Розроблено рекомендації що до перероблення пшениці спельти на борошно вищого та першого сорту. Проведеними дослідженнями впливу параметрів водо теплового оброблення на вихід борошна із зерна пшениці спельти, його білизну та вміст золи підтверджено гіпотезу, що дія вологи на властивості зерна пшениці спельти подібна до зерна голозерних пшениць. Зроблений порівняльний аналіз виходу та якості зразків, що розмелювали після проведення водо теплового оброблення та за фактичної початкової вологості від 13,0 % до 14,5 %. Використання водо теплового оброблення (вологість 15–16 %) дозволяє отримати на 0,6–3,0 % більший загальний його вихід, вміст золи у ньому зменшується на 0,26 % після першого розмелювання і на 0,22 % після другого. Білизна борошна після першого і другого розмелювання підвищується на 10 і 20 од. п. відповідно. Під час розмелювання зерна пшениці спельти без проведення водо теплового оброблення кращі результати (загальний вихід борошна 83,0–83,3 %, вміст золи 0,76–0,91 %, білизна 25–51 од. п.) мають зразки за найбільшої початкової вологості (14,0–14,5 %).

Під час виробництва борошна із зерна пшениці спельти рекомендований спосіб водо теплового оброблення полягає у однократному зволожуванні та відволожуванні зерна. Відмінність від класичного способу полягає у відсутності етапу зволожування перед першою драною системою. Оптимальним є зволожування зерна до 15,5 %, за тривалості відволожування 30 год. Використання запропонованого способу оброблення дозволяє отримати загальний вихід борошна 85,0 %. За основними показниками якості отриманий продукт відноситься до борошна вищого та першого сорту.

Результати, що наведено у статті, дозволяють обґрунтовано налаштовувати роботу апаратів для зволожування зерна та вибирати оптимальний час його відволожування

Ключові слова: пшениця спельта, водотеплове оброблення, вміст золи, білизна борошна, вихід борошна

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OPTIMIZATION OF WATER-HEAT TREATMENT WHEN MAKING FLOUR FROM ANCIENT WHEAT

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1. Introduction

At present, we face a substantial increase in the pace of life of modern society, an increase in the negative effect of factors of external natural environment on the human body, existence of a considerable large number of available foods with the unbalanced chemical composition. To balance the negative effect of these factors, a healthy way of life is becoming increasingly popular, and an integral part of it is healthy and dietary foods that enjoy a growing demand.

The main requirement for modern dietary and healthy products can be high biological value and safety, accessibility for consumers, and short-time cooking. One of the promising ways to meet the respective needs is the extension of the assortment of bakery products due to the use of grain of increased value, such as old kinds of wheat (polba and spelt wheat). It is known that consumer properties of bakery are mainly formed at the expense of qualitative indicators of wheat.

The essence of the traditional production of flour is to release wheat endosperm from the protective layers that have significant connections with each other. This is what complicates the appropriate manufacturing process. An increase in the effectiveness of getting flour of high grades is a result of the use of the water-heat treatment, which causes changes of technological properties of grain and fixes them at the optimum level. It is known that using water-heat treatment can reduce power consumption and improve technical and economic indicators of production. However, the relevant patterns are well-studied for the grain of traditional kinds of wheat. Different chemical composition and differences of anatomic structure of the grain of spelt wheat and the wheat used, in wheat milling industry, causes some doubts, that the effect of water and heat on them will be similar. The impact of the flour production modes on the spelt grain was not studied enough and requires clarification, the technologies of its processing need improvement, which determines the relevance of the conducted research.

2. Literature review and problem statement

In recent years, there has been an increased demand for wheat spelt grain, especially in Europe. In this regard it is considered not only as a valuable food culture, but also the selection material [1]. Paper [1] is valuable in terms of selection, it shows the potential of spelt wheat, offers the ways of its rational use, specifically, for the production of bakery. However, the information about the basis quality indicators was not shown. The specified problem was partially solved in paper [2]. A thorough comparison of the quality of varieties and lines of spelt wheat grown on the territory of Ukraine is a merit of the paper. It was proved that spelt wheat grain has high consumer properties. The possibility of using spelt wheat grain for the production of bread, which had a high score on the organoleptic evaluation, was explored. The flour for the production of bread was obtained using the technique for processing traditional wheat. That is why the influence of the basic parameters of flour milling production on the quality of flour remains unclear.

Spelt has a significant amount of dietary fiber and phytochemical substances. They contribute to the control of glucose levels in blood, increasing sensitivity to insulin and hyperinsulinemia. Antioxidant compounds can serve as protection from the negative effects of chronic hyperglycemia. Thus, spelt wheat grain can be considered as promising raw material for dietary foods, specifically, for the prevention of chronic diseases, such as diabetes of the second type [3]. In addition, the glutenin-bonded omega-gliadins that exist in traditional kinds of wheat were not detected in the spelt wheat grain [4]. The studies, aimed at developing technologies for bakery products that are gluten-free or with its low content, including the use of spelt wheat grain, are being currently carried out [5]. Despite the profound research into the chemical composition of spelt grain in papers [3–5], the rational modes of getting flour were not presented. The location of dietary fiber in the spelt grain remains not studied enough, which causes difficulty when choosing the optimal modes of its water-heat treatment. Solution of the relevant problem requires additional studies of the chemical composition of the surface layers of spelt wheat grain and establishment of their safety for nutrition. This will make it possible to develop effective technologies of whole-grain products from spelt wheat grain that enjoy increased demand now [6].

Spelt grain is also of interest for genetic engineering, in particular, it can contribute to designing programs aimed at biodiversity extension [7]. Genetic variations are the basis for crop improvement [8]. Comparison of the sequences of genomes of joining *Triticum spelt* and of one of the derivatives of hexaploid lines with the sequences in the international reference genotype *Chinese Spring* revealed the variants that are more than ten times higher than those that exist among genotypes of plain wheat (*T. aestivum L*). That is why the importance of *T. spelt* in enrichment of the genetic variation of plain wheat can be enormous [9].

Modern agrotechnology uses a significant number of the synthesized plant protection systems, growth stimulants, and nutrients of chemical origin. The peculiarity of their application is that they are sprayed on a plant. That is why many of them and their decomposition products can be accumulated on the surface layers of caryopsis. The existence of harmful residues of pesticides in food products is a major cause of concern among consumers, which creates the need to control their content [10]. Spelt wheat grain is better protected from the effects of negative biotic and abiotic factors, which creates the grounds to consider that it is safer raw material for nutrition compared to traditional film forms, however, the corresponding research has not yet been performed.

The stable demand can be expected from the implementation of composite mixtures. In this case, the improvement of the biological value of respective products can be achieved by using fruit and vegetable raw materials [11]. The effectiveness of mixing flour from spelt and amaranth was proved. The resulting product was of high biological value, had excellent culinary ratings and significant storage life without significant quality losses [12]. However, the effect of the granulometric composition of wheat flour and its quality on the formation of the quality of bakery products with combined composition of raw materials remains unaddressed in paper [12].

Competitiveness of bakery products is formed at the expense of quality of raw materials, specifically, flour [13]. The technical and economic indicators of flour milling production are greatly influenced by the effectiveness of grain cleaning, its conditioning (water-heat treatment) and crushing (breaking and milling process) [14]. In this case, the share of the influence of water-heat treatment is the largest. However, the effect of granulometric composition of flour is also significant; in particular, it affects the rheological properties of dough [15]. Causal relations were established between the baking quality, biotic and abiotic factors during the cultivation of grain, modes of its primary treatment [16]. That is why the study of the modes of water-heat treatment and crushing of grain is appropriate. Given the change of the technological properties of grain (including spelt wheat grain) as a consequence of selection and hybridization, it is advisable to check the reaction of the grain to the action of water, heat and to study its strength. This will make it possible to select energy-effective modes of grain processing to achieve the maximum quality of finished products.

Analysis of the information in literature [2, 5, 6, 11] makes it possible to make the following conclusions. Spelt wheat grain, which has high biological value can effectively extend the assortment of bakery products and is competitive in today's market environment. Among the assortment of bakery products from spelt wheat grain, whole-grain products, obtained from peeled flour and 2nd grade flour, are most common. Appropriate technology does not require adapting to new raw materials (spelt) due to the simple production process. However, bakery products from spelt wheat grain, produced from high and first grade flour, are becoming increasingly popular. Obtaining the relevant products is a complex process and its effectiveness greatly depends on the parameters of the water-heat treatment. Usually, a grade milling of spelt wheat grain is carried out using conventional technologies. The lack of data in papers [9, 13, 15, 17], the absence of a comprehensive evaluation of the action of damping and duration of softening on the quantitative and qualitative indicators of flour milling production prevents its optimization.

3. The aim and objectives of the study

The aim of the study conducted was to substantiate the modes of water-heat treatment of spelt wheat grain during its processing to high and first grade flour with the use of shortened technological process. This will create the possibility to effectively conduct damping and softening of grain to get the maximize yield of high and first grade flour.

To achieve the set aim, the following tasks have been solved:

– to explore the influence of humidity of grain and the duration of its softening on the flour whiteness after the first and second milling, the flour ash content after the first and second milling and total yield of flour;

– to analyze the flour making process mathematically and to set the optimum zone, in which it is possible to achieve the greatest yield of high and first grade flour.

4. Materials and methods of research

The object of the study was the spelt grain of the variety Zoria of Ukraine. The indicators of the quality of raw material are shown in [17].

The study was performed under conditions of the laboratory of the department of the grain storage and processing technology of Uman National University of horticulture (Uman, Ukraine). The production of flour was carried out on the milling complex MVP-000342.90. The principle of operation of the milling complex and the program of studies was dealt with in scientific papers [18, 19]. Chemical indicators of flour were determined by generally accepted methods [20].

The weight of spelt wheat grain to conduct one experiment was 5 kg. The yield of flour was determined from the following formula:

$$X = \frac{100F}{k}, \quad (1)$$

where F is the actual yield of the product, %; k is the initial amount of grain, kg.

The actually obtained products were weighed at the laboratory scales made by CBA company (discreteness is 0.05 g).

Statistical data processing was carried out by using the software Microsoft Excel 2010 and STATISTICA 10.

The study was carried out in four repetitions that were randomized in time. The obtained samplings of the data of analytical repetitions were processed by descriptive statistics to determine the variation factor. The results of the experiment were believed to be reliable at weak variation of data of sample of analytical repetitions that were used for subsequent statistical processing. The relationships between the factors were established by using the dispersion and regression analyses [21, 22].

During the dispersion analysis, “the zero hypothesis” was either proved or rejected. To do this, the value of the coefficient “p”, which showed the probability of the corresponding hypothesis, was determined. In cases when $p<0.05$ “the zero hypothesis” was rejected and the impact of the factor was reliable [21, 22]. The strength of the impact of the factors was established by determining the value of the Partial eta-squared. Partial eta-squared is an indicator, which shows the effect size (similar to the R^2 indicator of multiple linear regression). Effect size is a measure of the relationship between two variables and is a standard indicator for comparison of two data samples [21, 22].

During the optimization of the flour production process, the preference was given to the central composite plan [21, 22].

The quality of the obtained mathematical models was checked by determining the determination factor and by studying the existence of autocorrelation of residues. A model was considered acceptable if it described at least 80 percent of the process and theory of autocorrelation of its remnants was rejected [21, 22].

5. Results of research into the influence of conditioning parameters on the yield and quality of flour

The previous studies proved a significant impact of processing parameters on the comprehensive technical indicators of milling production and the yield of the finished product [18, 19]. However, given the modern laws of the market environment and the requirements for competitiveness of finished products, the results of the previous research [20, 21] are not enough to form the optimum modes of processing spelt wheat grain. There is no relevant information in other papers [2, 15, 16]. That is why it was appropriate to conduct a comprehensive study of the influence of these parameters on the quantitative and qualitative indicators of milling production. Because the quality of flour significantly differed depending on the modes of grain processing before milling, the impact of the factors was assessed separately for the samples with conditioning and without it. The effect of the parameters of water-heat processing of spelt wheat grain on the key indicators of the flour quality (whiteness, ash contents), which were previously examined separately, was studied in the new integrity.

In accordance with “The Rules of organization and conduction of the technological process on milling factories” that are currently in force in the territory of Ukraine, the yield of flour at two-grade wheat grain milling is 73–78 %. The yield of flour without the use of water-heat treatment (grain milling at its actual humidity of 13.0–14.5 %) was higher than the basic indicators (Fig. 1).

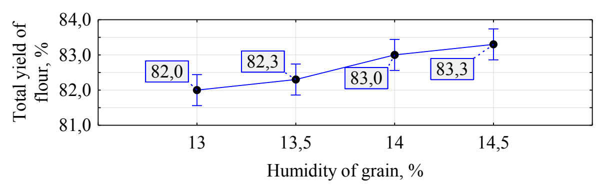
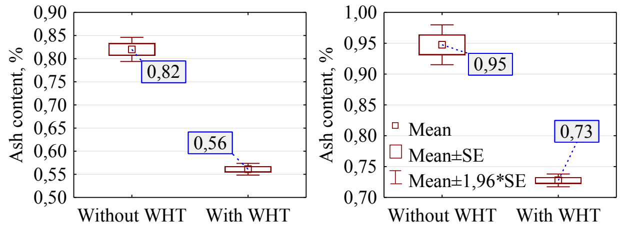


Fig. 1. Yield of flour from spelt grain without using water-heat treatment at actual grain humidity of 13.0–14.5 %

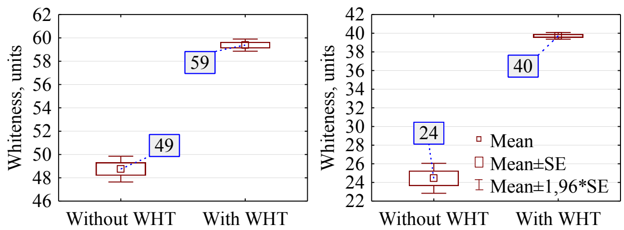
It is possible to argue with the probability of 98.3 % that the use of water-heat treatment (WHT) reliably increased the yield of flour on average by 0.8 %. The quality of wheat is important, specifically, the ash content and its whiteness, which is a prerequisite when determining its grade. Corresponding indicators reliably differed in the samples that underwent water-heat treatment and in those without it (Fig. 3).

The lowest ash content in flour was recorded after the first milling in the samples that were damped and softened. It was 0.56 %. The highest ash content was recorded after the second milling in the samples that did not undergo the water-heat treatment (0.95 %). Thus, according to the flour characteristics by the standard of DSTU 46.004-99, the samples, which were not subject to water-heat treatment after the first and second milling, were referred to the second grade by the ash content. The use of the WHT reduced the ash content in the samples after the first milling on average by 0.25 %, and after the second – by 0.21 %. The use of the WHT by the specified indicator enabled obtaining the high-grade flour after the first milling, and of the first grade flour – after the second milling.



a *b*

Fig. 2. Ash content in flour from spelt wheat grain depending on the use of water-heat treatment: *a* – after the first milling; *b* – after the second milling



a *b*

Fig. 3. Quality indicators of flour from spelt wheat grain depending on the use of water-heat treatment: *a* – after the first milling; *b* – after the second milling

Similarly to the improvement of the indicators of ash contents, the use of WHT positively affected the whiteness of flour. Thus, after the first milling, flour whiteness on average by 10 %, and after the second – by 15 % as a result of WHT.

In Ukraine, the spelt wheat grain is not widely spread, however it enjoys a growing demand abroad, which encourages farmers to increase production volumes. Now spelt wheat is exported in the form of raw materials. Its processing into the products with the highest added value is more appropriate. However, modern production of spelt wheat grain is not enough to design high performance factories, so the development of the enterprises of low performance for its processing is quite predictable. Improvement of the quality and the technical and economic indicators as a result of carrying out the water-heat treatment must be considered separately for each company. The marketing strategy of the enterprise development, specifically, promotion of products with a high content of fiber, for the production of which spelt wheat grain has a number of advantages, is important.

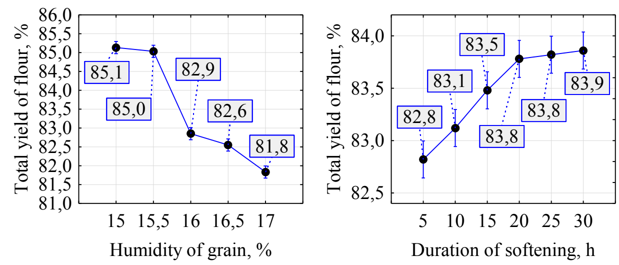
That is why it was appropriate to examine separately the effect of major factors of water-heat treatment. In the samples that were processed at the initial humidity from 13.0 % to 14.5 %, the highest yield of flour was recorded at its highest value of 83.3 % (Fig. 1). At the humidity of 13.0 %, the yield of flour was the least and made up 82.0 %. An increase in humidity up to 15.0–15.5 % significantly increased the yield of flour up to 85.0–85.0 % (Fig. 4).

A gradual increasing humidity up to 16.5–17.0 % contributed to a decrease in the yield of flour by 2.5–3.3 %. Subsequent increasing humidity was ineffective because it essentially worsened the process of flour production, decreased the performance of the rolling machine.

However, an increase in the duration of softening spelt grain had a positive impact on flour yield. The greatest effect (an increase in yield up to 1 %) was observed at an increase in duration of softening from 5 to 20 h. Further increase in the duration of softening influenced insignificantly the yield of flour.

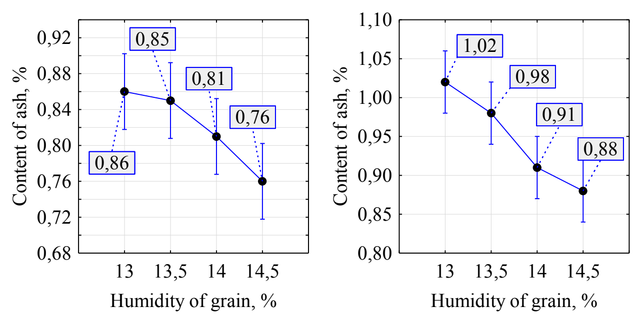
It was established that the greatest impact on flour yield was caused by the humidity of grain before milling (Partial eta-squared=0.92). The effect of the duration of softening was almost two times less in comparison with the effect of humidity (Partial eta-squared=0.51).

The ash content in flour that was produced without conducting the WHT was the smallest in the samples with the humidity of 14.5 % (Fig. 5). An increase in the initial moisture contributed to a decrease in the ash content in flour. This tendency was similar to the first and second milling.



a *b*

Fig. 4. Influence of parameters of water-heat treatment on the yield of flour (vertical bars denote 0.95 confidence intervals): *a* – depending on the gradient of damping; *b* – depending on duration of softening



a *b*

Fig. 5. Ash content in flour from spelt grain that was produced without performing the WHT (vertical bars denote 0.95 confidence intervals); *a* – after the first milling; *b* – after the second milling

The increase in humidity from 15.0 to 17.0 % was caused by the substantial increase in ash content in flour on average by 0.1 % (after the first milling from 0.60 to 0.50 %, and after the second milling – from 0.78 to 0.68 %) (Fig. 6). An increase in the duration of softening had the similar action and contributed to a decrease in ash content by 0.08 % after the first milling and by 0.06 % after the second milling.

During the first milling, an increase in moisture and the duration of softening had the same impact, because the partial eta-squared was 0.26 and 0.21, respectively (Fig. 7). However, flour quality after the second milling was more influenced by humidity of grain (Partial eta-squared=0.46), while the effect of the duration of softening did not change significantly (Partial eta-squared=0.25).

Whiteness of flour was reliably different at the initial humidity of spelt wheat grain (Fig. 8). Significant differences were not recorded between the indicators of the whiteness of the flour produced during the first milling of grain at humidity of 13.0 % and 13.15 %. An increase in the initial humidity up to 14.0–14.5 % contributed to a significant increase in flour whiteness (up to 5 %). The effect of moisture on the indicator of flour whiteness during the second milling was similar, and the corresponding indicator was within 21–29 units, which is by 45–50 % less in comparison with the results of the first milling.

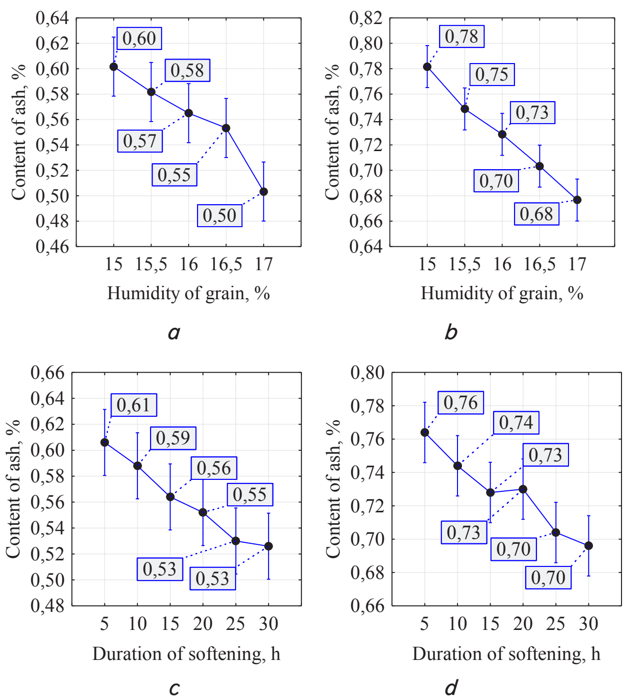


Fig. 6. The influence of modes of WHT on ash content in flour after the first and second milling (vertical bars denote 0.95 confidence intervals): *a, c* — after the first milling; *b, d* — after the second milling

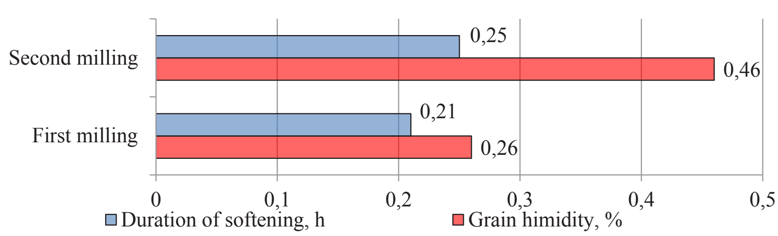


Fig. 7. The degree of influence of the WHT parameters on ash content in flour after the first and the second milling

The use of the WHT significantly increased flour whiteness (Fig. 9). The most rapid increase in flour whiteness during the first and second milling was recorded at the humidity of 15.0–16.0 %. A further increase in humidity had less significant influence on flour whiteness, regardless of the order of milling.

An increase in the duration of softening also influenced positively the indicator of flour whiteness. Its highest increase during the first and second milling was recorded at the duration of softening of 15 h. At longer softening, the indicator of flour whiteness was stabilized at the level of 61–62 units after the first milling and 40–41 units after the second, which corresponded to the high and first grade.

It is proved that the humidity of grain most affected flour whiteness during the first and second milling (Fig. 10).

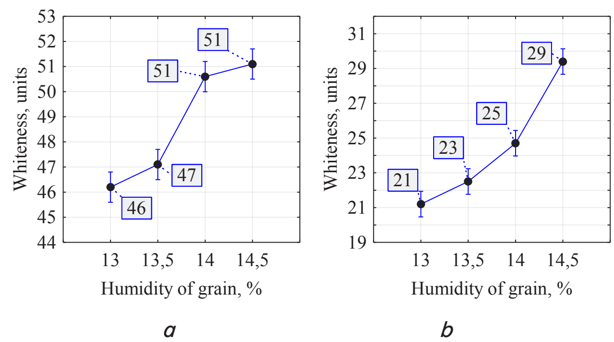


Fig. 8. Whiteness of flour from spelt grain, produced without performing the WHT (vertical bars denote 0.95 of confidence intervals): *a* — after the first milling; *b* — after the second milling

The impact of the duration of softening was smaller, but significant. A change in the WHT modes had more importance during the first milling.

To describe the process, a polynomial of the second degree was chosen:

$$Y_i = b_0 + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2, \qquad (2)$$

where i is the index that corresponds to the number of the input variable: i=1 for the total yield of flour, i=2 for ash content after the first milling, i=3 for ash content after the second milling, i=4 for flour whiteness after the first milling, i=5 for flour whiteness after the second milling; X_1 the grain humidity, %; X_2 is the duration of softening, h; b_0–b_5 are the regression coefficients.

During the studies, we used the plan of passive experiment. The calculation of coefficients of regression and of estimation of mathematical models was implemented using the software Statistica 10 [22, 23]. The results of the statistical treatment of experimental data are shown in Table 1.

The obtained mathematical dependences were adequate and reliable, as evidenced by the deviations of the theory of the presence of autocorrelation and high indicators of determination coefficients.

During statistical treatment, we used an add-on to the software Statistica 10 design & Analysis of Experiments (Central composite, non-factorial, surface designs). To construct the model and to analyze it, all experimentally obtained data (including the of data analytical repetitions) were used. During the establishment of the optimum, the desired indicators were assigned. In particular, the whiteness indicator level after the first milling was established within 54.0–63.4 units, which meets the requirements for the high-grade flour, and after the second – 36.0–42.4 units (first grade). The desired ash content in flour after the first milling was 0.55–0.80 % (high grade), and after the second – 0.75–0.87 % (first grade). No restrictions to flour yield were created, since all the obtained results (80.9–86.2 %) exceeded the basic indicators (72–76 %). Preference was given to the samples with the highest yield of flour.

To determine the rational parameters of processing of spelt wheat grain into flour, desirability functions that most satisfy the set restrictions were constructed with the help of Statistica 10 (Fig. 11).

Table 1

Values of regression coefficients

Model	Regression coefficient		Level of confidence p	Existence of autocorrelation	Determination coefficient (R^2)
Y_1	b_0	152.24666700	0.000003	autocorrelation of residues was not found	0.86
	b_1	−7.34952381	0.041848		
	b_2	0.185714286	0.012969		
	b_3	0.482785714	0.000668		
	b_4	−0.00184285	0.025860		
	b_5	−0.02342857	0.006374		
Y_2	b_0	−1.92960000	0.050856	autocorrelation of residues was not found	0.73
	b_1	0.41205714	0.028210		
	b_2	−0.01571428	0.018946		
	b_3	−0.04717285	0.000678		
	b_4	0.00005571	0.004868		
	b_5	0.00261714	0.001938		
Y_3	b_0	2.41553333	0.028585	autocorrelation of residues was not found	0.79
	b_1	−0.14059047	0.061828		
	b_2	0.00238095	0.007868		
	b_3	−0.01536857	0.012574		
	b_4	0.00001428	0.008089		
	b_5	0.00076571	0.021095		
Y_4	b_0	−512.54133300	0.000000	autocorrelation of residues was not found	0.91
	b_1	66.50933330	0.000000		
	b_2	−1.93333333	0.000000		
	b_3	1.59088571	0.000000		
	b_4	−0.00568571	0.000000		
	b_5	−0.07862857	0.000000		
Y_5	b_0	−231.88866700	0.000011	autocorrelation of residues was not found	0.81
	b_1	29.87352380	0.000000		
	b_2	−0.81904761	0.000006		
	b_3	2.04661429	0.000000		
	b_4	−0.00852857	0.000000		
	b_5	−0.10308571	0.000000		

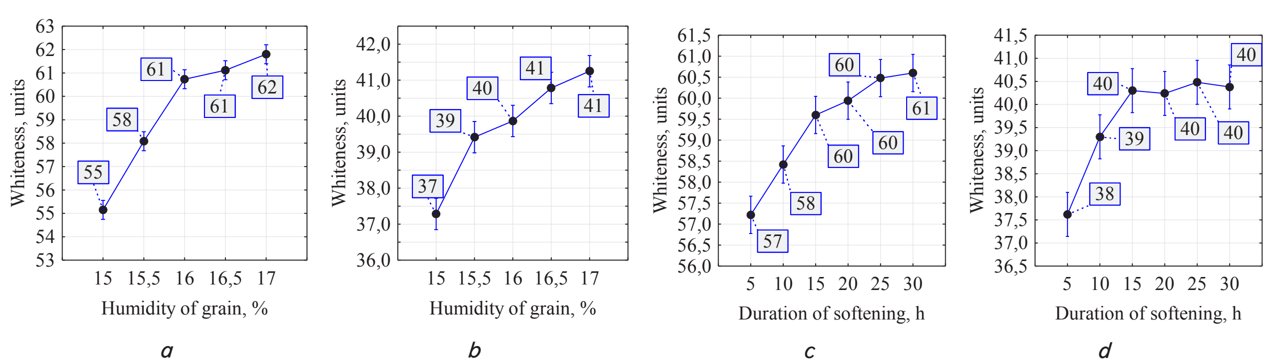


Fig. 9. Influence of modes of WTO on flour whiteness after the first and second milling (vertical bars denote 0.95 confidence intervals): *a* – after the first milling; *b* – after second milling; *c* – the flour whiteness depending on the duration of wetting after first milling; *d* – the flour whiteness depending on the duration of wetting after second milling

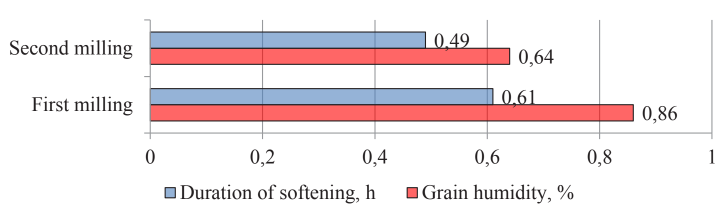


Fig. 10. The degree of influence of the WHT parameters on flour whiteness after the first and second milling

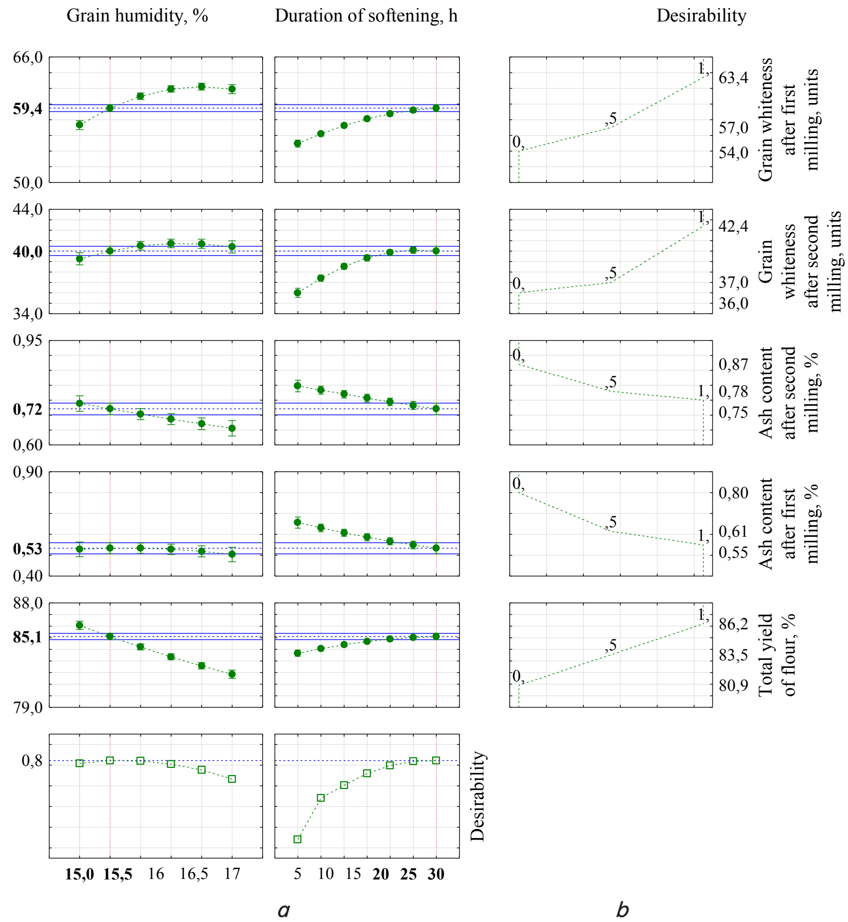


Fig. 11. Comprehensive evaluation of the impact of WHT on the yield and quality of flour of spelt wheat grain: *a* — flour whiteness after the first milling, units; *b* — flour whiteness after the second millin

The humidity of spelt wheat grain up to 15.5 % and its softening for 30 hours satisfy the set desirability requirements most. The use of the proposed method of treatment makes it possible to obtain the total yield of flour of 85.1 %. The resulting product by whiteness can be divided into the flour of high and first grade, which was 59.4 and 40.0 units. Similarly, it can be also classified by ash content (0.53, 0.72 %).

6. Discussion of results of applying the water-heat treatment during processing spelt grain

The research proved that spelt wheat grain was effectively processed into flour using a shortened technological process: single damping up to 15.5 % with subsequent softening for 30 h, because the largest number of intermediate products of crushing are formed at this level of softening. Further damping is ineffective because excessive moisture contributes to the formation of sticky particles (grits and dunst). This results into a significant decrease in the yield since sticky particles go to wastes at the stage of separation. The maximum duration of softening is appropriate due to the step-by-step penetration of moisture into the caryopsis, which follows from Fig. 6. In the absence of the required number of operational tankers, it is acceptable to decrease the duration of softening up to 20 h. It is not necessary to conduct additional softening before early break. There is a possibility of producing flour from spelt grain without using the water-heat treatment, however, the quality of the obtained products significantly deteriorates, and technical indicators of production decrease.

An increased total yield of flour (up to 85 %) is caused by the greater content of endosperm in wheat spelt grain, compared with bare-grain kinds of wheat. In addition, application of water-heat treatment has a positive effect on the indicators of flour production, which is shown in Fig. 2, 3.

According to the Rules of organization and conducting the technological process at milling factories [23], different modes of water-heat treatment are recommended. They are selected based on the technological properties of raw materials and are characterized by the stage-by-stage character. Material consumption of this process usually significantly increases with an increase in productivity of an enterprise. Results of the study show that it is possible to process spelt wheat grain effectively alter single damping and softening without additional damping before the first milling. Obviously, the structure of the surface layers of the film forms of spelt wheat grain differs from bare-grain forms. It promotes a special mechanism of moisture penetration into the central parts of endosperm. Small thickness of the surface layers of spelt wheat causes effective penetration of moisture after single softening. Processing spelt grain into flour without using the WHT causes a decrease in yield and quality worsening.

A decrease in flour yield after damping of grain up to humidity of 16.0 % or more is associated with the formation of intermediate roll-pressed products that are released along with the bran. However, an increase in the duration of spelt grain softening has a positive effect on flour yield.

High ash content in the samples that were not damped is due to the small number and quality of the formed intermediate products. It is known that water-heat treatment contributes to the formation of microcracks of endosperm and reduction of its glass-likeness. As a result of crushing such grain at breaks, a significant part of flour endosperm can be effectively separated, which was proved by the results of the research, shown in Fig. 5, 6, 8, 9.

However, despite the improvement of flour quality at an increase in grain humidity and duration of its softening, excessive humidity negatively influenced the technological process.

However, the results and recommendations of the conducted studies have limitations, specifically: they concern small enterprises with the shortened technological process, which use the complexes of the type MBR-000342.90. It is impossible to predict the influence of the WHT parameters on the indicators of milling production with the advanced technological process, which determines the direction of further research.

7. Conclusions

1. Humidity of grain and duration of its softening reliably influenced flour yield and its main indicators of quality. As a result of the use of the water-heat treatment, the total flour yield increased on average by 0.8 %. Flour whiteness improved by 10–15 units and ash content decreased by 0.22–0.26 %. Gradient of grain damping has the greatest influence on the specified indicators.

2. The modes of water-heat treatment during production of flour from spelt wheat grain on the systems with the shortened technological process, specifically, its damping to humidity 15.0–15.5 % and softening for 20–30 hours, were scientifically grounded and refined. If it is impossible to conduct long-term softening, its value can be decreased up to 10–15 %, but the obtained products will have a lower quality. At the use of the recommended modes of processing at double milling, it is possible to get high grade and first grade flour with total yield of 85 %.

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