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# IMPROVEMENT OF THE PROCESS OF HYDROTHERMAL TREATMENT AND PEELING OF SPELT WHEAT GRAIN DURING CEREAL PRODUCTION

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***Досліджено вплив водотеплового оброблення (зволожування, відволожування зерна) та тривалості лущення на вихід і якість крупи із зерна пшениці спельти. Встановлено механізм впливу досліджених чинників на утворення крупи і кулінарну якість продукту. Зроблено порівняльний аналіз виходу та якості круп'яних продуктів після проведення водотеплового оброблення та за фактичної вологості від 13,0 до 14,0 %. Завдяки проведенню водотеплового оброблення істотно змінюються властивості ендосперму та оболонок. Це призводить до підвищення міцності ендосперму та формуванню вищого виходу готового продукту. Достовірним є вплив тривалості лущення та градієнта зволожування на вихід крупи та мучки. Вплив тривалості відволожування зерна пшениці спельти на цей процес був неістотним. Застосування зволожування зерна (вологість 15,0–16,0 %) дозволяє підвищити вихід крупи від 88,6 до 91,7 %. Кулінарна якість при цьому не змінюється.***

***Отримані математичні моделі впливу зволожування, відволожування, лущення зерна на вихід та якість крупи є лінійними. Їхня точність підтверджена високими коефіцієнтами детермінації ($R^2$=0,97–0,98), відсутністю автокореляції залишків.***

***У технології виробництва крупи із зерна пшениці спельти рекомендований спосіб проведення водотелового оброблення полягає в зволожуванні його до вологості 15,0 %, що дозволяє підвищити вихід крупи на 3,1 %. Відмінність від класичного способу полягає у відсутності етапу відволожування зерна перед лущенням. Оптимальним є зволожування зерна пшениці спельти до вологості 15,0 % з тривалістю лущення 160 с. Запропонований спосіб оброблення дозволяє отримати 86,5 % крупи з кулінарною якістю 8–9 бала.***

***Розроблені рекомендації можуть бути використані підприємствами харчової промисловості під час проведення маркетингової діяльності або інтенсифікації виробництва***

***Ключові слова: водотеплове оброблення, пшениця спельта, кулінарне оцінювання, компетенція експертів***

## 1. Introduction

Along with bakery products, cereals are traditional food products. An increase in the popularity of cereals products over the last decade was caused by the popularization of healthy eating and active development of biological plant growing [1]. Priority directions of development of technologies of food products include increasing their biological values and reduction of production costs. In paper [2], an effective technology of the directed power supply for the intensification of heat and mass transfer during the processing food raw materials was proposed. At that, it is inadmissible to reduce the level of food product safety as a result of the application of new methods of treatment.

Nanotechnologies, specifically, cryo-treatment of raw materials, are becoming increasingly popular [3]. It was proved that during using the«shocking» modes of freezing, it is possible to achieve complete preservation of vitamins, phenolic compounds and aromatic substances.

The health-promoting products that are high in chlorophyll, obtained as a result of innovative ways of steam and heat treatment have high consumer properties[4].

It is possible to obtain the products with high content of biologically active substances during processing fruit and vegetable products. At that, cereal products contain the minimum amount of water-soluble vitamins, but satisfy by half the need of the human organism for vitamins of group B. A considerable amount of biologically active substances is contained in surface layers of grain, which are removed during its processing into cereal products. That is why the emergence of the products with elevated content of fiber is substantiated and effective during the formation of the marketing strategy of processing enterprises [5].

The extension of the range of finished products due to the use of raw materials of higher biological value, in particular, spelt wheat, deserve attention [6].

Spelt wheat grain has a long history. Asian spelt first appeared on the Caspian coast of Iran and became the ancestor of soft wheat. European spelt is the result of hybridization of soft and tetraploid wheat [7]. Active use of spelt grain as food raw material has begun quite recently [8]. This is due to its low yield compared with traditional varieties of wheat. However, the higher content of protein, balanced by amino acid composition, advantageously distinguishes the spelt grain for dietary products [9]. The great cost of the grain and the demand for the products of its processing cause high profitability of growing spelt grain.

Despite the similarity of spelt grain to soft wheat, the shells of spelt have strong bonds with grain, not separated during threshing [10]. This creates the need for additional peeling of spelt grain. Taking into consideration the peculiarities of the structure of the ear and the caryopsis of spelt, it is necessary to substantiate scientifically the existing modes of processing the grain of traditional kinds of wheat into cereals.

Given the tendency of the increasing volume of production of spelt wheat grain, there arises the necessity of finding rational ways of its processing. The lack of information on the properties of spelt wheat leads to a decrease in technical and economic indicators of processing industries due to the impossibility of technology optimization. Cereal production at a low investment risk is attractive for investors. That is why the research in this field is relevant and has practical value.

## 2. Literature review and problem statement

An interest of consumers to bakery, pastry, pasta products and cereals, made of flour eincorn (*Triticum monococcum*), polba (*Triticum dicoccum*) and spelt (*Triticum spelta*) has been growing in the European countries and in the USA for the last decade [11].

Spelt wheat grain is of great value for selection and improvement of the quality of traditional wheat varieties [12]. Obtained hybrids enable the substantial expansion of the range of food products and improvement of their quality [13].

Application of hybridization between non-spread lines of wheat from the Swiss Bank of genes, in particular forms of ancient wheat varieties, made it possible to identify the samples that differ significantly in terms of quality indicators from modern varieties. This enables further improvement of food properties of future hybrids and their quality control [14].

Revival of the interest in membranous wheats is due to their high nutritional value, suitability for organic farming and selection-genetic improvement of soft wheat. A considerable interest in spelt is also due to higher yields compared with other membranous kinds. The flour from spelt grain is most similar to the flour from soft wheat by its technological properties. In addition, membranous wheats absorb more mineral elements from the soil, and therefore contain more ash, compared to modern varieties of soft wheat [15].

Scientists pay great attention to diseases of gastrointestinal tract, which is associated with the allergic reaction to protein of cereal crops (celiac disease). Gluten – $\alpha$-gliadin is considered to be an allergen for patients with celiac disease. The specific feature of celiac disease is its difficult identification, since there are no direct signs of disease. The main indirect manifestations of celiac disease include poly hypovitaminosis, paresthesia, muscle cramps, tetany. Today, there are no effective treatments for celiac disease. That is why it is recommended for the sick patients to keep to a special diet that excludes the use of crop products. Considering these traditional foods in the diet, the diet may cause inconvenience for the patients. That is why selectionists do research and improve existing varieties in order to remove the corresponding allergens for spelt wheat to become valuable raw material [16].

The effectiveness of using spelt grain in the diets of people to prevent type 2 diabetes was proved. There are several known factors influencing the flow of diabetes. Some of them are very difficult to regulate, in particular, the age over 45, hereditary predisposition to diabetes and related diseases. However, there are important factors that can be controlled. Physical activity, weight control, alcohol consumption level, smoking status and level of consumption of meat products, vegetables and fruits deserve special attention. It was established that simple changes in a diet may result in a substantial decrease in development of type 2 diabetes. It is pointed out that foods with a high content of membranes or whole grain products from spelt grain have more effect in this kind of nutrition [17].

Bakery from spelt grain with addition of spicy-aromatic raw materials, such as Amaranthus, has high nutritional properties. It was proved that the quality of such products is high during long storage term (up to 6 days) [18].

Low yields of spelt grain results in the high cost of its cultivation, which significantly increases the price of ready raw materials. However, despite this fact, the population of Europe prefers this raw material, as its positive impact on the immune system of the body was proven and there are recommendations to its application for dietary nutrition [19].

Production volumes of spelt grain substantially increased, so its processing in cereal products is promising. It is caused by lesser material consumption of cereal plants in comparison with wheat milling complexes, the possibility of efficient grain processing at the enterprises of low productivity, lower requirements for the technological properties of the raw material. Given the qualitative properties of spelt grain, it is possible to develop an effective marketing strategy of a cereal plant of low and medium productivity.

One of the main processes of cereal production is hydrothermal treatment and grain peeling. In paper [20], a reliable change of technological properties of the oats grain as a result of its water and heat treatment was proved. The energy consumption for damping and steeping of grain is leveled due to a substantial increase in the number of high-quality nucleus. As a result, there is an increase of yield of cereals that have greater value. This process occurs at the stage of peeling that follows damping and steeping. However, the studies that are presented in [20] refer to oats grain that has the properties different from those of spelt grain. Similar results were obtained during the study of the properties of the wheat grain, which is shown in [21]. In paper [21], it was stated that as a result of the use of hydrothermal treatment and decrease in the duration of grain peeling, it is possible to achieve an increase in the yield of cereals by 10–15 %, while energy consumption is reduced by 50 %. The optimization of modes of hydrothermal treatment of triticale grain and of its peeling has a positive influence [22]. The research found that the yield of the whole cereal from the triticale grain at humidity of 9.0 % amounted to 47.4 %, and damping of grain up to 15.0 % increased it up to 54.4 %.

During the wheat grain processing, an increase in the duration of peeling causes gradual rubbing of surface layers containing most fiber and dietary fibers. The application of damping and steeping of the grain promotes a controlled change in technological properties with the fixation at the optimum level. The positive effect of hydrothermal treatment during processing the grain of hard and soft wheat was proved and corresponding processes are used in industry [23].

Papers [20–22] proved the importance of the stage of hydrothermal treatment and peeling for the performance of cereal production. An important point is a significant reduction of energy consumption by reducing the peeling systems. However, the issues related to the quality and safety of obtained products remained unresolved. Culinary assessment of a finished product is the most essential for a consumer among a large number of indicators. This problem was partially solved in article [24]. It is proved that the organoleptic characteristics of cereal products may improve as a result of frying or steaming due to the flow of irreversible processes in raw material as a result of such treatment. However, these changes occur under the influence of high temperatures, which is uncharacteristic of the technology of production of peeled cereals. That is why the influence of duration of peeling during the formation of culinary quality of peeled cereal is evident.

The anatomic structure of membranous wheats is different from the traditional ones. That is why the influence of damping, steeping and peeling on the formation of quality of cereal products demands specifying.

Now, the technical indicators of cereal production and of quality of the finished products from spelt wheat grain have been partially studied. In papers [25, 26, 29, 30], a reliable impact of the modes of peeling on the yield and culinary assessment of the cereal from spelt wheat grain was proved. However, the effect of the parameters of the water and heat treatment on these indicators was not established. In addition, the study of the peeling process was carried out using the simplest ways of the correlation and trajectory dispersion analysis, which does not enable creating mathematical models of the process.

The problems of processing the spelt wheat grain of different varieties were partially solved in paper [31]. Thus, the priority was to describe the mechanism of the action of repetitive rubbing of the spelt wheat grain in peelers of the periodic action in conjunction with damping and steeping. The dependences were established with the use of a comprehensive analysis and a more reliable organoleptic evaluation, which minimizes the subjective factor. This makes it possible to predict accurately the technical indicators of production, depending on the selected modes of hydrothermal treatment and grain peeling, to generate an idea of culinary quality of the obtained products.

## 3. The aim and objectives of the study

The aim of this study was to improve the modes of damping, steeping and peeling of spelt wheat grain as for the yield and culinary quality of the finished product. This makes it possible to produce cereal from spelt wheat No. 1, which has a high culinary quality. Mathematical models of the specified processes will enable the producers of cereal products to predict accurately the performance of the company. The research results will be especially valuable for enterprises with low performance.

To accomplish the aim, the following tasks have been set:

– to reveal the impact of actual moisture content of the spelt wheat grain on the yield of cereal, depending on the duration of peeling;

– to establish the influence of the parameters of hydrothermal treatment and peeling of spelt wheat grain on the output of cereal;

– to explore the culinary quality of cereals depending of parameters of hydrothermal treatment;

– to substantiate the rational modes of hydrothermal treatment and peeling during production of cereals.

## 4. Materials and methods for studying the influence of hydrothermal treatment parameters on the yield and quality of cereals

The research was conducted in the laboratory of the Department of technology of storage and processing of grain at the National University of Horticulture (Uman, Ukraine).

For the experiments, we used the grain of spelt of variety Star of Ukraine, grown under conditions of the Pravoberezhny forest-steppe of Ukraine. Previously it was fallow. Fertilizer: nitrogen in the amount of 120 kg/ha, phosphate and potassium in the amount of 60 kg/ha. Indicators of quality: vitrification – 98 % nature – 720 g/l, number of falling – 320 s, gluten deformation index – 60 units p., protein content is 20 %, starch content is 61 %, humidity content is 13.0±0.2 %.

The technological circuit of obtaining cereal products under laboratory conditions was generated in accordance with the requirements of the rules for organization and maintenance of the technological process at cereal mills [23].

Wetting was carried out using the drip method. Softening was carried out in metal cylinders. Peeling was performed on the laboratory peeler USZ-1 (circular rate is 3,000 rpm), separation of peeling products was performed at the laboratory sifter RLU-1. The obtained products were weighed on electronic scales with measurement accuracy of hundredth of fractions.

Experiment No. 1 involved the study of the influence of parameters of hydrothermal treatment and peeling on the yield of cereals. Humidity range was from 13.0 % to 16.0 % (interval of measurements – 0.5 %). The minimum and maximum duration of steeping was 30 and 120 min, respectively (measurement interval was 30 minutes). The grains were peeled from 20 to 180 s (measurement interval was 20 s).

Experiment No. 2 involved the study of the influence of parameters of hydrothermal treatment and peeling on smell, taste, color, consistency of the cereal, and cooked cereal consistency during chewing.

Culinary assessment was carried out according to the improved procedure that differs from the traditional by determining an additional indicator of cereal consistence during chewing [25, 26]. The proposed procedure makes it possible to identify more accurately the culinary quality by the higher content of fiber.

Since taste estimation can have a subjective character, an important factor is the indicator of competence of the Board. To determine the competence of the Board, the procedure by E. Golubkova [27] with modifications was used.

The essence of the procedure is that the maximum number of experts of the highest qualification, who specialize in the research subject, are chosen to make assessment. The education of an expert, his overall years of experience and years of working at the studied problem are important (Table 1). The degree of the expert's participation in solving the problem is also taken into consideration.

Table 1

Determining the competence of an expert

| Estimation criterion | Answer option | Point |
|---|---|---|
| Education | Doctor of sciences | 6 |
| | Candidate of sciences, Master | 4 |
| | higher education, Bachelor | 2 |
| Total duration of working | more than 10 years | 10 |
| | 5–10 years | 8 |
| | less than 5 years | 6 |
| Total duration of working at the problem | more than 10 years | 10 |
| | 5–10 years | 8 |
| | less than 5 years | 6 |
| Degree of participation in solving the problem | expert specializes in the problem | 10 |
| | expert takes part, but does not specialize in the problem | 8 |
| | the problem is closely relates to specialization of expert | 6 |
| | the problem is not related to specialization of expert | 3 |

Maximum number of points that an expert can gain is 36, which corresponds to the competence of 100 %. To determine the competence of each of the experts ($\gamma$), the formula was used:

$$\gamma = \frac{100a}{36}, \text{point}, \tag{1}$$

where $a$ is the total number of the points that an expert gained according to Table 1.

The overall competence of the Board was determined from formula:

$$\beta = \frac{\sum \gamma}{\sum n}, \text{ points.} \tag{2}$$

One of the most convenient ways of constructing a generalized response is the Harrington function of desirability [28]. This function is based on transformations of natural values into dimensionless scale of desirability [28]. Using the standard marks of the Harrington scale, the interpretation of general competence of the Board was proposed (Fig. 1).

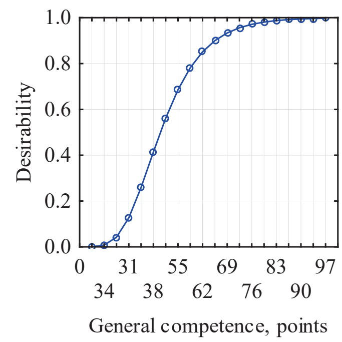



Fig. 1. Characteristics of competence of the Board

Given the standard marks on the Harrington scale of desirability, the recommendations for the evaluation of the competence of experts were stated (Table 2).

Table 2

Competence of the Board

| Harrington scale | Number of points of experts | Conclusion on competence of the Board |
|---|---|---|
| 0.80–1.00 | 60–100 | very good |
| 0.63–0.80 | 55–60 | good |
| 0.37–0.63 | 38–55 | satisfactory |
| 0.20–0.37 | 31–38 | bad |
| 0.00–0.20 | 17–31 | very bad |

Four experts were included to the Board that conducted the evaluation of cereal products. The general competence of the Board amounted to 82 points. That is why it can be argued that the competence of the Board was very good.

Using statistical processing with the methods of nonparametric statistics, it was proved that the statements of the experts coincided because $p(0) \leq 0.05$. In addition, the statements were in agreement, since the concordation (0.99517) was higher than its corrected value (0.99514). This creates the possibility of subsequent statistical processing of the results of the Board work.

The study had four analytical repetitions. The results of the analytical repetitions were treated by the methods of descriptive statistics using the programs Microsoft Excel 2010 and STATISTICA 10. The quality of the experiment was estimated by the value of the coefficient of samples variation that was formed from the data of analytical repetitions. The experiment was considered reliable at an insignificant variation of the data of analytical repetitions. The relationships between the factors were found by the method of dispersive and regressive analysis. The choice of the optimal methods for treatment was carried out by interpolating the samples of experimental data with plotting the desirability function.

Statistical treatment of the obtained results was carried out using add-in Experimental design (DOE) of Statistica 12 program. The choice of the model was carried out taking into consideration the coefficient of determination ($R^2$), the absence of autocorrelation of residues and confidence level ($p$).

The degree of influence of the factors was established using Pareto diagrams as a promising method for statistical processing [32].

The advantage of using desirability diagrams is the possibility of deriving reliable trends and recommendations. The essence of the corresponding analysis is comparison of all results of statistical processing of the patterns between the factors and criteria of improvement, plotting the complex function and search for its extreme values.

## 5. Results of studying the influence of parameters of hydrothermal treatment on the yield and culinary quality of cereals

The samples of digital data on the yield of cereals and middling, obtained without damping (at initial moisture content of 12.0 % 13.0 %; 14.0 %) and as a result damping up to moisture content of 15.0 % and 16.0 % at different duration of steeping, were processed using the add-in Descriptive statistics (Statistica 12).

At different duration of peeling of spelt wheat grain (from 20 s to 180 s) without water and heat treatment, the yield of cereal No. 1 from 77.6 % to 97.5 % was obtained. This is an average of 2.3–3.0 % less in comparison with the yield of cereal after water and heat treatment (Table 3).

Table 3

Primary statistical processing of the yield of peeled cereal No. 1 after using water and heat treatment and without it

| Parameter of statistical processing | Cereal yield, % | Middling yield, % | Mechanical losses, % |
|---|---|---|---|
| Mean | $88.58^a/97.71^b$ | $11.21^a/8.08^b$ | $0.20^a/0.19^b$ |
| Median | $88.6^a/91.6^b$ | $11.21^a/8.15^b$ | $0.2^a/0.2^b$ |
| Minimum | $77.6^a/82.3^b$ | $2.3^a/0.1^b$ | $0.1^a/0.1^b$ |
| Maximum | $97.5^a/99.8^b$ | $22.1^a/17.5^b$ | $0.3^a/0.3^b$ |
| Std. Dev. | $5.427^a/4.576^b$ | $5.432^a/4.575^b$ | $0.079^a/0.081^b$ |
| Coef. Var. | $6.12^a/4.98^b$ | $48.35^a/56.56^b$ | $38.80^a/41.48^b$ |
| Standard Error | $0.452^a/0.220^b$ | $0.451^a/0.220^b$ | $0.006^a/0.003^b$ |

*Note: a – indicators without conducting hydrothermal treatment; b – indicators after conducting hydrothermal treatment*

Variation of the data of the samples of yield of cereals, obtained after hydrothermal treatment, was smaller compared with the similar ones, obtained without it. This indicates less deviation of the values of this parameter from the average number of the sample. However, in both cases, the data variation was insignificant, because the coefficient of variation was less than 10 %.

The use of hydrothermal decreased the yield of middling on average by 3.13 %. Variation of the data of the samples of this indicator was strong, regardless of the used mode of processing (Coef. Var=48.35 and 56.56 for the samples without hydrothermal treatment and after it, respectively).

Mechanical losses are an inseparable part of any production and are associated with grain transportation, unaccounted drying, etc. Mechanical losses are regulated by the current norms and must be up to 0.7 % [23]. During the production of peeled cereals from spelt wheat grain, mechanical losses ranged from 0.1 to 0.3 %, which corresponds to the current standards.

Using the methods of variance analysis, a reliable impact of hydrothermal treatment on the yield of cereals and middling was proved (Fig. 2).

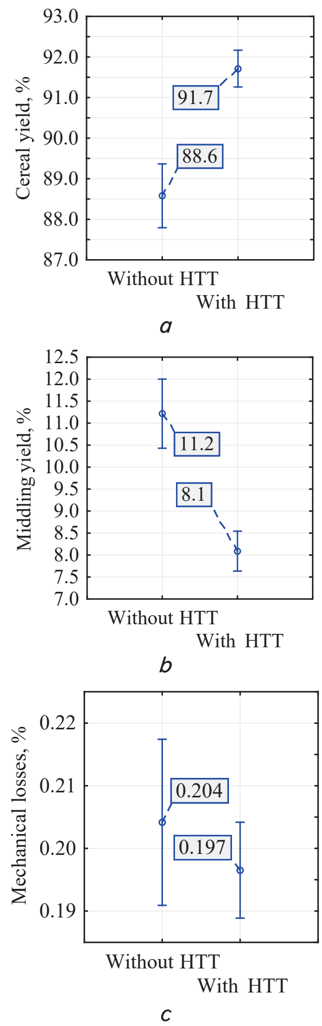



Fig. 2. Results of dispersive analysis of dependence between the application of WHT and technical indicators of the cereal production (vertical bands designate 0.95 of confidence intervals): *a* is the cereal yield; *b* is the middling yield; *c* is the mechanical losses

There was no reliable relation between the amount of mechanical losses and the use of hydrothermal treatment ($p$=0.32). That is why this indicator was not used for modeling later, and was equated with the research error.

In spite of better indicators of cereal production, which were received after the hydrothermal treatment, it was appropriate to examine the modes of grain processing at the initial moisture content from 13.0 to 14.5 %.

Establishment of the relations between the initial moisture content and the duration of peeling was carried out by using analysis of the central compositional plan, the pitches and levels of which are shown in Table 4.

Table 4

Pitches and levels of variation

| Factor | Lower level | Higher level | Mean value |
|---|---|---|---|
| Duration of peeling, s | 20 | 180 | 80 |
| Moisture content, % | 13.0 | 14.5 | 0.75 |

The results of the experimental studies are shown in Tables 5, 6. Because variation of the results of analytical repetitions was insignificant, we used mean values of the samples for further analysis.

Table 5

Influence of duration of peeling on cereal yield at different initial moisture content of grain

| Duration of peeling, s | Moisture content, % | | | |
|---|---|---|---|---|
| | 13.0 | 13.5 | 14.0 | 14.5 |
| 20 | 94.5±0.4* | 94.9±0.4* | 95.6±0.5* | 96.1±0.2* |
| 40 | 93.8±0.5* | 94.2±0.3* | 95.0±0.3* | 95.8±0.4* |
| 60 | 93.0±0.5* | 93.7±0.3* | 94.2±0.3* | 95.2±0.5* |
| 80 | 89.5±0.3* | 89.8±0.3* | 90.0±0.4* | 90.8±0.4* |
| 100 | 86.9±0.3* | 87.3±0.6* | 89.3±0.5* | 90.1±0.4* |
| 120 | 86.2±0.5* | 87.9±0.3* | 88.1±0.4* | 89.0±0.4* |
| 140 | 83.0±0.3* | 83.7±0.4* | 85.1±0.5* | 86.1±0.2* |
| 160 | 81.9±0.5* | 82.1±0.4* | 82.8±0.4* | 83.5±0.5* |
| 180 | 79.0±0.4* | 79.7±0.4* | 80.1±0.3* | 81.0±0.4* |

*Notes: * – coefficient of variation of results of analytical repetitions is less than 10 %; ** – coefficient of variation of results of analytical repetitions is 10–20 %; *** –coefficient of variation of results of analytical repetitions is more than 20 %*

Table 6

Influence of duration of peeling on yield of middling, taking into consideration mechanical losses at different initial moisture content of grain

| Duration of peeling, s | Moisture content, % | | | |
|---|---|---|---|---|
| | 13.0 | 13.5 | 14.0 | 14.5 |
| 20 | 5.5±0.4* | 5.1±0.4* | 4.4±0.5 | 3.9±0.2* |
| 40 | 6.2±0.5* | 5.8±0.3* | 5.0±0.3* | 4.2±0.4* |
| 60 | 7.0±0.5* | 6.3±0.3* | 5.8±0.3* | 4.8±0.5 |
| 80 | 10.5±0.3* | 10.2±0.3* | 10.0±0.4* | 9.2±0.4* |
| 100 | 13.1±0.3* | 12.7±0.6* | 10.7±0.5* | 9.9±0.4* |
| 120 | 13.8±0.5* | 12.1±0.3* | 11.9±0.4* | 11.0±0.4* |
| 140 | 17.0±0.3* | 16.3±0.4* | 14.9±0.5* | 13.9±0.2* |
| 160 | 18.1±0.5* | 17.9±0.4* | 17.2±0.4* | 16.5±0.5* |
| 180 | 21.0±0.4* | 20.3±0.4* | 19.9±0.3* | 19.0±0.4* |

*Notes: * – coefficient of variation of results of analytical repetitions is less than 10 %; ** – coefficient of variation of results of analytical repetitions is 10–20 %; *** – coefficient of variation of results of analytical repetitions is more than 20 %*

The processes can be described most accurately with the help of linear models:

$$\text{Yield of cereal} = 78.23889 - 0.009917X_1 + 1.47333X_2, \%, \quad (3)$$

$$\text{Yield of middling} = 21.76111 + 0.09926X_1 - 1.47346X_2, \%, \quad (4)$$

where $X_1$ is the duration of peeling, s; $X_2$ is the moisture content, %.

Dependences 3 and 4 can be shown graphically (Fig. 3).

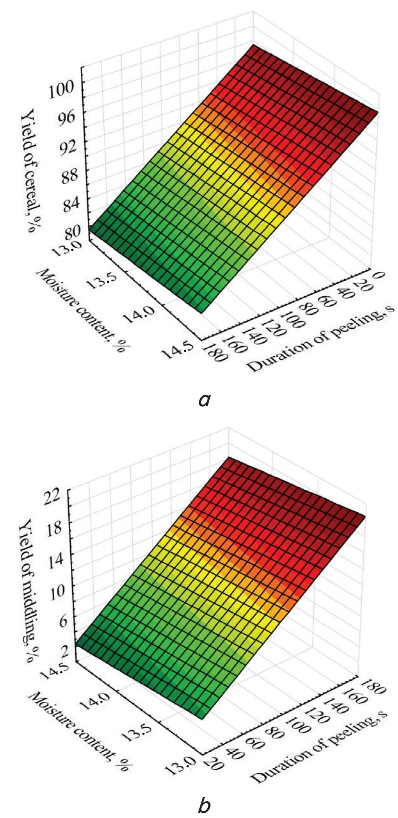



Fig. 3. Influence of initial moisture content and duration of steeping on technical indicators of cereal production: *a* — cereal yield; *b* — middling yield

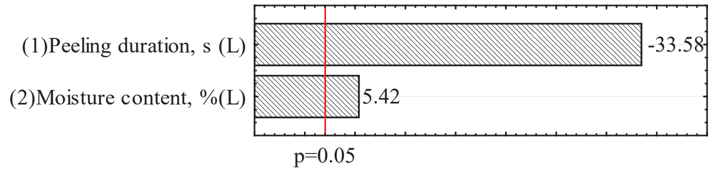
Duration of peeling made great impact on the yield of cereals and middling (Fig. 4). An increase in initial moisture content increased the yield of cereals and decreased the yield of middling.

Since functions (3) and (4) are linear, the optimum area for cereals and middling will be obtained at the shortest duration of peeling (20 s) and the highest initial moisture content (14.5 %).

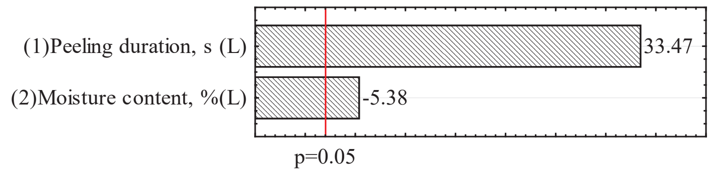
The best results of the yield of cereals were obtained after damping and steeping. The minimum value of duration of steeping (30 min) was experimentally substantiated and is not contrary to the current requirements. Grain peeling immediately after damping was ineffective. Pitches and levels of variation are shown in Table 7.

The procedure of processing of experimental data is identical to the one on previous studies.

Results of experimental research are shown in Tables 8–10.




*a*




*b*

Fig. 4. Pareto chart, which shows the influence of duration of peeling and initial humidity content on the yield of cereals and middling: *a* – yield of cereals; *b* – yield of middling

Table 7

Pitches and levels of variation

| Factor | Lower level | Higher level | Mean value |
|---|---|---|---|
| Duration of peeling, s | 20 | 180 | 80 |
| Moisture content, % | 15 | 16 | 0.5 |
| Duration of steeping, min | 30 | 120 | 45 |

The yield of cereals and middling can be described with high accuracy ($R^2$=0.98) by linear dependences:

$$\text{Yield of cereals} = 105.7951 - 0.0842X_1 - 0.3583X_2 - 0.0014X_3, \%, \quad (5)$$

$$\text{Yield of middling} = -5.79514 + 0.8419X_1 + 0.35833X_2 + 0.00143\,X_3, \%, \quad (6)$$

where $X_1$ is the duration of peeling, s; $X_2$ is the moisture content, %; $X_3$ is the duration of steeping, min.

Table 8

Influence of duration of steeping and peeling on the yield of cereal after damping of grain up to 15.0 %

| Duration of peeling, s | Duration of steeping, min | | | |
|---|---|---|---|---|
| | 30 | 60 | 90 | 120 |
| 20 | 97.8±0.5* | 98.0±0.3* | 97.9±0.5* | 97.7±0.4* |
| 40 | 96.9±0.4* | 97.1±0.5* | 97.1±0.4* | 96.7±0.3* |
| 60 | 96.0±0.4* | 96.3±0.3* | 96.2±0.3* | 95.9±0.5* |
| 80 | 93.5±0.4* | 93.7±0.5* | 93.8±0.4* | 93.7±0.4* |
| 100 | 91.6±0.3* | 91.8±0.4* | 92.0±0.4* | 91.8±0.3* |
| 120 | 89.8±0.3* | 90.0±0.3* | 90.3±0.3* | 90.0±0.4* |
| 140 | 88.2±0.3* | 88.4±0.3* | 88.6±0.5* | 87.7±0.4* |
| 160 | 87.3±0.3* | 87.0±0.3* | 87.4±0.4* | 87.2±0.4* |
| 180 | 85.1±0.3* | 85.3±0.4* | 85.5±0.3* | 85.3±0.5* |

*Notes: * – coefficient of variation of results of analytical repetitions is less than 10 %; ** – coefficient of variation of results of analytical repetitions is 10–20 %; *** – coefficient of variation of results of analytical repetitions is more than 20 %*

Table 9

Influence of duration of steeping and peeling on yield of cereals after softening grain up to 15.5 %

| Duration of peeling, S | Duration of steeping, min | | | |
|---|---|---|---|---|
| | 30 | 60 | 90 | 120 |
| 20 | 97.9±0.4* | 97.8±0.4* | 98.0±0.4* | 98.2±0.5* |
| 40 | 97.0±0.5* | 96.9±0.4* | 97.1±0.6* | 96.9±0.3* |
| 60 | 95.9±0.4* | 96.0±0.4* | 96.2±0.3* | 96.0±0.4* |
| 80 | 93.8±0.4* | 94.1±0.3* | 93.1±0.3* | 92.6±0.3* |
| 100 | 91.7±0.5* | 91.3±0.4* | 90.7±0.5* | 91.3±0.3* |
| 120 | 89.9±0.3* | 89.8±0.4* | 90.0±0.4* | 90.2±0.2* |
| 140 | 87.9±0.4* | 87.9±0.4* | 87.9±0.4* | 87.5±0.5* |
| 160 | 86.9±0.4* | 87.2±0.5* | 87.2±0.3* | 86.8±0.3* |
| 180 | 85.0±0.3* | 85.1±0.5* | 84.9±0.2* | 84.2±0.4* |

*Notes: * – coefficient of variation of results of analytical repetitions is less than 10 %; ** – coefficient of variation of results of analytical repetitions is 10–20 %; *** – coefficient of variation of results of analytical repetitions is more than 20 %*

Table 10

Influence of duration of steeping and peeling on the yield of cereals after grain moistening up to 16.0 %

| Duration of peeling, s | Duration of steeping, min | | | |
|---|---|---|---|---|
| | 30 | 60 | 90 | 120 |
| 20 | 97.7±0.4* | 97.5±0.5* | 97.9±0.3* | 98.0±0.3* |
| 40 | 96.8±0.3* | 96.6±0.5* | 96.9±0.2* | 96.8±0.1* |
| 60 | 95.8±0.3* | 96.1±0.5* | 96.0±0.5* | 95.9±0.3* |
| 80 | 93.7±0.4* | 93.9±0.3* | 92.9±0.5* | 92.8±0.4* |
| 100 | 91.3±0.4* | 91.0±0.4* | 90.8±0.5* | 91.1±0.3* |
| 120 | 89.7±0.3* | 89.5±0.5* | 89.9±0.4* | 90.0±0.3* |
| 140 | 87.7±0.4* | 87.7±0.3* | 87.7±0.3* | 87.4±0.3* |
| 160 | 86.8±0.4* | 87.0±0.3* | 87.0±0.4* | 86.6±0.2* |
| 180 | 84.9±0.5* | 85.0±0.4* | 84.8±0.3* | 84.5±0.2* |

*Notes: * – coefficient of variation of results of analytical repetitions is less than 10 %; ** – coefficient of variation of results of analytical repetitions is 10–20 %; *** – coefficient of variation of results of analytical repetitions is more than 20 %*

According to the results of statistical processing, it is possible to argue about the significant impact of duration of peeling and gradient of damping on the yield of cereals and middling.

The probability of the influence of the duration of steeping on the corresponding process was low and amounted up to 67 %. The mentioned hypothesis is proved by the Pareto charts (Fig. 5).

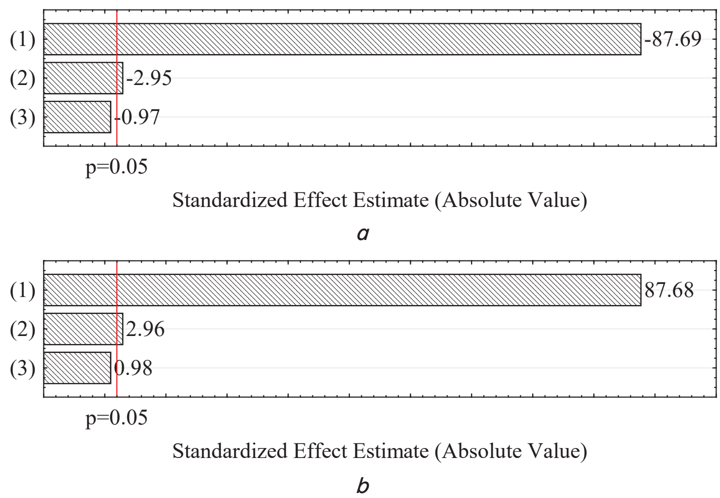



Fig. 5. Pareto chart, which shows the influence of parameters of peeling and hydrothermal treatment on the yield of cereals and middling: *a* — yield of cereals; *b* — yield of middling; 1 — duration of peeling, 2 — moisture content, 3 — duration of steeping

It should be noted that the weight of the influence of moisture content of grain before peeling was higher in samples that did not undergo hydrothermal treatment, whereas duration of peeling had the highest value for this parameter after hydrothermal treatment.

Results of plotting the function of desirability (add-in Experimental design (DOE) of Statistica 12 program) based on dependences (5) and (6) revealed that the highest yield of cereals (98.22 %) and the lowest yield of middling (1.77 %) can be obtained at the shortest duration of peeling (20 s) at steeping of grain for 120 minutes at its moisture content of 15.75 %.

The specified processing mode is oriented to getting the highest yield of cereals, however, but does not take its quality into account. That is why it was appropriate to examine the influence of processing parameters on culinary quality of obtained products.

Culinary evaluation was carried out for cereals that did not undergo hydrothermal treatment and for the cereals after hydrothermal treatment. The influence of duration of steeping on culinary quality of cereals was not studied, using its minimum possible value.

The probability of the influence of the initial moisture content of grain before peeling on culinary evaluation of cereals was low and made up 66 % (Fig. 6).

Almost all indicators of culinary assessment significantly changed, depending on duration of grain peeling (Fig. 7).

The minimum evaluation of the experts (6.3–6.8 points) by the smell parameter was gained by cereal, peeled for 20–80 s. A further increase in the duration of peeling up to 80 s or more led to significant improvement of this indicator and its fixation at a high level.

The taste of the cereal significantly improved after increasing the duration of peeling up to 100 s. A further increase in duration of peeling did not influence reliably this indicator, which remained at the high level (8.8–9.0 points).

The color of the obtained cereal products depended essentially on the duration of peeling. In the range of the duration of peeling from 20 s to 40 s, the color was assessed as 5 points. Significant improvement of this indicator was provided by increasing duration of peeling up to 60 s. Cereal products that were peeled for 60–100 s had similar color, which was estimated at 6.8–7.0 points. The highest score (8.5–9.0 points) by the given indicator was obtained by the products that were peeled for more than 120 s.

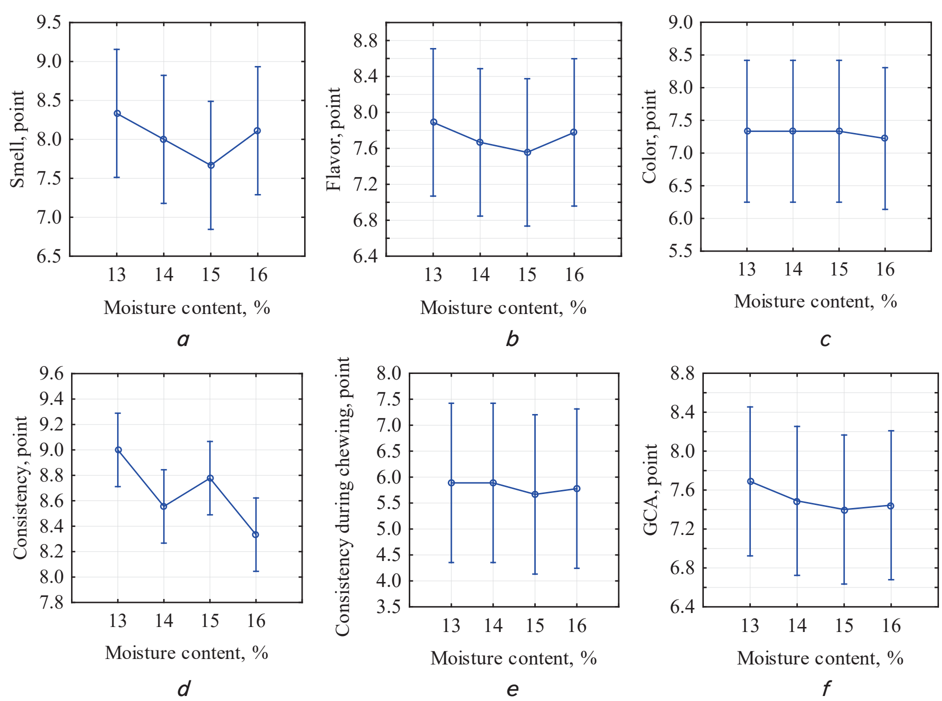



Fig. 6. Influence of initial moisture content of grain before peeling on culinary quality of cereal: *a* — smell assessment; *b* — flavor assessment; *c* — color assessment; *d* — consistency assessment; *e* — assessment of cereal quality during chewing; *f* — indicator of general culinary assessment of cereal

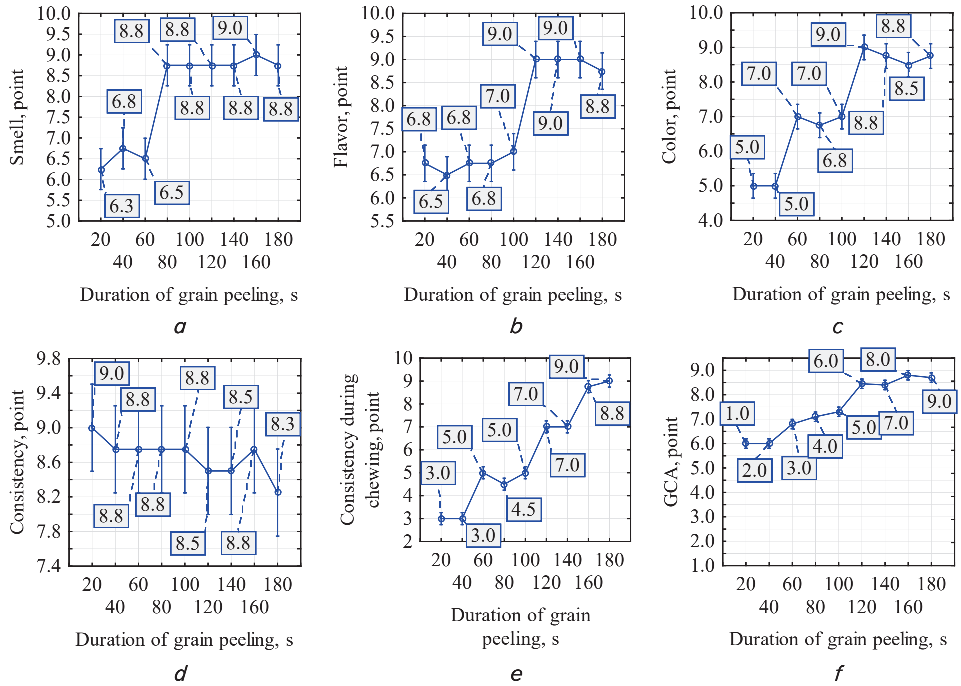



Fig. 7. Influence of duration of grain peeling on culinary quality of cereal: *a* – smell assessment; *b* – flavor assessment; *c* – color assessment; *d* – consistency assessment; *e* – assessment of cereal quality during chewing; *f* – indicator of general culinary assessment of cereal

A reliable difference between the samples with different duration of peeling in terms of consistency of cereal was not found. All the samples had a high corresponding indicator that was rated at 8.3–9.0 points.

The duration of peeling the grain influenced the consistency of cereal during chewing most of all. The cereal with a minimum duration of peeling (20–40 s) had an unsatisfactory indicator of consistency during chewing that was 3.0 points. This indicator increased by 1.5–2 points in the samples that were peeled for 60–100 s. The following substantial quality improvement was at an increase in duration of peeling up to 120–140 s. The products received by grain peeling for 160–180 s had the highest score (8.8–9.0 points).

It is possible to generalize the organoleptic quality indicators by determining the general culinary assessment. In accordance with this indicator, the products that were obtained after peeling for 20–40 s had the unsatisfactory quality. The products that were peeled from 60 to 100 s had satisfactory quality (3–5). The samples that were peeled for 120 or more seconds had high indicators of culinary quality.

To establish the rational mode of treatment, the desirability function was plotted (Fig. 8).

The limiting criteria were: high indicators of cooked cereal, its smell, taste, color, consistency, consistency during chewing and maximum yield of cereal. The minimum acceptable point of the specified indicators of the culinary assessment was 5. The maximum was 9 points, the average satisfactory level corresponded to 7 points.

The mode, under which the wheat grain was damped up to 15.0 % with steeping for 30 s and peeled for 160 s, met the set requirements by 80 %.

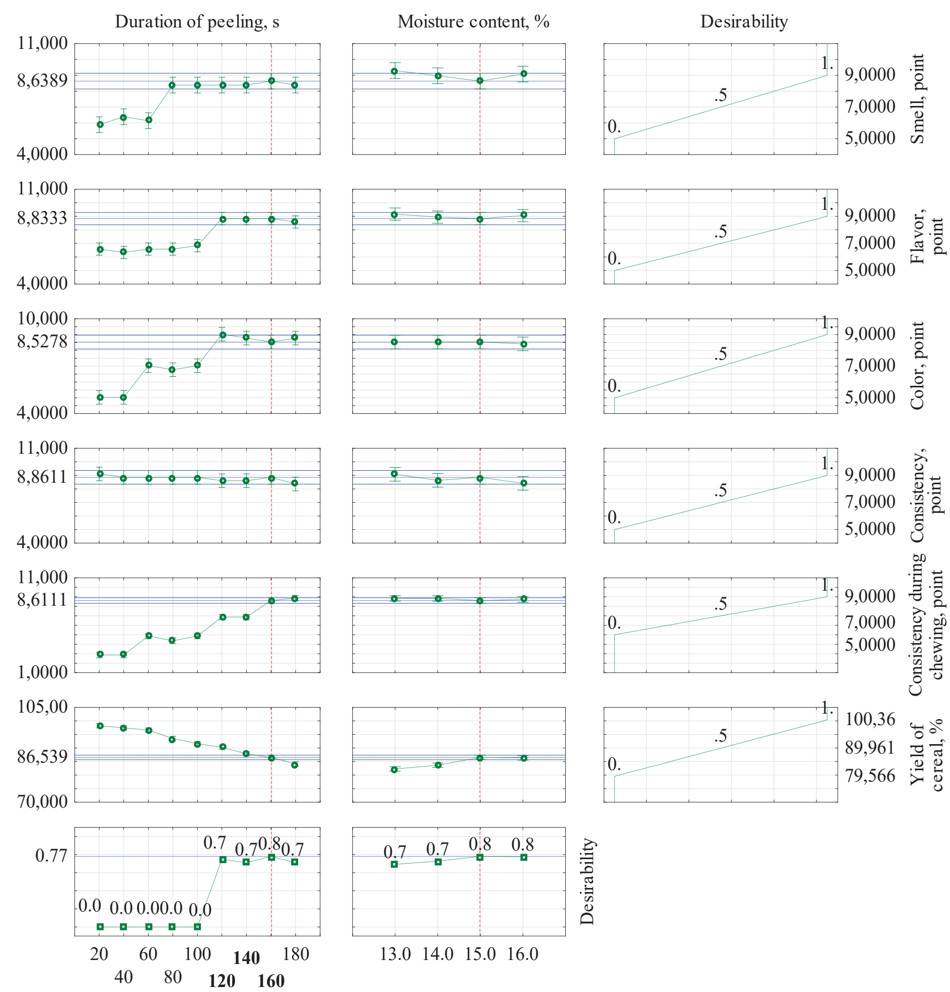



Fig. 8. Desirability function

It is impossible to attain the mode that would reach the maximum level of satisfaction because an increase in the duration of peeling influenced culinary evaluation of cereal and its yield in the opposite way.

The modes that had duration of peeling up to 100 s did not meet the requirement set for the model.

## 6. Discussion of results of research into processing of spelt wheat grain into peeled cereals

A comprehensive statistical analysis revealed the mechanism of the action of moisture on spelt wheat grain. The yield of cereal substantially changed depending on duration of peeling and, to a lesser extent, on the initial moisture content. The reason for this can be a rough rubbing action of the abrasive surface of the peeling machine.

The low yield of the cereal obtained as a result of peeling the grain that was not damped is caused by a large amount of middling, which was formed as a result of rubbing not only the shells, but also partially wheat endosperm.

An increase in the yield of cereal as a result of hydrothermal treatment can be attributed to the increased efficiency of operation of a peeling machine due to more uniform removal of shells and lower rubbing and destruction of the nucleus. That is why a change in the technological properties of the grain of spelt wheat and traditional wheat varieties that have a naked structure is similar.

A decrease in the yield of cereal as a result of an increase in gradient of damping is explained by the deep penetration of moisture into the central part of the endosperm, which was the reason of its excessive destruction.

The unlikely effect of duration of steeping indicates excellent water absorbing ability of the spelt wheat grain. This may be related to its anatomic structure. Usually, the surface layers serve to protect the caryopsis from the action of environmental factors. For moisture exchange, there is a capillary network in caryopsis. However, the membranes of spelt wheat are more sensitive to the influence of the environmental factors compared with the traditional wheat varieties, since ear membranes partially perform the protective function. That is why the difficulty of peeling membranous wheats may be compensated by lower expenses for carrying out steeping. Such feature will be especially valuable for new enterprises of low productivity, as the need for additional capital expenditures for the construction of operational tanks for grain steeping will disappear.

Peeling dry grain of spelt wheat is possible, albeit it is less effective compared with peeling the grain after conditioning. Dry grain does not change the parameters of peeling, although the dust formation increases. However, in some cases, this method is justified. It will be appropriate for the farms that grow small portions of grain of spelt wheat to process it using the set equipment without hydrothermal treatment. Due to the low cost of such facilities, the risk of capital investments decreases.

The culinary quality of cereals is most of all influenced by the duration of grain peeling. It is related to the removal of surface layers that, having the greatest amount of fiber, negatively affect the consistency of cooked cereal during chewing. When the cold method of conditioning is used, the influence of moisture content and the duration of steeping on culinary quality of cereal products have not been established yet.

It is impossible to transport biologically active substances to the central parts of caryopsis during cold conditioning. The modes of hydrothermal treatment that make it possible to increase the biological value of cereal products (freezing, germination, treatment with biopreparation) are quite valuable and require the use of specialized technological equipment.

The basic requirement for effective processing of spelt wheat grain into cereal is removal of the required number of membranes. The results shown in Fig. 7, 8 indicate the impossibility to produce whole-grain products from spelt wheat grain, since the excessive number of membranes affects the consistency of cooked cereal during chewing and negatively affects physical indicators. However, despite the optimal value of desirability function at the duration of peeling of 160 s, there is an insignificant decrease in the value of desirability in the samples that were peeled for 120 and 140 s. That is why it is recommended for manufacturers to use the range of duration of peeling from 120 to 160 s.

High indicators of quality of the cereal from the grain of membranous wheat varieties were also received by other scientists. It was established that the cereals from grain of spelt wheat had a very high culinary quality, especially in terms of smell, taste and boiling capacity [33, 34]. However, the research dealt with the quality of cereal from polba wheat, referred to the tetraploid, and spelt wheat, referred to the hexaploidy group of varieties of wheat. It is known [33] that technological properties of wheat varieties significantly differ. Therefore, it is not rational to equate technological properties and the quality of finished products of the two varieties of wheat.

Limitations of the conducted studies concern grain peeling machines. The results, presented in the paper, concern machines of the periodic action (Golender). The peeling machines of the continuous operation are more characteristic of cereal production. However, despite the structural differences between голендерів and peeling-grinding machines, the principle of their operation is similar and therefore the tendencies remain.

The use of one grade of spelt wheat grain can be referred to the shortcomings of the study. It is appropriate to establish the change of cereal properties of the spelt wheat grain, depending on the variety, growing conditions, and agricultural technologies. However, the variety, selected in this research, is most common in production. The specified conditions of growing and processing have practical value for small farms.

The research will be subsequently directed at the search for new efficient ways of processing the spelt wheat grain into cereal products and concentrated foods. The priority is to establish the influence of the directed power supply on the quality and safety of products of processing of spelt wheat grain.

## 7. Conclusions

1. Duration of peeling has most influence of the yield of cereal at actual humidity (13.0–14.5 %) of spelt wheat grain. The influence of initial moisture content of grain before peeling is significantly smaller, but reliable. During grain peeling from 20 to 180 s, the yield of cereals is the highest at the initial moisture content of 14.0 and 14.5 %, respectively, 80.1–95,6 % and 81.0–96.1 %.

2. The hydrothermal treatment of spelt wheat grain before peeling increases the yield of cereals. Standardized evaluation of peeling effect after the hydrothermal treatment is thrice as high, compared to the indicator without damping.

3. The culinary quality of cereals substantially depends on the duration of peeling. The parameters of hydrothermal treatment insignificantly affect the culinary quality. The cereals with the duration of peeling of 120–180 s have a high score of culinary assessment (6.0–9.0 points).

4. During the production of cereal from the spelt wheat grain, it is rational to damp it up to 15.0 %, steep up to 30 min and peel up to 120–160 s. The use of these parameters will ensure the yield of cereal from 86.5 to 89.0 % and high culinary qualities (8.5–8.8 points).

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