UDC: [633.11:658.627]-021.479:339.564

IMPROVING THE QUALITY OF EXPORT CONSIGNMENTS OF CLASS 4 WHEAT INTENDED TO BE USED AS FOOD

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DOI: https://doi.org/10.15673/fst.v14i2.1724

Article history

Received 22.01.2020
Reviewed 24.02.2020
Revised 11.04.2020
Approved 02.16.2020

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Cite as Vancuver style citation

Stankevych G, Borta A, Penaki A. Improving the quality of export consignments of class 4 wheat intended to be used as food. Food science and technology. 2020;14(2):129-138. DOI: https://doi.org/10.15673/fst.v14i2.1724

Цитування згідно ДСТУ 8302:2015

Stankevych G., Borta A., Penaki A. Improving the quality of export consignments of class 4 wheat intended to be used as food // Food science and technology. 2020. Vol. 14, Issue 2. P. 129-138 DOI: https://doi.org/10.15673/fst.v14i2.1724

Abstract. In Ukraine, the gross harvest of grain, including wheat, is growing from year to year. However, along with this, there is a steady tendency towards deterioration in the technological properties of wheat grain: the share of food grain is reduced in comparison with non-food wheat. That is why an important yet little studied issue is how to form export consignments with the use of grain which is substandard by some quality indicators. Primarily, this relates to class 4 non-food wheat grain. In the work, the changes and reproducibility of the quality indicators of consignments formed from different quantities of class 4 wheat of different quality have been studied. It has been shown that export consignments of food wheat can be formed from local batches of non-food wheat. On analysing their class-making characteristics, the quantitative and qualitative parameters have been determined for 11 samples of class 4 soft wheat (harvested in 2019) selected at enterprises of the Odessa Region, and for batches of export wheat formed from these samples by mixing. It has been shown that mixing individual local batches of wheat grain, which belong to class 4 by their quality characteristics, makes it possible to obtain export consignments of wheat conforming to the food class standards. It has been established that the more local batches are mixed, the greater are the differences between the calculated weighed average quality indicators and the experimentally obtained values of the same parameters. The class-making parameters "quantity and quality of gluten" do not always obey the law of mixing 2–4-component mixtures, and can behave in a most unpredictable way. This applies mainly to consignments formed on the basis of local batches where a lot of grains are damaged by the sunn pest. The rest of the quality parameters, though different from the calculated data, are within the tolerance limits for each parameter. It has also been shown that from non-food wheat grains (class 4), by using linear programming methods implemented in the Microsoft Excel spreadsheet, one can obtain the optimal export consignments satisfying all the requirements for food wheat quality (class 3). Thus, exporting enterprises, due to the difference in prices, can receive additional profit. When a consignment is formed, the calculated quality parameters can sometimes differ from the final quality characteristics needed for the intended purpose of the export consignment. Therefore, it is not only necessary to calculate the weighed averages of the consignment quality, but also to form a test batch and experimentally determine its quality indicators in the laboratory, because some of them can deviate towards better quality as well as towards deterioration.

Key words: wheat grain, quality parameters, formation of wheat consignments, recipe tasks.

Introduction. Formulation of the problem

Wheat is the crop that accompanies people from ancient times. From a primitive form, it has evolved into currently cultivated forms that provide humanity with nutrients and proteins. Due to its high nutritional value and adaptation to the climatic conditions, wheat is the most important food crop in the world [1]. The nutrients that make up wheat not only provide natural energy, but also help improve overall health [2]. That is why the maximum use of wheat's potential is a very important issue. Wheat is widely grown on five continents, and besides its wide cultivation zone, it is a universal product that can be stored for a long time and transported over long distances [3]. Wheat cultivation in the world has a wave-like harvesting tendency, and after a certain period, its growth can decline. In low-yielding years, the prices are low, and not all farmers sell crops, waiting for higher prices [4]. But it should be noted that even with a price increase, it is not always possible to make big profits, because during storage, your grain can lose up to 4% of weight [5], and sometimes losses can reach 40%, as it happened in Africa after locust invasions [6]. But instead of making profit from the planted crop, farmers suffered losses; the state was forced to purchase grain from abroad. That is why the timely maximum use of the potential of wheat is a very important issue.

Ukraine has long been an extremely powerful country producing wheat and has long been among the ten largest grain exporting countries along with such countries as the USA, Canada, Pakistan, Australia, and others [7]. Export of cultivated agricultural products is one of the ways to overcome the economic crisis and replenish the country's foreign exchange reserves. However, in connection with the existing tendencies to deterioration of the quality of wheat, the question arises of how to use wheat rationally when forming export consignments of grain.

Analysis of recent research and publications

Basing on a lot of systematised experimental material on wheat quality collected over four decades in Ukraine and in the world, O. Rybalka, Doctor of Biology, notes in his monograph [8] that at the beginning of this decade, about 110–120 million tons of total world production were the volumes of world commercialisation of wheat grain, or export-import operations. Some countries of the world, such as the USA, Canada, Australia, Argentina, Ukraine, and others, grow more wheat for domestic needs and export surplus grain. Other countries, such as Iran, Iraq, Egypt, Algeria, Mexico, and others, have annual deficiencies in wheat production and are forced to import grain.

The strategy of development and changes in the grain market of Ukraine over the past decade has changed significantly. If earlier, the main direction of using the grain potential was domestic needs (consumption and livestock feeding), one of the present priorities is the export of grain crops [9]. It should also be noted that in the twentieth century, more and more high-yielding varieties were grown that allowed not only providing people with food, but also increasing the share of exports and grain reserves [10]. The constant development of agriculture has increased the productivity of crops, but farming systems have not improved much, and wheat varieties remain highly uniform genetically [11].

The export potential of Ukraine is quite high, and over the past five years, it has fluctuated in fairly high limits (16,400–17,900 thousand tons) [12,13]. It should be noted that the export of such an amount of wheat does not lead to a food crisis, because wheat productivity tends to increase [14].

In Ukraine, the gross harvest of grain, including wheat, is actually growing annually. This is explained by the improvement of technology and the gradual expansion of areas under commercially successful crops. At the same time, the leaders of many states are no longer limited to simple indicators of wheat productivity in their fields and are guided by the production of grain of the highest classes. This allows getting additional funds per one ton of sales, thereby increasing the profitability of production [15].

Analysis of literary sources shows that in recent decades there has been a steady tendency to deterioration in the technological properties of wheat, that is, with an increase in the gross yield of wheat, the proportion of food grain is reduced compared to non-food wheat. Our studies have shown [16] that in 2000–2019, there were wave-like fluctuations in the gross harvest of wheat. According to some indicators, the grain quality was also deteriorating: there were fluctuations in grain unit weight, protein and gluten content, falling number, and the damage to grain from the sunn pest increased. In 2019, due to the low bulk density of wheat, its grain had to be moved to class 4 (non-food wheat).

At the same time, analysis of the quality of wheat grain that has been processed since 1997 at south-Ukrainian flour mills shows [17] that modern Ukrainian wheat varieties have potentially high baking properties and are resistant to the sunn pest's proteolytic enzymes. Another research in this field shows [18] that using individual indicators ("falling number," "gluten quality") to form grinding lots of wheat can improve the quality of products of grain processing.

Due to the lack of high-quality food wheat, there is a need to find new ways to use different-quality wheat grains, which would allow using harvested crops more rationally and efficiently [19].

Now there are no clear instructions on storage and formation of class 4 wheat batches at grain-producing enterprises, terminals, and elevators. Unlike food wheat, class 4 wheat has no minimally determined quality indicators. In the course of the acceptance procedure, all class 4 batches are stored in one container (or in one warehouse). There are only few enterprises that, when storing class 4 wheat, rely on the parameter according to which a batch should be classified as non-food wheat.

When forming export contracts, only two types of wheat are distinguished: food wheat, which corresponds to classes 1, 2, and 3 (according to the classification traditionally used in Ukraine), and non-food wheat, which corresponds to class 4. The difference in the price of food and non-food wheat is significant. That is why one of the important yet little studied issues is how to form an export food-purpose wheat consignment from batches of wheat that enterprises classified as low as class 4.

According to the website UkrAgroConsult [20], in Ukraine, wheat traders pay, on average, 5,380 UAH/ton for class 2 wheat, 5,380 UAH/ton for class 3 wheat, and 5,230 UAH/ton for class 4 wheat. The difference in price between classes 3 and 4, depending on the region and the enterprise, ranges 100–200 UAH/ton, so the economic benefit is quite significant.

When forming a grain batch of a given quality, it is very important to compare the calculated values of the quality indicators' weighed averages that a grain batch is supposed to have and the experimentally determined indicators obtained after mixing the local batches into a common mixture. The study of deviations and fluctuations between the mathematical calculation and the experimental values of quality indicators will allow timely correcting the ratio of the mixture components and, as a result, receive additional profit, because the correct formation of a batch will allow transferring wheat from the non-food to the food category.

Currently, mixing grains of various classes in warehouses is prohibited. In 2017–2019, since Instruction 661 was cancelled and a document to replace it started being discussed, one of the pressing issues was the possibility of mixing different classes of wheat grain in receiving containers (bins, silos). However, there is no consensus about how practical this method is [21].

The permission to mix wheat grains of different classes on linear grain elevators is a sore subject for both traders and producers. Supporters of mixing argue that this will facilitate the work of elevators, since different classes of grain will not have to be stored separately, in different silos. And even with separate storage, grain is, nevertheless, ultimately mixed on a merchant ship. Their opponents point out that farmers will have no motivation to grow high-class wheat, as mixing will be heterogeneous [22].

The problems of forming wheat batches with specified quality indicators have been dealt with by many scientists. To determine the relationship between the individual components of such batches, both analytical and graphoanalytical calculation methods were proposed, as well as certain graphoanalytical dependencies for the formation of wheat batches at flour mills [18,23,24]. Scientists have also developed mathematical models that describe the relationship between technological indicators of wheat grain quality [25], which allows us to predict their changes.

Thus, a review of scientific sources has shown that currently, the issues of forming export consignments using grain with substandard quality indicators are relevant and poorly studied. This determined the purpose of our studies.

The purpose of the study was to establish patterns of change and reproducibility of quality indicators for wheat batches formed from different quantities and quality of local batches of class 4, which will improve the quality of formation of export wheat batches. To achieve this purpose, it was necessary to solve the following **tasks**:

– in the grain harvesting period of 2019, at industrial enterprises of the Odessa Region, to select class 4 wheat samples according to different class conditions;

– to determine the quality indicators of some local batches of wheat taken in the specified period;

– to mix samples of non-food wheat having various quality indicators in order to form food-purpose export consignments;

– to calculate the weighed average quality indicators of the export consignments obtained from mixing local samples;

– to determine the quality indicators of the obtained laboratory samples of export consignments;

– to compare the calculated and experimentally determined quality indicators of the new-formed consignment of wheat grain;

– to make a mathematical model of the export consignment and determine the optimal composition by linear programming methods.

The subject of the study was the class-making characteristics of wheat grain batches.

The object of research was the quantitative and qualitative parameters of 11 samples of class 4 soft wheat (harvested in 2019) selected at enterprises of the Odessa Region, and batches of export wheat formed from these samples by mixing.

Research materials and methods

Wheat sampling. During the harvesting period, wheat samples to be researched were taken at industrial enterprises in the Odessa Region. The samples were included in class 4 according to different quality indicators (grain unit weight, protein, grain admixture, quantity and quality of gluten, grains damaged by the sunn pest, etc.).

Methodology for the test weight determination. The determination of grain test weight was carried out according to GOST 10840-64 "Grain. Methods for determining test weight." According to the current method, the grain unit weight (the weight of one litre of grain) is determined with grain-unit scales. Tolerance of determination ±5 g/l.

Determination of grain moisture content is carried out according to GOST 13586.5-93 "Grain. Method for determination of moisture content." To determine the moisture content, the main instrument was a SESh-3M drying oven. According to an effective methodology, a 20 g sample of grain must be ground in a laboratory mill. Subsequently, 2 weighed pieces weighing 5 g each are taken into weighing bottles. The bottles are placed in the oven for 40 minutes at 130°C. After drying, the bottles are cooled, weighed, and the moisture content in the sample is calculated by a formula. Tolerance ±0.5% for control and reference measurements.

Determination of grain and weed impurities is carried out in accordance with GOST 30483-97 "Grain. Methods for determining the total and fractional content of weed and grain impurities; content of small grains and grain size; the content of wheat grains damaged by the sunn pest; content of metallomagnetic impurities."

The content of weed and grain impurities, namely beaten, sprouted, and empty, damaged grains, the barley content is determined in a sample of grain weighing 50 g. The content of contaminated grains (affected by stinking smut) is determined with a sample weight of 20g.

The permissible discrepancy depends on the data obtained and is specified in GOST 30483-97.

Protein determination was performed using an Infratec 1241 analyser (PERTEN). When analysing the main components of grain (protein, water, fat, etc.), they absorb electromagnetic radiation in the near infrared range, so there is no need to prepare the grain. For analysis, they use unmilled grain that has not been treated with disinfectants, growth regulators, and other chemicals. The process lasts about 1 min., after which the results of the analysis are displayed.

Methods for determining the quantity and quality of gluten (GOST 13586.1-68 Grain. Methods for determining the quantity and quality of gluten in wheat).

Ground grain (meal) is thoroughly mixed and a weighed mass of 25 g or more is taken, so as to ensure a raw gluten yield of at least 4 g. The meal is placed in a porcelain mortar or bowl and covered with water. The volume of water for kneading dough with a mass of a sample of 25 g is 14 cm^3. After that, the dough is kneaded.

The dough formed in the ball is placed in a bowl and covered with glass (or another cup) for 20 minutes. After that, gluten is washed under a weak stream of tap water over a thick piece of silk or a sieve, the dough being kneaded slightly by fingers. First, cleaning is carried out carefully, not allowing pieces of dough to come off together with starch and shells, and after the removal of starch and shells, the cleaning is more energetic. Gluten pieces accidentally torn off are collected and attached to the total mass of gluten.

Having finished washing the gluten, it is squeezed between the palms, which are wiped dry with a towel from time to time. The pressed gluten is weighed, washed again for 2-3 minutes. Again squeeze and weigh. Gluten washing is considered complete if the differences in weight between two weighings are not more than 0.1 g. Crude gluten is expressed in mass fractions as a percentage of a portion of ground grain (meal).

For kneading, washing and determining the quality of gluten, ordinary tap water is used, the temperature of which must be 18±2°C.

Gluten quality is understood as its physical properties taken together: elongation, elasticity, viscosity, ability to maintain physical properties over time.

The elastic properties of gluten were determined in arbitrary units of the IDK-7 instrument scale (gluten deformation meter).

From the washed gluten, a piece weighing 4 g is separated. Knead it 3-4 times with fingers, then form a ball, and place it for 15 minutes in a bowl of water, the temperature of which is 18±2°C. If the gluten after washing is spongiform, it is easily torn and does not form a ball, and then it is assigned to group 2 without determining the quality on the device.

After 15 minutes of resting in water, the gluten ball is placed in the centre of the IDK-7 device table and the "Start" timer switch is pressed. The punch freely falls on gluten and compresses it. The display of the device shows a number characterising the elasticity of the studied gluten sample in arbitrary units of the scale of the device.

The allowable discrepancy for the amount of gluten is ±2.0% and for the quality of gluten ±5 units of the instrument.

The Falling Number Method was carried out in accordance with GOST 30498-97 "Cereals. Determination of the falling number." It is based on rapid gelatinisation of an aqueous suspension of flour in a boiling water bath with subsequent measurement of the degree of rarefaction of starch gel under the influence of alpha-amylase. The falling number is determined on a device PChP-7 (LLC *ANALIT DEVICE*). The falling number is determined in a sample of meal, the mass of which is taken depending on the initial moisture content of the grain. 25 cm^3 of distilled water is added to the weighed fraction, after which the mixture is shaken vigorously 20-25 times until a homogeneous suspension is formed. The viscometric suspension tubes are placed in a water bath, where the suspension is stirred for 60 s, after which the stirring rods are released and they drop freely. The falling number is the time in seconds required to mix and drop a viscometric stirrer in a hot suspension of flour and water to a certain distance.

Tolerance ±10% of the arithmetic mean value.

Determination of grains damaged by the sunn pest is carried out according to GOST 30483-97 "Grain. Methods for determining the total and fractional content of weed and grain impurities; content of small grains and grain size; the content of wheat grains damaged by the sunn pest; content of metallomagnetic impurities." To do this, from a sample weighing 10 g, previously cleaned of grain and weed impurities, the presence of specific signs grains are selected having the specific signs of being damaged by the sunn pest. The arithmetic average of the weight of the samples from two parallel measurements is expressed as a percentage accurate to a tenth.

All studies and measurements were carried out on calibrated, certified equipment, in accordance with applicable metrological requirements.

The permissible discrepancy depends on the data obtained and is specified in GOST 30483-97.

The formation of individual batches of wheat grain was carried out by mixing individual selected samples of wheat grain of class 4 (according to DSTU 3768:2019). Mass fractions of each individual sample for mixing were taken in uniform proportions, i. e. 1:1, 1:1:1, etc. By mixing, 6 mixtures (batches) were formed.

After uniform mixing of the selected samples, grain samples were taken from which medium samples were made and the quality indicators of the formed batches of wheat grain were experimentally determined. The quality indicators for each batch were determined in two parallels, on the basis of which the weighted average values of each of the studied parameters were mathematically calculated.

At the same time, on the basis of the known quality indicators of individual wheat samples of class 4, the mean values of the quality indicators of the formed batches were calculated, which were then compared with experimentally determined values and maximum permissible errors for each of the quality indicators.

Optimisation of the composition of formed batches of wheat grain. At the last stage of the work, a mathematical model was compiled for the formation of a batch of food wheat grains of a given quality from individual samples of non-commercial wheat (class 4). The possibility of determining the optimum composition has been shown on the basis of the linear programming method, which will make it possible to move the mixture to the food wheat category.

Results of the research and their discussion

According to the purpose and objectives of the research, in the grain production period, from wheat harvested in 2019, 11 wheat samples were selected. The samples belonged to class 4 according to DSTU 3768:2019 by different quality indicators (both class-making and non-class-making). The values of certain quality indicators of these samples are given in Table 1. It also contains standards (requirements) for the values of indicators of classes 3 and 4. The quality indicators highlighted in bold are those for which the samples are classified as belonging to class 4 (non-food wheat).

The next step was mixing various samples in equal proportions and determining the quality of the samples (formed batches).

For the correct determination of mixing properties, stage-by-stage mixing of different amounts of wheat samples of class 4 was carried out (according to different indicators), and deviations of the calculated and factual batch values of the quality indicators were compared. Stage-by-stage mixing and determining the quality of different numbers of samples were carried out in order to study the influence of the number of samples in the formation of the batch.

Analysis of the data has shown that each of the 11 samples of wheat grains studied did not meet the requirements for food wheat in one or several quality indicators, which is why each was attributed as non-food wheat of class 4. Most of the other indicators met the requirements for food-purpose wheat. By mixing, they improve the quality of the mixture and bring it to the same level as the requirements for edible wheat, that is, move such a batch from class 4 to class 3.

The first two batches (I and II) were obtained by mixing 2 wheat samples, which according to different indicators (indicated in brackets) were assigned to class 4:

– batch I from samples 1 (by crude protein content) and 2 (by the gluten content);

– batch II from samples 8 (by the grain unit weight and grain admixture content) and 9 (by protein and gluten content).

The experimentally determined quality indicators of the obtained batches and their calculated values are given in Table 2 (the quality indicators of the formed batches by which they are included in class 4 are highlighted in bold).

Table 1 – Characterisation of the quality indicators of the class 4 wheat samples

No. samples	**Class-making parameters**									**Non-class-making**
	Test weight, g/l	Moisture content, %	Grain impurity, %	including beaten grains, %	Extraneous matter, %	Crude protein content, %	Crude gluten content, %	Gluten quality, GDM units	Falling number, sec	Pest Damaged Grains, %
	Designation of grain quality indicators									
	T_w	M	G_i	I_{bg}	E_m	C_p	C_g	G_q	F_n	B_d
1	802	13.1	3.92	2/60	0.94	**10.7**	**17.2**	95	268	0.4
2	**703**	9.5	4.12	3.24	0.94	16.1	36.2	74	320	0.6
3	**715**	12.8	5.00	2.00	0.82	13.1	28.2	87	318	0.5
4	763	12.3	4.88	3.10	1.00	12.4	19.4	**112**	348	**4.8**
5	760	12.2	4.78	3.06	1.00	12.3	19.2	**117**	294	**5.2**
6	**720**	12.8	**12.20**	**8.64**	0.78	12.6	23.4	84	285	1.2
7	**700**	14.1	5.00	2.20	1.00	13.8	26.4	89	264	0.7
8	**700**	13.2	**8.40**	1.70	1.00	12.1	20.4	79	290	0.8
9	792	13.0	4.06	2.42	0.82	**10.4**	**15.4**	92	326	0.2
10	772	12.1	4.16	2.54	0.82	**10.9**	**17.4**	97	310	1.2
11	798	13.0	4.30	2.34	0.86	**10.2**	**14.2**	83	280	0.4
Class	Class requirements									
3th	≥730	≤14	≤8	≤5	≤2	≥11	≥18	45–100	≥180	≤2
4th	–	≤14	≤15	≤15	≤3	–	–	–	–	–

Table 2 – Quality indicators of batches of wheat formed from different samples of class 4 wheat

Quality indicators	Numbers of mixed samples and formed batches											
	No. 1, 2 (I)		No. 8, 9 (II)		No. 1, 2, 6 (III)		No. 3, 5, 9 (IV)		No. 4, 6, 7, 10 (V)		No. 1–11 (VI)	
	Expe-riment	Calcu-lation	Expe-riment	Calcu-lation	Expe-riment	Calcu-lation	Expe-riment	Calcu-lation	Expe-riment	Calcu-lation	Expe-riment	Calcu-lation
T_w, g/l	746	750	741	746	734	742	759	756	739	739	741	748
M, %	11.5	11.3	13.2	13.1	11.5	11.8	12.7	12.7	12.8	12.8	12.4	12.5
G_i, %	4.1	4.0	6.8	6.2	7.24	6.75	5.1	4.61	7.02	6.56	5.92	5.53
I_{bg}, %	3.1	2.9	2.3	2.1	**5.2**	4.83	2.74	2.49	4.38	4.12	3.26	3.08
E_m, %	0.86	0.94	0.92	0.91	0.84	0.89	0.94	0.88	0.98	0.90	0.90	0.91
C_p, %	13.4	13.4	11.1	11.2	13.1	13.1	11.7	11.9	12.3	12.4	12.1	12.2
C_g, %	26.8	26.7	**17.2**	**17.9**	24.8	25.6	19.2	20.9	20.1	21.6	19.9	21.6
G_q, un. VDK	87	84	89	85	89	84	**107**	99	**104**	95	98	92
F_n, sec	309	294	308	308	287	291	294	313	302	302	314	300
B_d, %	0.6	0.5	0.7	0.5	0.8	0.7	**2.1**	2.0	2.0	2.0	1.6	1.4
Grain class	3	3	4	4	4	3	4	3	4	3	3	3

As a result of mixing samples No 1 and No 2, wheat batch I was obtained, which, according to experimentally determined quality indicators, belonged to class 3. Although there are discrepancies between the mathematically calculated and experimentally determined values of the quality indicators, they are within the norms of permissible deviations for each indicator.

As a result of mixing samples No 8 and No 9, class 4 wheat batch II was obtained, although according to the calculations of weighted average quality indicators, this wheat belonged to class 3. There are discrepancies between the mathematically calculated and experimentally determined values of the quality indicators, but they are within the norms of permissible deviations for each of them. Despite this, according to the indicator "mass fraction of crude gluten," the second wheat batch was moved to class 4.

Each of the considered indicators can be corrected by changing the ratio (percentage) of each of the samples during mixing. Despite the higher content of crude gluten in sample No 8 (see Table 1), it is necessary to increase its share in batch II, and should lead it to the requirements of class 3.

The following two batches (III and IV) were received by mixing three wheat samples assigned by different parameters (indicated in brackets) to class 4:
– batch III from samples No. 1 (by protein and gluten content), No 2 (by test weight), and No. 6 (by test weight, grain impurities, including beaten grains);
– batch IV from samples No 3 (by test weight), No 5 (according to the GDM units and grains damaged by the sunn pest), and No 9 (according to the protein and gluten content).

As a result of mixing samples No 1, No 2, and No 6 and determination of quality indicators, which are given in Table 2, the third batch of wheat of class 4 was obtained, although according to the calculations of the average weighed quality, wheat belongs to class 3. Fluctuations between mathematically calculated and experimentally determined values are within the norms of permissible deviations, except for the grain unit weight parameter. However, according to the "broken grains" indicator, this wheat sample was moved to class 4.

As a result of mixing samples No 3, No 5, and No 9, batch IV of class 4 wheat was obtained, although according to weighed average quality calculations, wheat belongs to class 3 of quality. The fluctuations between the mathematically calculated and practically obtained values of the quality indicators fluctuate and are within the limits of permissible deviations for each of the indicators, except for the quality of gluten, according to which this wheat sample is included in class 4.

A possible reason for the increased experimental value of the gluten quality indicator could be uneven mixing of the components of the mixture, because it consisted of sample No 5, which significantly differed from samples No 3 and No 9 in gluten quality (117 against 84 and 92 GDM units, respectively).

Batch V was obtained as a result of mixing 4 wheat samples assigned to class 4 for different quality indicators:
– sample 4 (due to GDM units and pest damaged grains);
– sample 6 (due to test weight, grain impurities and including broken grains);
– sample 7 (due to test weight);
– sample 10 (due to the protein and gluten content).

The results of experimentally and computationally determined quality indicators of the received batch are shown in Table 2.

It can be seen that batch V obtained by mixing samples No. 4, No. 6, No. 7, and No. 10, by its quality belongs to class 4, although according to the results of the calculated values of the weighted average indicators, this is class 3 wheat. Fluctuations between mathematically calculated and experimentally determined values of quality indicators are within the norms of permissible deviations for each of them, except for the indicator "gluten quality," according to which this sample was moved to class 4. The reason for this may be similar to the that of the previous batch IV. In batch V, there was also sample No 4 with a high quality index of gluten.

Wheat batch V, the last one, was formed as a result of mixing all 11 samples, each of which belonged to class 4 according to certain individual indicators, indicated in bold in Table 1. The results of the determination by mathematical calculations of weighted average quality indicators have shown that batch V belongs to class 3. The experimentally obtained mixing results confirmed this: all quality indicators are within acceptable deviations, except for the "gluten quality" indicator, which goes beyond the permissible 5 units of the GDM units.

The example in Fig. 1 clearly shows the difference in the discrepancies between experimentally and mathematically determined quality values in terms of "gluten quality" and "pest damaged grains." It is important to note that in all the formed batches, experimentally found quality indicators exceed their calculated values, which may be a manifestation of the synergy effect. It is positive for gluten quality, but for the number of damaged grains, this will lead to a deterioration in the quality of the existing batch of wheat. Although the number of pest damaged grains is not a class-making indicator according to DSTU, in contractual requirements, this indicator is clearly regulated and it can lower the class of shipped wheat grain.

It is also not necessary to exclude the possibility of the occurrence of these differences in quality indicators as a result of insufficiently uniform mixing of samples at the stage of formation of a grain batch.

There are almost always deviations between the calculated and experimental data, in most cases they are within acceptable limits. However, it should be noted that in almost all cases, for most quality indicators, experimental data show large (and not always the best) values.

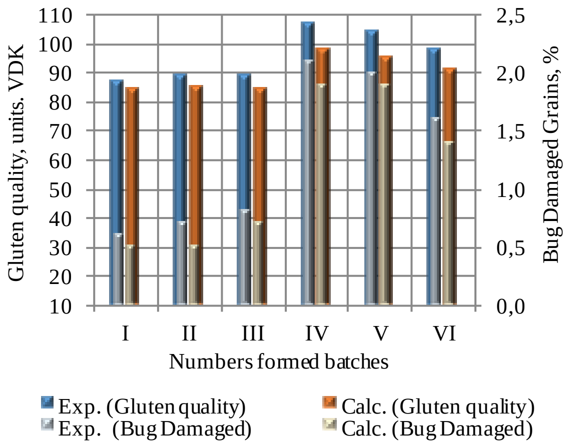

Fig. 1. Histogram of differences between experimental and calculated values of grain quality indicators in the formed batches

At the last stage of the work, it was shown how the optimal composition of grain batches could be determined, which would meet certain requirements for grain quality, for example, class 3 wheat. This can be done using linear programming methods designed to optimise recipe tasks, which are implemented in the Microsoft Excel spreadsheet processor in the "Search for Solutions" procedure. To do this, you must first draw up a mathematical model of the formulation, which should have a certain optimality criterion (objective function), requirements for grain batch quality indicators will be formed for a number of other restrictions necessary for the correct solution of the problem.

Let us draw up a mathematical model of the second batch of wheat grain, which will include class 4 grain samples No 8 and No 9. It has been shown above that mixing these samples in a 1:1 ratio did not allow receiving a class 3 wheat batch due to the low content of crude gluten. For this purpose, as the objective function, we select the requirement of obtaining a normalised value of the mass fraction of crude gluten (18%) in the existing batch, which will ensure the quality of the batch at the level of class 3.

However, it should be noted that some class-making indicators may have "critical" values, to be on the border of classes. In this case, for the second batch, this indicator is the mass fraction of crude gluten C_g, which is equal to 18%. It should also be borne in mind that between the calculated values of quality indicators and the ones determined experimentally, as shown above in Table 2, there are some differences. Besides, each method of experimental determination of certain indicators is characterised by certain permissible errors.

Thus, in order to prevent the transition of the calculated and established batch to the lower class, one must take into account the above circumstances and put them into the mathematical recipe model of the batch of grain, which is formed. In this case, it would be advisable to increase the raw gluten content normalised for class 3 by the amount of possible disagreements and errors (for example, by 1%). That is, the value of the objective function (crude gluten content) will be taken at the level of 19.0%, which should guarantee compliance with the requirements for the content of gluten with the requirements of wheat grains of class 3.

Also, as already noted, after calculating the optimal composition of the grain batch, it is necessary to compile a laboratory sample of the batch to be formed, and experimentally check all class-making quality indicators and, if necessary, make certain adjustments.

Thus, the objective function will look like this:

$$C_{gII} = (C_{g8} \cdot x_8 + C_{g9} \cdot x_9)/100 = (20.4 \cdot x_8 + 15.4 \cdot x_9)/100 = 19.0; \quad (1)$$

where C_{gII} – crude gluten content in the formed batch, %;

C_{g8}, C_{g9} – crude gluten content in the formed batch in samples 8 and 9, % (Table 1);

x_8, x_9 – mass fraction of samples 8 and 9 in the formed batches, %.

Further, based on Table 1, we write down the requirements for quality indicators in the form of restrictions imposed on a batch of class 3 wheat:

$$\left.\begin{aligned}
&T_{wII} = (T_{w8}\cdot x_8 + T_{w9}\cdot x_9) = (700\cdot x_8 + 792\cdot x_9) \geq 730 \text{ g/l};\\
&M_{II} = (M_8\cdot x_8 + M_9\cdot x_9)/100 = (13.2\cdot x_8 + 13.0\cdot x_9)/100 \leq 14\%;\\
&G_{iII} = (G_{i8}\cdot x_8 + G_{i9}\cdot x_9)/100 = (8.4\cdot x_8 + 4.06\cdot x_9)/100 \leq 8\%;\\
&I_{bgII} = (I_{bg8}\cdot x_8 + I_{bg9}\cdot x_9)/100 = (1.7\cdot x_8 + 2.42\cdot x_9)/100 \leq 5\%;\\
&E_{mII} = (E_{m8}\cdot x_8 + E_{m9}\cdot x_9)/100 = (1.00\cdot x_8 + 0.82\cdot x_9)/100 \leq 2\%;\\
&C_{pII} = (C_{p8}\cdot x_8 + C_{p9}\cdot x_9)/100 = (12.1\cdot x_8 + 10.4\cdot x_9)/100 \geq 11\%;\\
&C_{gII} = (C_{g8}\cdot x_8 + C_{g9}\cdot x_9)/100 = (20.4\cdot x_8 + 15.4\cdot x_9)/100 \geq 19\%;\\
&G_{qII} = (G_{q8}\cdot x_8 + G_{q9}\cdot x_9)/100 = (79\cdot x_8 + 92\cdot x_9)/100 \geq 45 \text{ unit. VDK};\\
&G_{qII} = (G_{q8}\cdot x_8 + G_{q9}\cdot x_9) = (79\cdot x_8 + 92\cdot x_9) < 100 \text{ GDM units};\\
&F_{nII} = (F_{n8}\cdot x_8 + F_{n9}\cdot x_9)/100 = (290\cdot x_8 + 326\cdot x_9)/100 \geq 180 \text{ sec};\\
&B_{dII} = (B_{d8}\cdot x_8 + B_{d9}\cdot x_9)/100 = (0.8\cdot x_8 + 0.2\cdot x_9)/100 \leq 2\%.
\end{aligned}\right\} \quad (2)$$

In the restrictions, it is still necessary to specify the requirement $(x_8 + x_9) = 100$ and $(x_8, x_9) \geq 0$, which will allow obtaining the share of grain size x_8 and x_9 in percent and not negative.

Thus, the system of equations and inequalities of the above objective function (1), the requirements for quality indicators, which are written as restrictions in the form of inequalities (2), as well as the requirements of equality 100 and non-negative variables x_8 and x_9, make up a mathematical description (model) of a class 3 wheat batch. Based on this model, the "Search for Solutions" procedure has obtained the optimal composition of the formed batch of wheat grains of class 3: x_8 = 53.07%, x_9 = 46.93%.

According to this ratio of mass fractions of samples No. 8 and No. 9, the formed batch will have such predicted (calculated) quality indicators: T_w –743 g/l, M – 13.91 %, G_i –6.61%, I_{bg} – 2.19%, E_m – 0.97%, C_p – 11.94%, C_g – 19.00%, G_q – 85unit VDK, F_n – 307 sec, B_d – 0.53%.

As shown, the formed batch in all quality indicators will meet the requirements (norms) of class 3 food wheat.

Conclusion

When mixing separate (local) batches of wheat grains that belong to class 4 by different quality indicators, obtaining export consignments of wheat corresponding to the food class is quite a task. It should be noted that with an increase in the number of local batches, when mixing, there are differences between the calculated mean values of the quality indicators and the experimentally obtained values of the same indicators.

The class-making indicators "quantity and quality of gluten" do not obey the law of mixing 2–4-component mixtures and behave in a most unpredictable manner. However, this applies mainly to batches that are formed on the basis of local batches with a high value of the number of damaged grains. The remaining quality indicators, although they differ from the calculated data, are within the limits of permissible deviations for each of the indicators.

The calculated quality indicators during the formation of batches may not always correspond to the required final quality of the target export consignment. That is why it is necessary not only to calculate mathematically the weighed average batch quality indicators, but also to form a test laboratory batch and experimentally determine its quality indicators, because some indicators can deviate towards improvement as well as towards deterioration.

It has also been shown that the use of linear programming methods implemented in the Microsoft Excel spreadsheet allows you to get the optimal export consignments from non-food wheat grains (class 4). They meet all requirements for the quality of edible wheat (class 3). This makes it possible for exporting enterprises, due to the difference in the prices, to receive additional profit.

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ПОКРАЩЕННЯ ЯКОСТІ ФОРМУВАННЯ ЕКСПОРТНИХ ПАРТІЙ ПРОДОВОЛЬЧОГО ПРИЗНАЧЕННЯ З ПШЕНИЦІ 4 КЛАСУ

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Анотація. В Україні щороку зростає валовий збір зерна, в тому числі пшениці. Однак поряд з цим спостерігається стійка тенденція до погіршення технологічних властивостей зерна пшениці, зменшується доля продовольчого зерна у порівнянні з пшеницею непродовольчою. Тому актуальним та маловивченим залишається питання формування експортних партій з використанням некондиційного за деякими показниками якості зерна. У першу чергу це стосується використання пшениці 4 класу – зерна непродовольчого призначення. У роботі досліджено зміни та відтворюваність показників якості партій пшениці, сформованих з різної кількості та якості партій 4 класу, та показано можливість формування експортних партій продовольчої пшениці з локальних партій непродовольчої пшениці. Проведено аналіз їхніх класоутворювальних показників та визначено кількісно-якісні показники 11 відібраних на підприємствах Одеської області зразків м'якої пшениці 4 класу 2019 року врожаю, а також отриманих з них у результаті змішування партій пшениці експортного призначення. Показано, що змішування окремих (локальних) партій зерна пшениці, які віднесено до 4 класу за різними показниками якості, дозволяє отримувати експортні партії пшениці, що відповідають продовольчому класу. Встановлено, що зі збільшенням кількості локальних партій, при їх змішуванні збільшуються і розбіжності між розрахованими середньозваженими показниками якості та експериментально отриманими значеннями тих же показників. Класоутворювальні показники «кількість та якість клейковини» не завжди піддаються закону змішування (2–4)-х компонентних сумішей і проявляють себе найбільш непередбачувано. Це стосується в основному партій, які формуються на основі локальних партій з високим значенням кількості зерен, пошкоджених клопом-черепашкою. Решта показників якості, хоч і відрізняються від розрахункових даних, але знаходяться у межах допустимих відхилень по кожному з показників. Показано також, що використання методів лінійного програмування, реалізованих у табличному процесорі Microsoft Excel, дозволяє із непродовольчого зерна пшениці (4 клас) отримати оптимальні експортні партії, які задовольняють всім вимогам з якості продовольчої пшениці (3 клас). Це дозволяє за рахунок різниці у їх цінах отримувати підприємствам-експортерам додаткові прибутки. Розраховані показники якості при формуванні партій не завжди можуть відповідати необхідній кінцевій якості цільової експортної партії. Тому необхідно не тільки математично розраховувати середньозважені показники якості партії, а й формувати пробну лабораторну партію та експериментально визначати показники її якості, адже деякі показники можуть дати відхилення як у бік покращення, так і у бік погіршення якості.

Ключові слова: зерно пшениці, показники якості, формування партій пшениці, рецептурні задачі.

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