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Substantiation of the preparation technology of soft-grained wheat for deep processing

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Abstract. The process peculiarities of harvesting grain for processing and production of food products are impossible without determining the content of protein, starch, gluten, the same in the grain weight of soft-grained wheat, which comes to grain processing plants, contains grain and waste impurities. The purpose of the work was to substantiate the technologies of primary and advanced preparation of wheat grain using modern methods of storage and transportation for further use in the processes of deep grain processing. The method of identification was used for the technological features establishment, measuring with the morphological characteristics and impurities determination. Grain standards provide for the determination of moisture, test weight, waste and grain impurities, gluten content and gluten deformation index (GDI): grain batches of different varieties of spring and winter soft wheat. The obtained data met the requirements of the 2nd class, according to the indicator of crude protein content, falling number (FN) of the 2nd and 3rd classes. Commercial indicators of the qualitative composition of spring wheat and winter varieties of soft-grained wheat were experimentally determined. It was established that in the group of winter wheat varieties, the moisture content was within 10.1-11.2%, test weight was 757-773, weight per 1,000 seeds was 41.7-43.4 g, gluten content was 20.4-27.3%, GDI was 76.4-81.6 units, FN was 339-364 seconds; 11.4-12.2%, 740-755, 41.8-43.8 g, 21.8-26.2%, 71.1-80.4, 313-358, respectively, in spring wheat varieties. Regarding the nutritional qualities of wheat, in the group of winter varieties, crude protein was 20.9-21.7%, crude fat was 2.4-2.7%, crude fibre was 2.5-3.0%, nitrogen-free extractive substances were 71.1-71.5%; in spring varieties, respectively, 19.64-20.3%, 2.2-2.7%, 2.2-2.4%, 73.5-74.2%. The practical significance of the work lies in the implementation of modern methods of grain storage and transportation, which allows

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to significantly improve the quality of raw materials, increase the efficiency of food production, reduce losses during processing, and ensure compliance of products with high quality standards

Keywords: grain raw materials; equipment; impurities; peeling; separation

INTRODUCTION

The important directions for modernisation of the agro-industrial complex are the productivity growth and the technological processes intensification of complex processing of grain and grain waste. The problem of many plants, especially small ones, is the use of outdated, impractical systems of production processes automation. The development and implementation of the modern complex grain processing equipment with the possibility of computer setting and remote control significantly increases the technical level of enterprises and provides a high profitability level. Grain products are raw materials for many branches of the food and processing industry, therefore, the demand for them is constantly growing. Grain products are the basis of human nutrition and are characterised by high nutritional value and taste.

V. Khudaverdiyeva (2022) states that with export volumes of 40-45 million tons of grain per year, the transportation deficit is about 8 million tons, this potential can be used at grain processing plants for deep processing of grain. In addition, the events of 2022 led to significant limitations in the logistical possibilities for the grain raw materials export. The domestic production of seeds reached 75,000 tons or 63% of the total amount, however, taking into account the huge export flows of grain crops, the cultivated quality potential is lost due to the impossibility of processing raw materials into plant products with high added value, and only the introduction of new technologies for processing grain crops will ensure domestic market. According to H. Wieser *et al*. (2022), deep grain processing is the process of grinding raw materials into components and their effective use in products with high consumer value. As a result of the wheat grain processing technology improvement, opportunities appear not only for the production of dry wheat gluten, starch and feed products, but also for further processing into sugars, in particular glucose, fructose, mannose and galactose. The most common cereal crop, wheat, is considered as a raw material for the ethanol and biomethane production, however, modern processing industries require a larger line of products that are obtained through deep processing.

W. Cheng *et al*. (2021) describe the hardness of the grain endosperm of soft wheat varieties, which are divided into hard grain and soft-grained, and the grain hardness indicator is determined by the consistency diagnostics of wheat endosperm. According to M. Formentini *et al*. (2021), it is known that in the leading producing countries of the USA and Canada, exporters of soft-grained wheat, classify this raw material according to the endosperm consistency, which is the main determinant of the class-forming criterion of wheat quality, both in the domestic and world grain markets. Modern technologies and methods are playing a pivotal role in the enhancement of grain processing efficiency. For instance, the integration of deep learning models, as detailed in a study by Q. Gao *et al*. (2024) have significantly improved the detection and classification of grain quality. These models facilitate rapid and accurate on-site screening, essential for ensuring the high quality of grains intended for deep processing. The precision offered by these technologies reduces labour costs and enhances impurity detection in grain products, thus supporting the production of superior quality wheat products.

V. Liubych *et al*. (2020) provide information on grain stability, which depends on the characteristics of the wheat variety, processing and storage conditions. During storage, the grain ripens, therefore, the enzymes activity decreases, the number of water-soluble substances and non-protein nitrogen decreases, the synthesis of starch from sugars and fat from glycerine occurs and the content of unsaturated fatty acids increases. Usually, grains contain active microbes and pests represented by rodents and insects. According to the characteristics of L. Li *et al*. (2022), grain processing properties can be characterised by such indicators as vitreousness, grain size, bulk or natural weight, weight per 1,000 seeds, density, ash content, grinding ability and type grain composition. According to D. Kumar & V. Kukreja (2022), the characteristics of the flour baking properties are evaluated by indicators of nutrition, gluten quality, gas-forming capacity, dispersed composition, and physical properties of the resulting dough. N. Vasylenko & I. Pravdziva (2022) states that about 113 varieties are involved in the growing process of soft, soft-grained wheat in Ukraine.

When growing grain crops, it is important to increase not only the raw materials yield, but also technical characteristics, namely, grinding, flour-milling and baking properties, that determine the market value. The multi-stage processing technology in the agricultural industry is actively developing and can provide the end consumer with high-quality plant products. The purpose was to substantiate the preparation technologies of raw materials for processing using modern methods of storage, transportation and evaluation of the actual qualitative composition of wheat grain.

MATERIALS AND METHODS

The study was conducted in 2022 at the Institute of Plant Breeding in Ukraine and complied with the ethical standards set forth in the Convention "On Biological Diversity" (1992) and the Convention "On the Trade in Endangered Species of Wild Fauna and Flora" (1973). Ethical norms observed included sustainable use of resources to prevent depletion of wheat varieties and conservation of biological diversity by maintaining and studying various genotypes. Efforts ensured fair and equitable sharing of benefits from the use of genetic resources, ethical conduct in research, and protection of endangered species. These considerations ensured the research was conducted responsibly, aligning with international standards for biological resource conservation and use.

The object of the scientific work was soft winter wheat varieties widely grown in Ukraine – Cubus, Jersey, Palitra; varieties of spring soft wheat – Zlata, Heroinya, Kharkivska 26. Determination of grain quality was carried out according to biological and laboratory methods. Biological methods included organoleptic evaluation methods using the senses, determining the main indicators of grain freshness by colour, odour and taste. Laboratory tests were performed according to generally recognised methods in biology, based on complex biochemical studies by V. Vlizlo *et al*. (2023): on the content of total nitrogen calculated on the raw protein of Kjeldahl pores, crude fat, crude fibre, crude ash, nitrogen-free extractive substances (NFES).

The study used theoretical methods: identification to establish the main technological features of soft-grained wheat seeds; measuring to determine morphological characteristics and the number of foreign impurities. During the course of the work, a systematic approach was applied to the uniqueness of technical and economic conditions for effective evaluation of grain seed cleaning. The list of the main indicators of nutrition and quality of winter wheat grain of different varieties for different purposes in particular commodity and seed material characteristics has been determined.

The information base of the research consisted of regulatory and legal documents, scientific and analytical articles, informational materials published in official publications and on Internet sites, as well as own developments in the breeding industry. In particular, the study took into account the following normative acts: DSTU ISO No. 13690:2003 (2003), DSTU ISO No. 21415-1:2009 (2009), DSTU No. 3768:2019 (2019), DSTU No. 8840:2019 (2019) and DSTU GOST No. 1084 0:2019 (2019). These normative documents ensure the standardization of methods of research, determination and control of the quality of grain and grain products, which allows conducting complex laboratory tests and ensuring high quality and safety of products.

The qualitative wheat indicators were determined according to the methodology of the qualification examination of plant varieties for suitability for distribution in Ukraine by S. Tkachyk *et al*. (2016) according to the following indicators: technological: moisture, colour, smell, taste, impurities content, contamination, small grain fraction content; flour-milled: vitreousness, test weight, weight per 1,000 seeds, specific gravity, ash content, grinding, actual composition of nutrients; baking properties: gluten content and quality, falling number (FN), dispersed composition, acidity, and porosity.

RESULTS

According to the Food and Agriculture Organization (FAO) (2023), national policy measures have been established to increase productivity, food security, and food products, particularly grain crops, through the effective use and processing of raw materials from soft-grained wheat. An important issue addressed by the State Service of Ukraine for Food Safety and Consumer Protection (n.d.) is the control over the safety and quality of products of plant origin, aiming to enhance and improve existing methods of veterinary and sanitary control throughout the production cycle. These scientific implementations facilitate the application of a comprehensive set of special laboratory studies on grain crops, fodder, feed additives, and raw material systems, considering the potential productivity of different varieties. The most common methods of grain cleaning and sorting include wheat aspiration by air flow, separation by grid size, separation by length on triers according to shape, and cleaning and sorting by density and surface properties, as well as electrical methods. These methods ensure the quality and safety of wheat grains, making them suitable for various applications.

Figure 1 illustrates trending products produced through the deep processing of soft-grained wheat, such as gluten, starch, glucose monohydrate, ethanol derivatives (bioethanol), biomethane, glucose crystals, GFS-42 (glucose-fructose syrup), GFS-55, organic acids (citric, succinic, lactic), amino acids (lysine, methionine, threonine), biopolymers, and yeast extracts. These products highlight the diverse and valuable outputs achievable through effective grain processing, supporting both national policy objectives and industry needs.

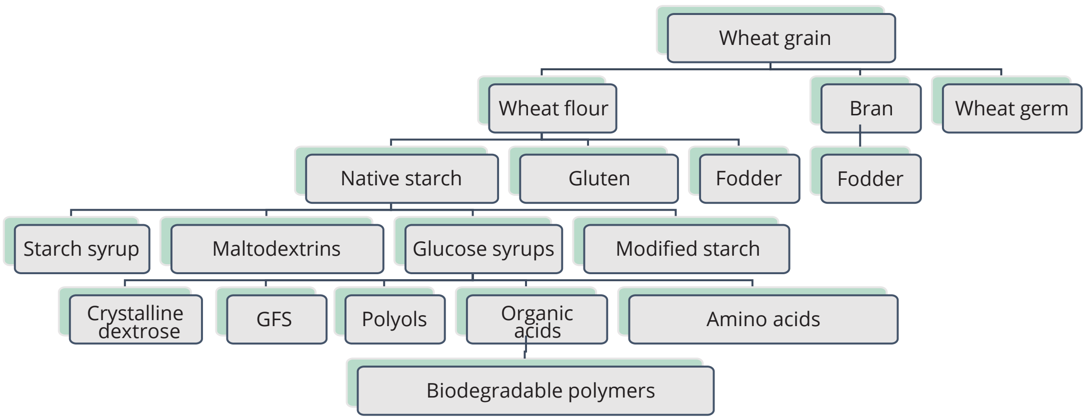

Figure 1. Products of deep wheat processing
Source: compiled by the authors based on National Academy of Agrarian Sciences of Ukraine (2021)

Wheat grain that arrives at grain processing plants always contains a certain amount of impurities in addition to the main component. Grain cleaning is conducted with the help of: dispersing units, washers, crushers, stone selectors, on pneumatic dispersing tables and air separators. Impurities are classified as: seeds of wild weeds: common wild oat, dandelion, wild radish, bitterling, bitter gourd, coronilla, curly weed; seeds of other grain and leguminous crops: barley, corn, peas; damaged seeds: small, underdeveloped, damaged by drying, self-heating, microorganisms, grain parasites; organic impurities: straw, crumbs; inorganic impurities – small stones, sand, ore, lumps. According to the characteristics, soft wheat is divided into six classes, its quality indicators are standardised according to the current standard provided in Table 1.

Table 1. Standard quality indicators of soft wheat

Indicator	Characteristics and standards for soft wheat by classes					
	1	2	3	4	5	6
Type composition	I-IV types			I-IV types, VII types are allowed		
Test weight, g/l, not less	760	755	730	710	710	Not limited
Moisture, %, no more	14.5	14.5	14.5	14.5	14.5	14.5
Grain impurity, %, no more	5	5	8	10	15	15

Table 1. Continued

Indicator	Characteristics and standards for soft wheat by classes					
	1	2	3	4	5	6
In particular, sprouted grains	1	1	3	3	5	Within grain impurity
Waste impurity, %, no more	1.5	2	3	4	5	5
In particular: spoiled grains	0.2	0.2	0.5	0.5	1	1
Fusarium grains	0.3	0.5	1	1	1	1
Ryegrass	0.3	0.5	0.5	0.5	0.5	0.5
Mineral impurity	0.3	0.3	0.5	1	1	1
In particular, pebbles and slag	0.15	0.15	0.2	0.3	Within mineral impurity	
Harmful impurity	0.2	0.3	0.5	0.5	0.5	0.5
In particular:						
smut and crowns	0.05	0.05	0.1	0.1	0.1	0.1
Russian centaury, darnel ryegrass, Sophora alopecuroides, golden banner (in a mixture)	0.05	0.05	0.1	0.1	0.1	0.1
Crown vetch	0.1	0.1	0.1	0.1	0.1	0.1
Smut grain, %, no more	5	5	5	8	8	10
Weight part:						
Crude protein, on dry basis, %, not less	14	13	12	11	10	Not limited
Crude gluten, %, not less	30	27	23	18	18	Same
Gluten quality						-
GDI device units	45-75	45-100	45-100	20-100	20-110	-
FN, sec., over	200	200	150	100	less than 100	-

Source: compiled by the authors based on DSTU ISO No. 21415-1:2009 (2009) and DSTU No. 3768:2019 (2019)

Soft wheat of the 1-3 classes is used for the production of food products, mainly in the flour mill, bakery industry and for export. Soft wheat of the 4 class is used for non-food products. Soft wheat of the 5 and 6 classes is used for technical and fodder purposes. Soft wheat quality indicators are: test weight, vitreousness, moisture, grain impurity, waste impurity, smut grain, protein mass fraction, crude gluten mass fraction, gluten quality and FN. If the wheat seed does not meet the established quality standards according to only one of the indicators, it is transferred to a lower class. Indicators of the crude gluten mass fraction and its quality indicators are not mandatory in determining the soft wheat class, their standards are necessarily included in the wheat supply contract for processing enterprises. The preparatory stages of deep processing include the following processes:

- grain receiving, primary cleaning and storage;
- grain separation at elevators or mills and screening from impurities;
- grinding with reduction of peel and crushing;
- grain classification according to the corresponding sizes with fractional sorting of preparation raw materials;
- granulation with screening of small fractional elements;
- quality control;
- transportation and packaging.

Grain mass impurities, which differ from the main seed in terms of geometric dimensions, in particular length, width, thickness, are separated on the grids. Depending on the purpose and technical means used for grain cleaning, the following stages are distinguished: preliminary, primary and secondary cleaning and sorting. Preliminary cleaning of the grain pile consists in separating light, small and large impurities and providing favourable conditions for further technical work on post-harvest grain processing. The primary cleaning of grain consists in separating large, small and light impurities, and sorting them into the main food and seed grain and fodder fractions with minimal losses. At the same time, the main fraction meets the criteria of the basic purchasing conditions. If grain contamination and moisture is low, post-harvest processing can be started with primary cleaning. After the primary cleaning, the grain undergoes secondary processing, it is sorted into food or seed. Sorting is the division of the main crop grain into fractions according to certain features of size and density, includes correction, which separates the seed material by size, post-harvest cleaning is a series of interrelated technical operations that ensure the grain quality for use in food, technical, fodder or sowing purposes. There is also a growing demand for cleaning to remove quarantine seeds to avoid risks during grain export.

The grain correspondence with grinding affects the biochemical wheat properties, because there are the following technical processing stages: preliminary cleaning of the grain mass from impurities, hydrothermal processing (HTP), particles surface treatment, final cleaning. Preliminary cleaning from lumps is carried out in separators, triers and aspiration shafts for the separation of small grain particles, heavy and light impurities, and stones. Grain HTP is based on the water and heat action, which reduce the endosperm strength, which leads to the grain peeling with the shells separation during sieving. Grain HTP includes the stages of moistening, steaming, drying, cooling, as a result of which it is possible to increase the strength of the grain core, and the shell, on the contrary, to make the grain brittle for quick separation from the shell. HTP equipment includes: steamers, dryers, moisturisers. When humidity and temperature change, biochemical processes develop in the grain, the consequence of which is the redistribution of chemical substances in the anatomical parts of the grain. Properly selected grain processing modes can change the gluten properties, weak gluten can be strengthened by rapid conditioning, and strong gluten can be weakened by cold conditioning. Secondary deep cleaning is a yield of pure products of at least 99.95%, with a hard-separable impurity that cannot be removed by conventional means. Cold conditioning is a process in which grain and water are not heated at a set temperature of grain and water not lower than 18-20°C. Under such conditions, the grain and water are heated and cooled to ensure normal conditions of moisture and at the same time dehydration of the grain. The grain temperature in the heaters is set up to 20-25°C, and the water temperature is set up to 60-70°C. The disadvantage of the cold conditioning method is the larger hopper capacity due to the longer time of moistening. Equipment for the grain raw materials preparation for processing begins with a complex of grain storage hoppers, regulatory and transport equipment, separation units of weeds and magnetic impurities according to geometric dimensions, shape and density. Installations for HTP of the grain surface and the product peeling into seeds and seed coat are shown in detail in the diagram of Figure 2.

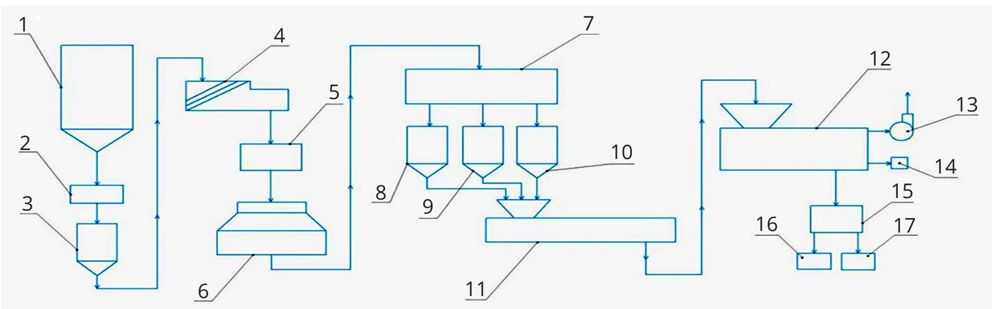

Figure 2. Technological diagram of the wheat seed peeling and cleaning plant for use in deep grain processing

Note: 1 – hopper for receiving raw materials; 2 – automated scales; 3 – intermediate bunker; 4 – grain cleaning plant; 5 – magnetic separator; 6 – trier; 7 – calibrator; 8 – small seed hopper; 9 – medium seed hopper; 10 – large seed hopper; 11 – raw material moisturiser; 12 – rotary-blade peeling installation; 13 – separation with fruit and seed coats; 14 – endosperm hopper; 15 – separator by vibrations; 16 – aleurone and subaleurone phases; 17 – seed hopper
Source: compiled by the authors based on DSTU No. 3768:2019 (2019)

Flour and water are mixed in a certain ratio in a dough-mixing unit, pumped into a homogeniser, where flour particles are fragmented. Then the mass is put to the tricanter, where there is an effective separation into solid, heavy and light liquid phases. The solid phase produces practically pure starch with a content of 54% in terms of an absolutely dry substance (ADS), which is already freed from gluten and contains up to 1.5% of crude protein. A-starch is dehydrated and dried to an ADS content of 88%. The heavy liquid phase consisting of gluten and B-starch, the resulting raw material is discharged from the tricanter under excess pressure using a combination of a phase separation disc and adjustable impeller. The light liquid phase that comes from the tricanter by gravity contains pentosans and non-starch polysaccharides, which are further sent either to the production of alcohol or substrate for the fodder additives manufacture. The percentage yield of semi-finished products from wheat flour depends on the flour quality and the selected technological scheme. The A-starch content is 55%, B-starch is 14%, dry gluten is 10%, liquid fodder is 12%, sewage liquid waste is 9%. Taking into account the complex technology of deep processing of soft wheat, the requirements for the grain quality supplied for production are provided in Table 2.

Table 2. The main nutrients content in spring and winter wheat grains in terms of ADS, %

Indicator	Crude protein	Crude fat	Crude gluten	Crude ash	NFES
Winter wheat grain, Palitra variety	21.42	2.74	2.5	1.83	71.51
Winter wheat grain, Jersey variety	20.99	2.65	3.06	1.94	71.36
Winter wheat grain, Cubus variety	21.7	2.44	2.94	1.76	71.16
Spring wheat grain, Zlata variety	19.89	2.71	2.44	1.46	73.5
Spring wheat grain, Heroinya variety	19.64	2.29	2.48	1.34	74.25
Spring wheat grain, Kharkivska 26 variety	20.33	2.18	2.28	1.37	73.84

Source: compiled by the authors

Varieties of soft winter and spring wheat according to their actual composition of nutrients in the grain were determined by the high content of crude protein, crude fat and NFES, being necessary raw materials in the food industry. In the group of winter wheat varieties, crude protein was 20.9-21.7%, crude fat was 2.4-2.7%, crude fibre was 2.5-3%, NFES were 71.1-71.5%. In the group of spring wheat varieties, crude protein was 19.64-20.3%, crude fat was 2.2-2.7%, crude fibre was 2.2-2.4%, NFES were 73.5-74.2%. Qualitative composition evaluation of wheat grain is necessary to comply with the storage indicators of plant products, however, in some cases, there are individual requirements for product monitoring, which are caused by special terms of contracts. Market qualities of wheat grain are represented by test weight indicators, weight per 1,000 seeds, GDI, FN, percentage of waste and grain impurities, data of various wheat varieties are provided in detail in Table 3.

Table 3. The main nutrients content in spring and winter wheat grains

Indicator	Moisture, %	Test weight, g/l	Weight per 1,000 seeds, g	Gluten, %	GDI, units	FN, sec.
Winter wheat grain, Palitra variety	10.15	757	42.2	24.2	78.2	364
Winter wheat grain, Jersey variety	11.25	773	41.7	20.4	76.4	339
Winter wheat grain, Cubus variety	10.15	784	43.4	27.3	81.6	345
Spring wheat grain, Zlata variety	12.32	740	43.3	26.2	71.1	358
Spring wheat grain, Heroinya variety	12.15	752	41.8	21.8	80.4	360
Spring wheat grain, Kharkivska 26 variety	11.45	755	43.8	23.1	74.7	313

Source: compiled by the authors

According to the received data on the qualitative composition in the winter wheat varieties group, the test weight varied at the level of 757-773, the weight per 1,000 seeds was 41.7-43.4 g, gluten was 20.4-27.3%, IDC – 76.4-81.6 units, state of emergency 339-364 seconds. In the group of spring wheat varieties, the nature fluctuated at the level of 740-755, the weight of 1,000 seeds – 41.8-43.8 g, gluten – 21.8-26.2%, GDI was 71.1-80.4 units, FN was 313-358 seconds.

The studied wheat was grown according to intensive technologies, therefore, protective operations were carried out in a timely manner, under favourable weather conditions for after-ripening and harvesting, winter varieties were not damaged by frost, pests, diseases, germination deterioration, seeds blackening or mold damage. The content of waste and grain impurities was determined from the average sample without preliminary washing. The distribution and analysis of the foreign impurities showed that they included grass seeds, sand, soil, parts of stems and chaff. No grain damaged by fusarium, smut or crowns fungi was found.

DISCUSSION

The results of the current study confirm the critical role of modern grain cleaning and sorting methods in ensuring the quality and safety of wheat grain. The study highlights that by removing impurities, pathogens, and substandard grains through techniques such as aspiration, separation by density, and the use of advanced sieving technologies, it is possible to significantly enhance the purity and quality of the grain before further processing. These processes are crucial not only for maintaining the nutritional and safety standards required for food products but also for meeting the regulatory standards set by national and international food safety organizations. Implementing advanced technologies at each stage of grain processing, such as automated sorting systems, real-time quality monitoring, and precision sieving, directly contributes to achieving national goals related to food security. These technologies help in maximizing the efficiency of the food industry by reducing waste, improving the consistency of grain products, and ensuring that the final products meet the high standards expected by consumers and regulators alike. For instance, the use of computer vision and machine learning in grain sorting allows for more precise identification and removal of defective grains, thus enhancing overall product quality.

The results of this study showed that the improvement of cultivation technologies and the introduction of new high-yielding varieties significantly increased the productivity and profitability of the production of grain crops. In particular, between 2010 and 2020, the production of agricultural products has increased by 25% due to the improvement of cultivation technologies and by 75% due to the genetic potential of new varieties. In particular, this concept is consistent with the research of S. Ostapenko (2022), which emphasises the importance of the natural value of new varieties for the growth of production. Analysis of modern equipment for grain processing revealed that the use of gravity tables, air and optical separators significantly increases the efficiency of processing with reduced energy consumption. A. Moghimi *et al*. (2020) note that such innovative technologies make it possible to improve the organoleptic and structural-mechanical characteristics of finished products. These conclusions are well-supported, as the current research also highlights that the implementation of intelligent sorting systems, regulated by computer algorithms, significantly enhances the quality of the final products.

The comparison of this study with others in the field reveals a general consensus among scientists on the necessity of adopting these advanced technologies throughout the grain processing chain. Despite variations in the specific methods and technologies employed, there is widespread agreement that these innovations are essential for maintaining high standards of food safety and quality. Moreover, the integration of these technologies into existing processing frameworks is seen as a key factor in improving the efficiency and sustainability of grain processing operations, thereby supporting broader food security objectives on a national and global scale. In a study conducted by S.D. Prakash *et al*. (2024), the emphasis on the importance of various grain processing stages and the need to ensure grain safety and quality throughout the supply chain aligns closely with the findings of this study. Both studies underscore the critical role of quality control at all stages, particularly during cleaning and sorting. Y. Lin *et al*. (2023) explored the behaviour of pathogens during the tempering of wheat grain, highlighting specific safety aspects. Although their focus differs slightly, the current study also addresses similar processing stages, emphasizing the importance of maintaining product quality. The findings from both studies underscore the necessity of technological control in preserving grain quality. The microstructure of wheat grain layers, particularly the aleurone layer, as examined by X. Tian *et al*. (2021), has a significant impact on the efficiency of processing operations. This observation is consistent with the technological aspects discussed in the current study, which also highlights the influence of grain structure on processing outcomes.

Research by K. Chen *et al*. (2024) on the microbiological composition and enrichment of kefir grains, although not directly related to grain processing, suggests that microbiological analysis techniques could be beneficial in improving quality control measures within the grain industry. The study by A. Bianco *et al*. (2024) highlights the role of agro-food waste fermentation in promoting environmental sustainability. The findings from their research can be complemented by the results of this study, particularly regarding sustainable resource use in deep grain processing technologies. Investigations by I. El Houssni *et al*. (2024) into the microbiological quality of wheat flour and bran in Morocco resonate with the current study's focus on the need for stringent microbiological control throughout the grain processing stages. The alignment of these studies emphasises the importance of technological oversight to maintain product safety. The work of T. Joshi *et al*. (2024) explored the use of modern technologies such as IoT and machine learning (ML) in agriculture. Integrating their findings with the current study could enhance the precision and efficiency of grain processing, particularly through the application of big data analytics.

The research by F. Jing *et al*. (2024) on reducing cadmium accumulation in wheat grain using biochar and selenium introduces important environmental considerations. Their findings, when viewed alongside the results of this study, provide a broader understanding of how different technological regimes affect grain safety and quality. The study by B. Zheng *et al*. (2021) on the impact of reduced nitrogen fertilizer rates on wheat grain quality echoes the current study's exploration of wheat classes and their applications. Their approach to balancing grain yield and quality through the adjustment of fertilizer rates and planting density offers valuable insights that could be applied to improve the grain handling methods described in this study. Research by J. Ren *et al*. (2024) on the effects of plant volatile organic compounds in preventing postharvest grain spoilage is relevant for further refining grain safety methods discussed in this study. The work by K. Laabassi *et al*. (2021) on automating grain classification using machine learning presents promising directions for enhancing the efficiency and accuracy of the grain cleaning and sorting processes outlined in the current study. S. Ma *et al*. (2024) investigation into the use of plasma-activated water to modify wheat starch gels could lead to improvements in grain processing technologies and the development of new wheat-based products. This research complements the findings of the current study by offering potential enhancements to grain processing methods.

The biotechnology of wheat bran fermentation to increase its nutritional value, as studied by L. Fan *et al*. (2024), aligns with the goals of the current research. These insights can be integrated to create more nutritious wheat-based products and improve overall grain processing techniques. L. Verdi *et al*. (2022) assessed the ecological impact of organic versus traditional agriculture on wheat, providing a useful complement to the current study's focus on sustainability and the environmental impact of grain processing. The study by J. Zhang *et al*. (2023) on the impact of microplastics on soils with long-term organic fertilizer application raises important concerns for future research. These findings are relevant to understanding how such factors might affect grain quality and processing methods, as considered in the current study. Finally, the systematic review by D. Kumar & V. Kukreja (2024) of wheat disease recognition methods using computer vision technologies offers practical applications for improving quality control during grain processing. This approach is particularly valuable for detecting defects and contamination, which are critical stages in the processes discussed in this study. According to C. Celestina *et al*. (2023), the development of new scales for assessing the growth stages of grain crops is instrumental in refining grain processing methods. Their focus on improving measurement accuracy and analytical methods aligns well with the technological goals outlined in the current study.

In conclusion, the results of this study confirm the crucial role of modern grain cleaning and sorting methods in ensuring quality and safety. The comparison with other studies demonstrates a broad consensus on the need for advanced technologies across all stages of grain processing, despite differing approaches. The current study offers a comprehensive framework for addressing quality assurance issues in grain processing, providing a solid foundation for further research and practical applications in this field.

CONCLUSIONS

Based on the conducted experimental studies, the levels of quality and market productivity of the varieties of soft winter and spring wheat according to their actual composition were established. Soft varieties of winter and spring wheat according to the actual nutrients' composition in the grain, according to the content of crude protein, crude fat, crude fibre, NFES, varied for winter wheat: crude protein from 20.9 to 21.7%, crude fat from 2.4 to 2.7%, crude fibre from 2.5 to 3% and NFES from 71.1 to 71.5%. In the group of spring wheat varieties, crude protein was from 19.6 to 20.3%, crude fat from 2.2 to 2.7%, crude fibre from 2.2 to 2.4%, NFES from 73.5 to 74.2%.

It was experimentally proven that the market indicators of the quality composition in the group of winter wheat varieties by moisture content varied within 10.1-11.2%, test weight within 757-773, weight per 1,000 seeds within 41.7-43.4 g, gluten content varied within 20.4-27.3%, GDI within 76.4-81.6 units, FN within 339-364 seconds. In the group of spring wheat varieties, the same indicators varied in the following interval, respectively: 11.4-12.2%, 740-755, 41.8-43.8 g, 21.8-26.2%, 71.1-80.4 units, 313-358 seconds. Grain standards provide for the indicator's determination of moisture, test weight, waste and grain impurities, gluten content and GDI: grain batches of various varieties of spring and winter soft wheat met the requirements of the 2nd class, according to the indicator of crude protein content, falling number of the 2nd and 3rd classes.

The substantiation of priority measures for competitive production in raw material preparation for the deep processing of wheat grain in modern economic conditions is a promising approach to obtaining high-quality crop production with added value. Therefore, it is recommended to thoroughly study the chemical composition and market qualities of raw materials, as well as standards for pests and diseases in wheat seeds, to fully reveal their genetic potential and contribute to increased economic profitability. Further research in this direction will help to develop and implement new technologies that will ensure stable growth of production and improvement of product quality.

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CONFLICT OF INTEREST

None.

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Обґрунтування технології підготовки м'якозерної пшениці до глибокої переробки

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Анотація. Технологічні особливості заготівлі зерна для переробки та виробництва харчових продуктів неможливі без визначення вмісту білка, крохмалю, клейковини, так само в зерновій масі м'якозерної пшениці, яка надходить на зернопереробні підприємства, міститься зернова та сміттєва домішки. Метою роботи було обґрунтування технологій первинної та поглибленої підготовки зерна пшениці з використанням сучасних методів зберігання і транспортування для подальшого використання в процесах глибокої переробки зерна. Для встановлення технологічних особливостей було використано метод ідентифікації, вимірювання морфологічних характеристик та визначення домішок. Стандарти зерна передбачають визначення вологості, натури, вмісту смітної та зернової домішок, вмісту клейковини та індексу деформації клейковини (ІДК) у партіях зерна різних сортів ярої та озимої м'якої пшениці. Отримані дані відповідали вимогам 2-го класу, за показником вмісту сирого протеїну, числа падіння (ПЧ) 2-го та 3-го класів. Експериментально визначено товарні показники якісного складу зерна пшениці м'якої ярої та сортів пшениці м'якої озимої. Встановлено, що в групі сортів пшениці озимої вологість була в межах 10,1-11,2 %, натура – 757-773, маса 1000 насінин – 41,7-43,4 г, вміст клейковини – 20,4-27,3 %, ІДК – 76,4-81,6 одиниць, число падіння – 339-364 секунди; у сортів пшениці м'якої ярої відповідно 11,4-12,2 %, 740-755, 41,8-43,8 г, 21,8-26,2 %, 71,1-80,4, 313-358. Щодо харчових якостей пшениці, то в групі озимих сортів вміст сирого протеїну становив 20,9-21,7 %, сирого жиру – 2,4-2,7 %, сирої клітковини – 2,5-3,0 %, безазотистих екстративних речовин – 71,1-71,5 %; у ярих сортів, відповідно, 19,64-20,3 %, 2,2-2,7 %, 2,2-2,4 %, 73,5-74,2 %. Практичне значення роботи полягає у впровадженні сучасних методів зберігання та транспортування зерна, що дозволяє значно покращити якість сировини, підвищити ефективність харчового виробництва, зменшити втрати при переробці, забезпечити відповідність продукції високим стандартам якості

Ключові слова: зернова сировина; обладнання; домішки; лущення; сепарація