive maintenance, or replacement of photo-sensitive components, and is less sensitive to dust in the production environment. This makes it more suitable for large-scale millet processing lines, where ensuring process stability and high throughput takes precedence over the detection of individual off-color kernels.

The final stage of millet processing involves the second phase of water-heat treatment, which is performed in batch or continuous steamers, such as the "PPSH-O" (manufactured by OLIS LLC, Odesa [21]), at a steam pressure of 0.20–0.22 MPa for 5–10 minutes.

The application of steaming in batch or continuous steamers–particularly in units like the "PPSH-O" (manufactured by OLIS LLC, Odesa [21]) is a scientifically and technologically justified approach that improves the physicochemical and functional-technological properties of the final groats. Steaming at 0.20–0.22 MPa for 5–10 minutes induces targeted structural-chemical transformations in endosperm components, primarily starch, proteins, and pentosans. These changes collectively enhance the quality characteristics of the groats, simplify further culinary use, and extend shelf life. Thermal degradation of part of the lipid–pigment complex concentrated mainly in the germ and peripheral endosperm layers reduces the risk of rancid taste and odor development in the final product, which is especially relevant for millet groats. In addition, steaming in the "PPSH-O" contributes to a reduction in enzymatic activity, particularly of lipase and lipoxygenase, which catalyze oxidative spoilage of fats. Lower enzyme activity results in decreased intensity of oxidation processes, thereby positively affecting the stability of the groats organoleptic properties during long-term storage. Partial inactivation of the microflora also occurs, increasing the microbiological safety of the final product. The "PPSH-O" steamer (manufactured by OLIS LLC, Odesa [21]) is characterized by stable steam delivery parameters, uniform product treatment, and the possibility of automated control of key operating modes. This ensures reproducible steaming effects and adaptability to various processing lines. Thanks to its structurally simple design, the unit also boasts high reliability, energy efficiency, and ease of maintenance, facilitating its integration into modern millet processing facilities producing polished millet groats.

The steamed groats are dried in vertical steam dryers until a moisture content of 12–13% is reached. After that, they undergo inspection in magnetic separators to remove any possible ferromagnetic impurities and are then directed either for packaging or for storage in finished product bins.

Conclusions

The developed technological scheme makes it possible to optimize the dehulling and polishing processes through preliminary conditioning of the grain, reduce the loss of valuable endosperm fractions, thereby increasing the yield of whole groats and ensuring stable quality indicators of the final product in accordance with modern requirements of the groats industry.

REFERENCES

1. Lu, H., Zhang, J., Liu, K.‑b., Wu, N., Li, Y., Zhou, K., et al. (2009). Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. Proceedings of the National Academy of Sciences, 106(18), 7367–7372. DOI: 10.1073/pnas.0900158106
2. Hunt, H. V., Vander Linden, M., Liu, X., Motuzaite‑Matuzeviciute, G., & Jones, M. K. (2008). Millets across Eurasia: Chronology and context of early records of the genera Panicum and Setaria from archaeological sites in the Old World. Vegetation History and Archaeobotany, 17(S5), S5–S18. DOI: 10.1007/s00334-008-0154-3
3. Martin, L., Messager, E., Bedianashvili, G., & Lebedeva, E. (2021). The place of millet in food globalization during Late Prehistory as evidenced by new bioarchaeological data from the Caucasus. Scientific Reports, 11, Article 12345 DOI: 10.1038/s41598-021-01623-4
4. Winchell, F., Brass, M., Manzo, A., Beldados, A., & Perna, V. (2018). On the origins and dissemination of domesticated sorghum and pearl millet across Africa and into India: A view from the Butana Group of the far eastern Sahel. African Archaeological Review, 35, 333–350. DOI: 10.1007/s10437-018-9300-5
5. Yadav, O. P., Longvah, T., & Bhadra, K. (2019). Nutritional and health benefits of millets. Journal of Food Science and Technology, 56(1), 11–21. DOI: 10.1007/s13197-018-3485-2
6. Saleh, A. S. M., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: Nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety, 12(3), 281–295. DOI:10.1111/1541-4337.12014
7. Dida, M. M., Ejeta, G., & Feyissa, T. (2018). Genetic improvement and breeding of millets for climate resilience and food security. Frontiers in Plant Science, 9, 1662. doi:10.3389/fpls.2018.01662
8. Govindaraj, M., Vetriventhan, M., & Srinivasan, M. (2020). Importance of millets in climate change and food security. Agriculture & Food Security, 9, 4. DOI:10.1186/s40066-020-00257-6
9. Nambiar, V. S., & Singh, U. (2014). Processing and product development of minor millets. Critical Reviews in Food Science and Nutrition, 54(10), 1232–1241. DOI:10.1080/10408398.2011.628713
10. Bhatt, R., & Choudhary, P. (2019). Technological advances in processing of millet grains. Journal of Cereal Science, 87, 55–66. DOI:10.1016/j.jcs.2019.05.007
11. Saleh, A. S. M., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: Nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety, 12(3), 281–295. DOI:10.1111/1541-4337.12014
12. Verma, A. K., & Singh, A. K. (2019). Processing and utilization of minor millets: A review. Trends in Food Science & Technology, 89, 30–43. DOI:10.1016/j.tifs.2019.03.006
13. Taylor, J. R. N., Schober, T. J., & Bean, S. R. (2006). Novel food and non-food uses for sorghum and millets. Journal of Cereal Science, 44(3), 252–271. DOI:10.1016/j.jcs.2006.06.007
14. Gupta, S., Singh, N., & Singh, D. (2017). Processing of millets for value addition and improved functionality. Journal of Food Science and Technology, 54(10), 3209–3219. DOI:10.1007/s13197-017-2807-3
15. Kostyuchenko, V. V., & Shevchenko, S. V. (2020). Analiz tendentsiy vyrobnytstva prosa v Ukrayini ta perspektyvakh yoho rozvytku. Visnyk Natsional′noho universytetu bioresursiv i pryrodokorystuvannya Ukrayiny, 309, 45–52. DOI:10.32607/2306-9721-2020-309-45-52
16. Pylypenko, O. M., & Lysenko, I. I. (2018). Osoblyvosti ahrotekhniky ta vyrobnytstva prosa v stepovykh rehionakh Ukrayiny. Ahroinzheneriya, 43, 22–28. DOI:10.31617/ai.2018.43.04
17. Romanyuk, M.V., & Bondarenko, T.P. (2019). Analiz suchasnoho stanu vyrobnytstva prosa v Ukrayini. Zbirnyk naukovykh prats′ Natsional′noho universytetu kharchovykh tekhnolohiy, 56(3), 117–123. DOI:10.24263/2304-974X-2019-56-3-14
18. Savchenko, I. P., & Dmytrenko, V. S. (2021). Rehionalna spetsyfika vyroshchuvannia prosa v Ukraini: problemy ta perspektyvy. Visnyk ahrarnoi nauky, 37(2), 58–65. DOI:10.31073/vas.2021.37.2.07
19. Pravyla orhanizatsii i vedennia tekhnolohichnoho protsesu na krupianykh zavodakh. – K., 1998. – 164 s.

20. Derzhavnyi reiestr sortiv roslyn, prydatnykh dlia poshyrennia v Ukraini na 2025 r.. [Elektronnyi resurs]. – Rezhym dostupu: https://minagro.gov.ua/file-storage/reyestr-sortiv-roslin
21. Elektronnyi kataloh tekhnolohichnoho obladnannia TOV OLYS [Elektronnyi resurs]. – Rezhym dostupu: https://olis.com.ua/oborudovanie/ochischennya-zer-na/?utm_source=google&utm_medium=cpc&utm_campaign=IW_/_Pmax_/_Brand_OLIS_/_MaxCR_/_21.05.2024&utm_con-tent=&utm_term=&gad_source=1&gad_campaignid=21312123569&gbraid=0AAAADpBaK3CUeTs0FlH0dOFqyVbQGp3g&gclid=Cj0KCQjwndHEBhDVARIsAGh0g3BHrwy4UkqIqJHmkm6pp5hfbkLlR4hGXsB_YVZWmB7kvXKgZzhBggQaAi1iEALw_wcB

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МОДЕРНІЗОВАНА СХЕМА ПЕРЕРОБКИ ПРОСА В КРУПИ ТИПУ ПШОНО ШЛІФОВАНЕ

Анотація

В Україні виробництво проса характеризується значними коливаннями площ посівів і обсягів валового збору протягом останніх трьох десятиліть, із максимальними значеннями у 1990-х роках. Сучасні середньорічні посіви становлять 70–120 тис. га, а виробництво – 100–200 тис. тонн, вирощування зосереджене у степових і лісостепових регіонах. Україна посідає провідні позиції у Європі, забезпечуючи близько 0,5–0,8 % світового виробництва. Асортимент круп'яних продуктів із проса в Україні обмежений переважно шліфованою пшоняною крупою. Селекційна робота в Україні є системною та безперервною, з постійним оновленням сортового складу. На 2025 рік в Реєстрі зареєстровано 37 сортів, серед яких найбільш розповсюджений сорт – «Миронівське 51». Виробництво шліфованого пшона є багатостадійним процесом, який включає очищення, фракціонування, лущення, сортування, шліфування та контроль. Лущення проводиться на вальцедекових верстатах із одною або двома деками, з послідовним очищенням продуктів після кожної лущильної системи. Шліфування забезпечує покращення якості ядра і подовження терміну зберігання. Вихід готової продукції становить 60–65 %, втрати під час лущення сягають 15,5 %, а решта – побічні продукти через подрібнення ядра і утворення борошенця. Технологія є складною, трудомісткою і енергоємною, з високими вимогами до площ та обладнання, що ускладнює виробництво на малих підприємствах. Основні обмеження – вузький асортимент і порівняно низький вихід продукції, а також висока складність технологічної схеми з численними етапами сортування і сепарування. Для підвищення ефективності та розширення асортименту необхідна модернізація технології: удосконалення лущильних і шліфувальних машин, оптимізація проміжного сортування, впровадження воднотеплової обробки та сучасних засобів контролю якості крупи. Це створить умови для розвитку круп'яного виробництва і збільшення частки проса на ринку. В ході виконання досліджень розроблено технологічний процес переробки проса в шліфовану крупу шляхом впровадження воднотеплової обробки на етапах підготовки та заключному етапі виробництва для готової продукції. Попереднє пропарювання при 0,10–0,15 МПа і подальше сушіння до 14 % вологості покращують фізико-механічні властивості зернівки, знижують міцність оболонок і сприяють ефективнішому лущенню. Лущення здійснюється у дві стадії на вальцедекових верстатах, що забезпечує поетапне зняття оболонок і зменшує руйнування ядра. Сепарація після кожного етапу обробки дозволяє ефективно видаляти лузгу та борошно. Шліфування ядра на машинах типу «Каскад» забезпечує м'яке стирання оболонок і мінімізацію втрат, а аспірація підвищує якість і тривалість зберігання. Заключна стадія – повторне пропарювання покращує функціональні властивості крупи, інактивує ферменти, стабілізує жир та підвищує мікробіологічну безпеку продукції.

Ключові слова: просо, вирощування і переробка, круп'яна промисловість, аналіз технології, пропарювання зерна і шліфованого ядра, застосування контролю ядра на пневмостолах, збільшення виходу продукції.

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