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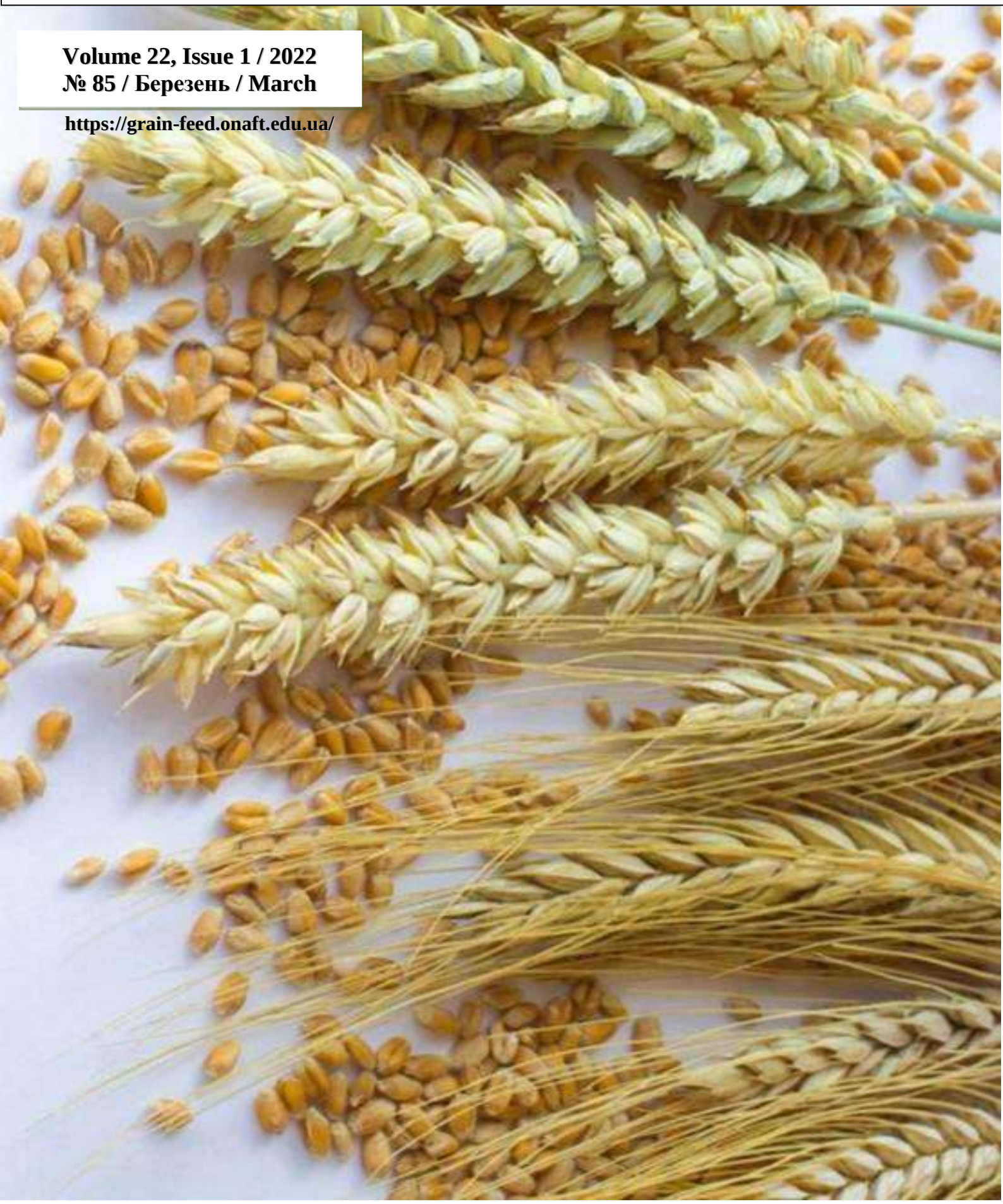

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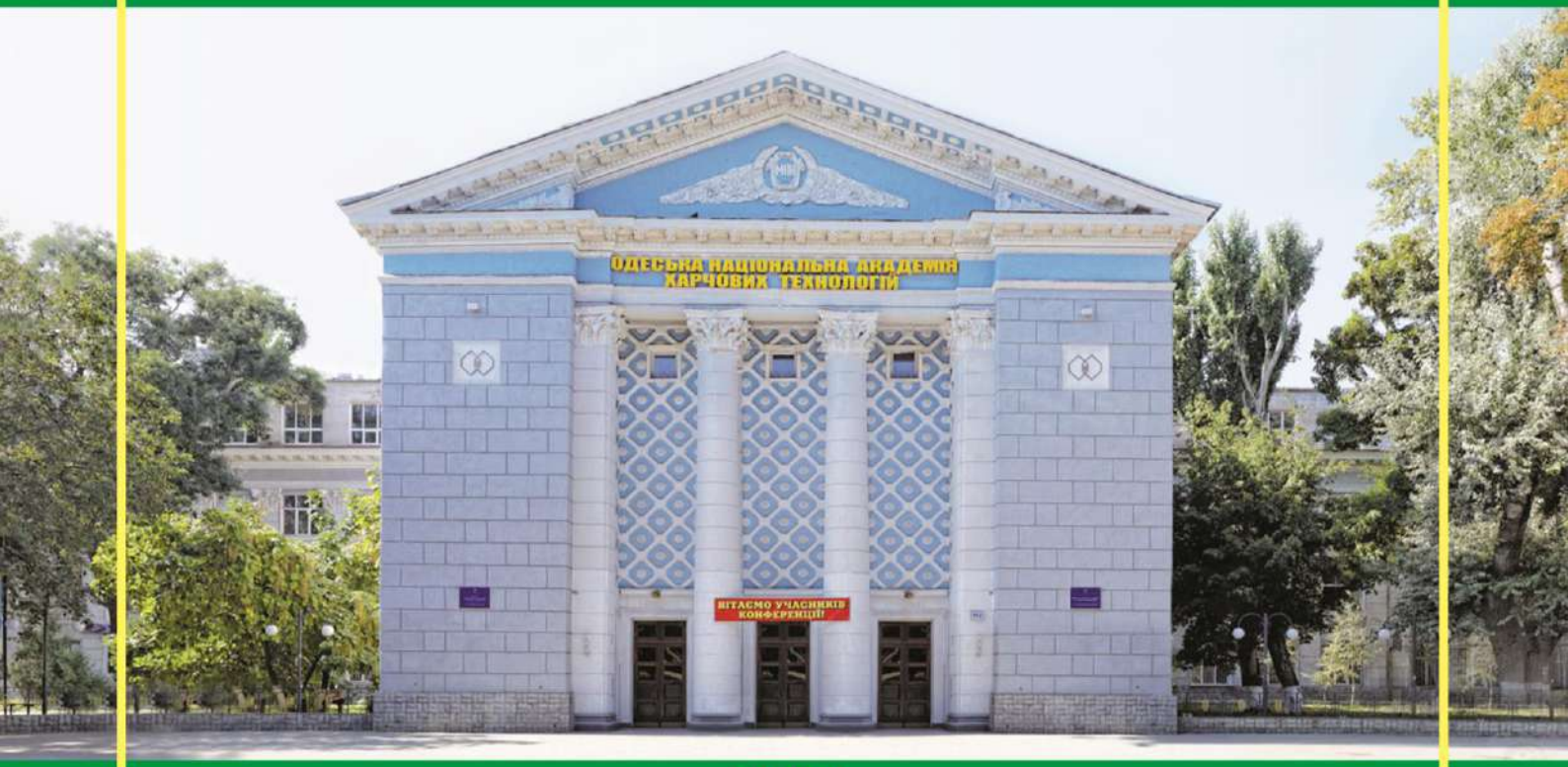

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Зернові продукти і комбікорми
Grain Products and Mixed Fodder's

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OPTIMIZATION OF PRESS-GRANULATOR WORK IN SMART TECHNOLOGIES SYSTEM

Abstract

It has been repeatedly tested and proven that granulated feed and granulated semolina have a number of advantages over loose feed, since there is no self-sorting of components, losses during transportation and loss of nutrients during storage is reduced. The effective effect of such compound feeds is higher than that of loose feeds by 10-15% due to an increase in the level of sanitary quality and an increase in the digestibility of nutrients. In addition, up to 3...4% of liquid components can be introduced into the compound feed during granulation, compared to 1...2% for loose compound feed. At present, there is a tendency towards an increase in the share of production of granulated feed. The technology of granulating feed allows you to ensure stable uniformity, improve sanitary and hygienic indicators, increase nutritional value, increase shelf life, and minimize losses during its transportation and distribution. All this affects both the consumption of compound feed and the performance of animal and poultry rearing. At the same time, the main equipment for the production of mixed feed pellets is a pellet press. The task of controlling the press granulator as part of SMART technologies is to determine and implement such a ratio of steam consumption and the initial product, in which the indicators of the granulation process such as productivity, specific consumption of steam and electricity, as well as the quality properties of the granules would correspond to the required values. According to the most important practical recommendation for conducting the technological process of granulation, it is to provide the required conditions for conditioning with steam, liquid components in accordance with the properties of the initial processed product. At the same time, the hydrothermal treatment of compound feed affects, practically, all indicators of the granulation process and the quality of its final product. An analysis of the dependence of productivity on steam consumption obtained for various compound feed recipes allows us to conclude that it is possible and expedient to search for the optimal position of the regulating body for supplying steam to the pellet press mixer. At the same time, it is necessary that the productivity of the press tend to the maximum depending on the position of the regulating body for supplying steam to the press, and the magnitude of the current load of the main drive motor, which mainly determines the energy intensity of the process, was limited in a given range of values at zeroing of the corresponding compound feed recipe: The increment in the filling time of the cooling column between the cycles of the unloading device, which characterizes the performance of the pellet press, can be used to indirectly evaluate it and be used as an output indicator in the control system for the granulation process. The search algorithm for the optimal granulation mode consists of two parts: the stepwise start algorithm (bringing the system into the search zone) and the search algorithm for the optimal granulation mode. It is proposed to use the SMART-INDIVIDUAL system, which is equipped with a module with a regulation for monitoring parameters of equipment according to passport characteristics. At the same time, the system maintains an archive and controls the timing of maintenance.

Keywords: press granulator, performance, stabilization, optimization, search algorithm, SMART technology

Introduction

It has been repeatedly tested and proven that granulated feed and granulated semolina have a number of advantages over loose feed, since there is no self-sorting of components, losses during transportation and loss of nutrients during storage is reduced. The effective effect of such compound feeds is higher than that of loose feeds by 10-15% due to an increase in the level of sanitary quality and an increase in the digestibility of nutrients. In addition, up to 3...4% of liquid components can be introduced into the compound feed during granulation, compared to 1...2% for loose compound feed. At present, there is a trend towards an increase in the share of production of granulated feed [1, 2].

Purpose and objectives of the study

One of the main directions of intensification of the technological process of granulation is the introduction of automated control systems, the highest form of which, at present, is the use of SMART technologies. Automatic control of the granulation process should be aimed at maintaining such a ratio of steam consumption and the initial product, which provides the nominal value of the stator current of the main drive electric motor of the press at a given output and the required quality of finished granules. However, it is far from always possible to establish the optimal value of this ratio in each specific case, since its value is not constant and depends on the physical and mechanical properties of the initial product, steam parameters. This circumstance leads to the need to apply methods for searching for regime parameters of granulation. Existing control systems for the granulation process do not implement search control methods, limiting themselves to stabilizing one or more parameters.

The purpose of this work is the implementation of search methods (on a model or directly on an object) that requires the use of a set of technical means of SMART technologies.

Equipment and research methods

Mixed feed granulation technology allows ensure stable uniformity, improve sanitary and hygienic indicators, increase nutritional value, increase shelf life, as well as minimize losses during its transportation and distribution. All this affects both the consumption of compound feed and the performance of animal and poultry rearing. At the same time, the main equipment for the production of mixed feed pellets is a pellet press [1]. The granulator press is rather specific, technological equipment, the design of which has several varieties [3]. The granules leaving the press are cooled in a cooling column to a temperature not exceeding the ambient temperature by more than 10°C, sieved to isolate the product required by its physical and mechanical properties, which is then weighed by portion scales and with the help of transport mechanisms is placed in the warehouse of finished products. The fine fraction (crumb) obtained by sieving the granules is returned for re-granulation. Figure 1 shows the principle of operation of the press-granulator.

Structurally, press-granulators consist of the following main units: feeder, mixer, pressing section, communications for supplying steam and liquid components.

Loose mixed fodder (initial product) in the process of production enters the auger-feeder I, designed for uniform feeding and dosing of the initial product into the press mixer. The rotation speed of the auger is changed using a V-belt variation 2. Under the feeder there is a mixer 3 designed for hydrothermal processing (conditioning) of loose feed with steam or water, as well as enrichment with liquid components (molasses, hydrol, fats, etc.).

The conditioned product is fed into the pressing section 4, where it is pressed through the holes of the rotating annular die 5 with the help of corrugated rolls 6. The pressed product is cut off at the exit from the die by knives fixed on the press casing.

The most widely used in domestic and foreign practice is the "dry" method of granulation, implemented on roller-type presses with a vertically rotating matrix. At the same time, the task of controlling the granulator press as part of SMART technologies is to determine and implement such a ratio of steam and initial product consumption, in which the indicators of the granulation process such as productivity, specific consumption of steam and electricity, as well as the quality properties of the granules would correspond to required values. However, the optimal value of the indicated ratio, for each specific case, differs from each other and cannot be determined a priori, due to the instability of the composition and quality of raw materials, the peculiarities of the technology for preparing loose feed intended for subsequent granulation, a large number of options feed recipes.

According to the most important practical recommendation for conducting the technological process of granulation, it is to provide the required conditions for conditioning with steam, liquid components in accordance with the properties of the initial processed product. At the same time, the hydrothermal treatment of compound feed affects, practically, all indicators of the granulation process and the quality of its final product.

Results and discussion

Considering the press - granulator as a control object in the form of a "black box", it is advisable to highlight the main parameters that affect the granulation process [3]. The input parameters are: the flow rate of the initial product G and the flow rate of steam Q for conditioning. The outputs parameters are taken as - load

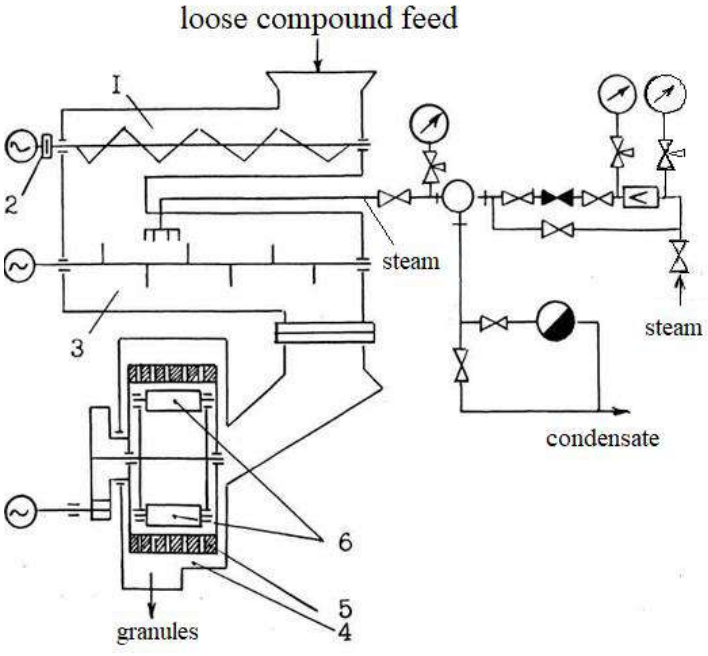

Fig. 1. Schematic diagram of the technological process of granulation of feed:
1 - screw feeder; 2 – feeder rotation speed variation;
3 - mixer; 4 - pressing section: 5 - rotating matrix;
6 - corrugated rolls.

current - Jm of the main drive motor of the press and temperature $\theta_{к-к}$of the conditioned product at the outlet of the press mixer. Disturbing influences that cause changes in the current load of the main drive electric motor of the press are determined by the variability of the physical and mechanical properties of the original product, and disturbances that affect both the conditioning temperature and the current load of the main drive of the press are due to a change in the steam meters of steam, fluctuations in temperature and quality of the original product.

As a result of the experimental studies carried out in production conditions, it was revealed that the analysis of the dependence Pri = f (Q) obtained for various compound feed recipes allows us to conclude that it is possible and expedient to search for the optimal position of the regulating body for supplying steam to the mixer of the granulator press . At the same time, it is necessary that the productivity of the press tend to the maximum depending on the position of the regulating body for supplying steam to the press, and the magnitude of the current load of the main drive motor, which mainly determines the energy intensity of the process, was limited in a given range of values at zeroing of the corresponding compound feed recipe:

$$P_{ri}=f(Q) \qquad \max$$
$$\text{при } J_{1i} < J_i < J_{2i}$$

where: Pri-productivity of the press granulator at development1st compound feed recipe, kg / s;

J_i –`is the value of the current load of the main drive electric motor, which varies in a certain range of values of $J_{1i} < J_i < J_{2i}$ during the development of the i-th compound feed recipe, A;

Q - position of the regulator of steam supply to the press,% r.b.s.

The task of implementing the search for the optimal granulation mode required the solution of two issues: the development of a method for measuring the performance of a granulator press and the choice (development) of an automatic search algorithm.

The formulation of the problem of automatic search for the optimal granulation regime is determined by the presence of factors that ensure the possibility and necessity of this search.

It is known [2] that in order to be able to implement the search, there must be an extreme static dependence between the output parameter of the object and the corrective action; As the results of the research showed, there is such a dependence. We are talking about the dependence of the press productivity on steam consumption at a stabilized current load of the stator of the main drive electric motor of the press.

On the other hand, the need for an automatic search for the optimal granulation mode is confirmed by the fact that this dependence is characterized by an extremum drift, which occurs not only when changing the recipe, but also when developing the same feed recipe.

When considering the issue of measuring the productivity of a press, it should be noted that there are known methods for directly determining the productivity of technological equipment using flow meters. However, the attempts of researchers to use these tools to measure the instantaneous value of the press performance turned out to be unsuccessful, since the low noise immunity did not allow estimating and taking into account the measurement error.

The productivity of the press- granulator can be estimated from the rotational speed G of the feeder. However, when stabilizing the current load J of the main drive electric motor of the press through the channel G - J, it is difficult to obtain reliable performance values under the conditions of existing disturbances.

With automatic control of the granulation process, the performance of the press can be determined by the number of weights (per unit time) of portion scales installed after the granule sifter in the production line. This method has certain advantages, since it allows you to indirectly assess the quality of the produced granules, since only a high-quality product without a fine fraction is sent for weighing, which is returned for re-granulation. However, the technological scheme of the granulation process can be built in such a way that the weighing of the finished product is carried out by one common scale installed for a group of presses. At the same time, the problem arises of determining the productivity of the press in other ways, for example, by the time of filling T_n of the cooling column between the cycles of the unloading device.

The task of the study is to confirm the assumption made about the possibility of measuring the productivity of the press in terms of time Tn, which is spent on filling the working chamber of the cooling column between the next cycles of the unloading device.

A positive solution to this problem depends on the degree of correlation between Tn and the rotational speed G of the press feeder, for which it is necessary to determine the correlation coefficient between these parameters. On the other hand, it is necessary to estimate the relative error in determining the productivity by filling time Tn to obtain the probabilistic characteristics (expectation, dispersion) of this process.

The proposed method for measuring productivity can be used in the development of a control system for the granulation process, the relative error does not exceed 10%. However, the practical application of this method is hampered by the need to determine the current value of the bulk density of granulated feed. In addition, when changing the unloading time of the cooling column (the cycle of operation of the unloading device), which is associated with technological features, it can become significantly more complicated, which will lead to difficulties or impossibility of determining it. In this case, it is proposed to determine the productivity by the number of cycles of operation of the unloading device of the cooling column for a certain fixed operating time of the press.

Conclusion

Thus, based on the foregoing, the following conclusion was drawn - the increment ΔTn of the cooling column filling time between the cycles of the unloading device, which characterizes the performance of the

granulator press, can be used to indirectly evaluate it and be used as an output indicator in the granulation process control system.

The search algorithm for the optimal granulation mode consists of two parts:

- step-by-step start algorithm (system output to the search area);

- search algorithm for the optimal granulation mode,

A feature of this algorithm is the fact that after the control system enters the search zone (regulated zone), after a time equal to the period of the switch, a trial step is made (the search begins). At the same time, it is not known exactly at what point of the static characteristic the system is located. After the end of the trial step, a time delay is provided corresponding to the time of the transient process in the object, and the values of Tn (memorized and steady) are compared. The analysis of the obtained increment ΔTn in this case allows you to determine the need for further execution of a trial step, if the increment value is greater than the value of the dead zone value, or to carry out a working step, i.e. change the position of the steam supply regulator in the direction of increase. Trial steps of the value set for each compound feed recipe are made by changing the position of the steam supply regulator only to decrease, working steps – only to increase. Taking into account the studies carried out, as well as on the basis of the SMART-INDIVIDUAL system, created using SMART technology by specialists of the Scientific and Production Complex "Elevator Equipment Plant" (ZEO), together with employees of the Department of Technological Equipment of Grain Production of the Odessa National Academy of Food Technologies ", it seems it is possible to apply the developed system to control the granulation lines of feed mills.

SMART self-control and reporting technology is an effective technology for setting and formulating goals is inextricably linked with the SCADA system [4] of supervisory control and data collection, which is designed to monitor and supervise a large number of remote objects or one geographically distributed object.

The tasks of SCADA systems include:

- automatic optimization of the operation of technological and transport equipment, including press granulators

- data exchange with USO (devices for communication with the object), that is, with industrial controllers and input - output boards) in real time through drivers;

- processing of information in real time;

- displaying information on the monitor screen in a form understandable to humans;

- maintenance of a real-time database with technological information.

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ОПТИМІЗАЦІЯ РОБОТИ ПРЕСА-ГРАНУЛЯТОРА В СИСТЕМІ SMART ТЕХНОЛОГІЙ

Анотація

Неодноразово перевірено і доведено, що гранульований комбікорм і гранульована манна крупа мають ряд переваг перед сипучими комбікормами, оскільки не відбувається самосортування компонентів, зменшуються втрати при транспортуванні та втрати поживних речовин при зберіганні. Ефективна дія таких комбікормів вища від сипучих кормів на 10-15 % за рахунок підвищення рівня санітарної якості та підвищення засвоюваності поживних речовин. Крім того, при грануляції в комбікорм можна вводити до 3...4% рідких компонентів проти 1...2% для сипучих комбікормів. В даний час спостерігається тенденція до збільшення частки виробництва гранульованих кормів. Технологія гранулювання корму дозволяє забезпечити стабільну однорідність, покращити санітарно-гігієнічні показники, підвищити харчову цінність, збільшити термін зберігання, мінімізувати втрати при його транспортуванні та розподілі. Все це впливає як на споживання комбікорму, так і на продуктивність вирощування тварин і птиці. При цьому основним обладнанням для виробництва гранул для комбікормів є пелетний прес. Завданням управління прес-гранулятором у складі технологій SMART є визначення та впровадження такого співвідношення витрати пари та вихідного продукту, при якому враховуються такі показники процесу гранулювання, як продуктивність, питома витрата пари та електроенергії, а також якісні властивості гранул відповідали б необхідним значенням. Згідно з найважливішою практичною рекомендацією щодо проведення технологічного процесу гранулювання, це забезпечення необхідних умов для кондиціонування парою, рідкими компонентами відповідно до властивостей вихідного продукту обробки. Водночас гідротермічна обробка комбікорму впливає практично на всі показники процесу гранулювання та якість його кінцевого продукту. Аналіз залежності продуктивності від витрати пари, отриманий для

різних рецептур комбікормів, дозволяє зробити висновок про можливість і доцільність пошуку оптимального положення регулюючого органу для подачі пари до змішувача прес-пеллет. При цьому необхідно, щоб продуктивність преса прагнула до максимуму в залежності від положення регулюючого органу подачі пари на прес, а також величини поточного навантаження двигуна головного приводу, що в основному визначає енергоємність процесу, була обмежена в заданому діапазоні значень при обнулінні відповідної рецептури комбікорму: Приріст часу заповнення колони охолодження між циклами розвантажувального пристрою, що характеризує продуктивність преса - гранулятора, може бути використаний для опосередкованої його оцінки та використаний як вихідний показник у системі керування процесом гранулювання. Алгоритм пошуку оптимального режиму грануляції складається з двох частин: алгоритму покрокового запуску (переведення системи в зону пошуку) та алгоритму пошуку оптимального режиму грануляції. Запропоновано використовувати систему SMART-INDIVIDUAL, яка оснащена модулем з регулюванням моніторингу параметрів обладнання за паспортними характеристиками. При цьому система веде архів і контролює терміни обслуговування.

Ключові слова: прес-гранулятор, продуктивність, стабілізація, оптимізація, алгоритм пошуку, технологія SMART.

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FORECASTING GRAIN CARGO HANDLING AT PORT ELEVATORS SOUTH-EASTERN REGION OF UKRAINE

Abstract

The results of a study of the state and possibilities of increasing the capacity of grain transshipment in the ports of Ukraine and substantiation based on the developed trend models of forecast volumes of grain cargo transshipment in Berdyansk and Mariupol seaports of the South-Eastern region of Ukraine until 2025 are presented. The studies established the characteristics of grain cargo flows in the seaports of Ukraine, the SWOT analysis revealed the strengths and weaknesses, advantages and threats of the Mariupol Sea Trade Port, developed trend forecast models for grain transshipment volumes in the ports of the South-Eastern region of Ukraine and substantiated the forecast volumes of transshipment grain cargo until 2025. A rather uneven loading of the Mariupol port during the year is shown. August and all summer months are especially critical, when both industrial and agricultural goods

need to be exported from the nearby region at the same time. The urgent need to increase the capacity of elevators for the ports of Chornomorsk, Reni and Olvia, as well as the ports of the Sea of Azov, in particular, the construction of a new elevator in the port of Mariupol, which is a timely strategic decision, has been substantiated. It was noted that at present most of the country's seaports are expected to increase the transshipment of food cargo of all kinds. To predict the volumes of transshipment of grain cargo at the Berdyansk and Mariupol seaports, based on the analysis of data from the state enterprise "Administration of the Sea Ports of Ukraine", forecast models (trends) are proposed that contribute to the growth of production capacity and competitiveness of agricultural products of the adjacent agro-industrial region. It is shown that the forecast for the next 2-4 years is optimistic – subject to a good grain harvest, the transshipment of grain cargo by 2025 in the Berdyansk and Mariupol ports can reach 2,000 and 1,300 thousand tons, respectively, that is, increase compared to 2021, respectively, 5 and 1.3 times. The conducted SWOT-analysis made it possible to identify and evaluate the factors influencing decision-making on the possibility of developing the Mariupol seaport. On the basis of analytical data, a long-term forecast was made for the further development of the transport and logistics component of the seaports of the South-East region of Ukraine, which will expand and improve port services aimed at increasing its throughput. Among the most important measures is the construction of an elevator in the Mariupol seaport, which will help increase the quality and safe transportation of agricultural products in the chain from the producer to the end consumer. The main measures aimed at increasing the competitiveness of the Mariupol port were identified, including: construction of complexes for transshipment of grain, containers, vegetable oil; dredging, construction of hydrotechnical bank protection structures; reconstruction of berths 2-4 and 14-15 of the port; reconstruction of the nearby railway station Mariupol-Port.

Key words: region, seaport, grain cargoes, innovations. elevator, statistical analysis, trend model, forecast

Formulation of the problem

The development of the agro-industrial complex and, first of all, the grain economy is one of the areas that ensures socio-economic progress and determines the country's food security. According to the level and condition of the grain economy and the grain market, they judge the efficiency of the functioning of the economy of the agro-industrial complex and the reliability of the country's grain forage supply.

In recent years, grain yields in Ukraine have consistently exceeded the optimistic expectations of experts. Increasing volumes have significantly actualized the issue of preserving grain reserves in the country, and domestic agricultural producers have acutely felt a shortage of high-quality storage capacities.

Storage of grain of different crops is an important stage in the implementation of international transportation and transportation of products in the food supply chain from producer to consumer. Therefore, it is necessary to constantly assess the ability of seaports to serve the flow of goods, especially grain, which, under improper storage conditions, can quickly deteriorate.

Literature review

The availability of modern elevator capacities in the seaports of Ukraine for the intermediate storage of grain products that are exported is very important. This allows you to temporarily accumulate the necessary batches of grain and minimize costs in general, which positively affects the export opportunities of ports [1].

According to the Elevatorist.com website [2], certified elevator capacities in Ukraine are about 45–50 million tons. Currently, 65–70% of elevators are morally and physically obsolete and do not meet modern requirements for grain storage, acceptance and shipment efficiency.

Against the backdrop of a record harvest of more than 100 million tons, the shortage of elevators exceeds 50%. According to various estimates for 2021, it is about 30 million tons and will only increase with the growth of yields. Given the trend of the last five years to an increase in modern elevator capacities of about 1.5 million tons per year, the trend towards an increase in grain storage capacities will continue in the next 3–5 years [2]. It is easy to calculate that with a projected grain harvest of 100 million tons in 2022 and beyond, this deficit will only increase.

In addition to the construction of new transshipment complexes, a very interesting alternative is the transshipment of grain crops into containers in polypropylene liners (liner-runs), which protect the cargo from contact with the container and protect the container from contact with the cargo. The absence of the need for additional transshipment (transshipment) of these cargoes simplifies loading and unloading operations and significantly expands the geography of deliveries [3].

It is known that the development of seaports with the deregulation of cargo transportation is a big problem. In this direction, studies have already been carried out in order to increase the efficiency of the functioning of the transport and technological system of the seaport serving the industrially agrarian East Ukrainian region [4]. A number of projects for the development of Ukrainian ports have been developed, which embody scientific approaches to the design and development of domestic port facilities [5], taking into account all the requirements of regulatory and technical documentation and methodological literature [6, 7].

The general decline, which was observed due to the stagnation of the Ukrainian economy over the past 5-7 years, is almost over, and at present, an increase in the transshipment of food cargo of all types is expected in most of the country's seaports. This general trend can be described by a predictive model – a trend, that is, a certain equation based on the statistical processing of a relatively small amount of data. Extrapolation by trends can also be used as the initial stage of a complex forecasting technique that answers questions about the consequences of continuing the previous development trend [8].

To compile a trend model, you need to select a trend function, find its characteristics, check the adequacy and accuracy. For trends that describe changes in indicators over time (dynamics), polynomial, exponential and S-shaped types of equations are most often used. The resulting adequate trend model is further used for point and interval forecasts [8, 9]. Regarding polynomial trends, there are mutually accurate recommendations – from the use of polynomials not higher than degree 3 [8, 10] to the use of polynomials of degree 6 [9]. Thus, for the possibility of objective forecasting, it is necessary to carry out a certain analysis of the choice of the corre-

sponding trend equations.

In recent decades, Ukraine has confidently entered the top five world grain exporters, which allows our state to steadily replenish its gold and foreign exchange earnings [11]. These achievements would not have been possible without the proper development and well-functioning of seaports. Their further development is a strategic task that requires deepening research to find reserves to improve the efficiency of seaports for grain transshipment, in particular, the promising South-Eastern region of Ukraine. The above determined the purpose and objectives of our research.

The purpose of the research was to study the state and possibilities of increasing the capacity of grain transshipment in the ports of Ukraine and substantiate, on the basis of the developed trend models, the forecast volumes of grain cargo transshipment in Berdyansk and Mariupol seaports of the South-Eastern region of Ukraine until 2025.

According to the objectives of the research, it was to establish the characteristics of grain cargo flows in the seaports of Ukraine, to identify the strengths and weaknesses, advantages and threats of the Mariupol Sea Port, to develop trend forecast models of grain transshipment volumes in the ports of the South-Eastern region of Ukraine and to substantiate the forecast volumes of grain cargo transshipment to them up to 2025.

Materials and methods of research

The research materials were statistical data on the performance of the ports of Ukraine for 2015-2021 for the transshipment of all types of cargo and, in particular, grain cargo. The work used graphic-analytical and statistical methods of research, mathematical description, modeling and evaluation of the results of the analysis.

In the tasks of approximating observational data (volumes of grain transshipment) and compiling trend mathematical models (equations), the MS Excel 2007 environment was used, in particular its procedure "Search for a solution" (Excel Solver), by which the empirical coefficients in the equations were determined by the least squares method (LSM) trends models.

The adequacy of the obtained trend models and their suitability for forecasting the volumes of grain transshipment was carried out according to a simplified method [10], which provides for their assessment according to statistical criteria:

– the index (coefficient) of determination R^2 and the correlation coefficient r_{xy}, showing the tightness of the time series of observational data with the trend curve on the Chaddock scale;

– the autocorrelation coefficient of M. Ezekiel and K. Fox r_{ai} and the Durbin-Watson D-test DW, which allow assessing the absence of autocorrelation of residuals;

– the average relative approximation error A, which gives an estimate of the accuracy of the forecast.

To detect autocorrelation of residuals based on the Durbin-Watson D-test, such an algorithm was used. The formulas given in [10] were used to calculate the values of the autocorrelation coefficient r_{xy} and the D-criterion DW. Further, according to special tables [12], for a given number of observations n, the number of independent variables of the model m and significance level α=0.05, the critical values of the D-criterion were determined – its lower d_1 and upper limit d_2.

When the condition DW > d2 is met, it is concluded that there is no autocorrelation of residuals (in case of negative autocorrelation of residuals, not DW, but 4–DW is compared with tabular values). The closer the actual value of the Durbin-Watson criterion to 2, the greater the confidence in the absence of autocorrelation in the residuals and the possibility of using the found trend in forecasting.

Results and discussion.

Characteristics of grain cargo flows. The volumes of cargo transshipment passing through the Mariupol port over the past 7 years, plotted according to [13] as a percentage, are given in table 1 and table 2.

According to table 1 and table 2, it is obvious that the loading of the Mariupol port during the year is rather uneven. August and all summer months are especially critical, when both industrial and agricultural goods must be exported from the nearby region at the same time. Therefore, in order to meet the growing demand for the export of grain cargo through the logistics system of the industrial and agrarian region of Eastern Ukraine, it is proposed to build a new elevator on the territory of the Mariupol Commercial Sea Port with a total capacity of up to 2 million tons of grain per year. The construction of an elevator in the port will help reduce the queues for idle transport for unloading grain, to a greater extent in the summer.

Table 1 – Results of the total transshipment of all types of cargo through the port of Mariupol, %

Year	Month											
	Jan	Feb	March	April	May	June	July	August	Sept	Octob	Nov	Decem
2015	64.44	66.58	88.03	74.30	89.40	68.37	83.73	87.63	86.95	**100.00**	42.93	48.39
2016	46.58	37.40	47.21	57.31	72.48	85.69	94.59	**100.00**	86.26	77.16	70.58	53.08
2017	41.02	47.02	55.72	65.71	**100.00**	78.18	82.06	33.99	46.52	93.28	62.94	69.33
2018	77.24	60.53	88.16	81.84	87.49	**100.00**	96.26	81.18	85.48	91.13	64.71	83.57
2019	43.41	49.11	71.98	51.14	66.62	46.43	69.70	**100.00**	95.44	91.58	65.95	89.38
2020	72.35	74.34	70.56	73.17	62.48	71.01	87.38	**100.00**	89.39	71.70	80.88	69.45
2021	72.80	80.91	73.59	90.95	84.62	63.59	63.44	92.13	**100.00**	76.79	77.86	78.00

Table 2 – The results of the total transshipment of grain cargo through the port of Mariupol, %

Year	Month											
	Jan	Feb	March	April	May	June	July	August	Sept	Octob	Nov	Decem
2015	50.13	7.90	20.73	28.95	22.37	0.00	25.84	**100.00**	78.50	69.86	30,89	83.37
2016	17.74	19.81	43.42	43.87	56.65	39.10	67.55	**100.00**	56.45	48.31	47.15	61.13
2017	28.00	47.80	38.09	21.27	31.72	16.62	39.49	**100.00**	45.10	37.94	23.25	61.78
2018	34.88	56.56	**100.00**	54.10	50.82	12.57	93.33	84.56	82.38	49.04	49.45	86.72
2019	31.90	27.14	30.76	23.48	30.76	5.89	50.33	**100.00**	76.92	68.45	60.84	55.37
2020	31.37	28.34	52.66	48.61	27.62	8.96	61.76	**100.00**	51.22	34.38	25.68	16.38
2021	27.29	31.01	22.45	37.63	33.33	37.74	46.60	**100.00**	73.42	74.94	33.67	54.21

The particles of each seaport of Ukraine as a percentage of the total volume of transshipment of grain cargo for 2021 are shown in fig. 1. It can be seen that the main ports reloading more grain cargo in Ukraine are the ports of Chornomorsk, Mykolaiv, Yuzhny and Odesa. The ports of Mariupol and Berdyansk, although they are not competitors of these powerful ports, play an extremely important role in servicing the nearby region of South-Eastern Ukraine. On the part of agricultural enterprises, there is a certain demand for the services of these ports, which makes it possible to optimize transport and logistics costs in the overall supply chain.

On fig. 2 shows how the shares of grain cargoes have changed in the seaports of Ukraine over the past 7 years as a percentage of the total volume of transshipped cargo.

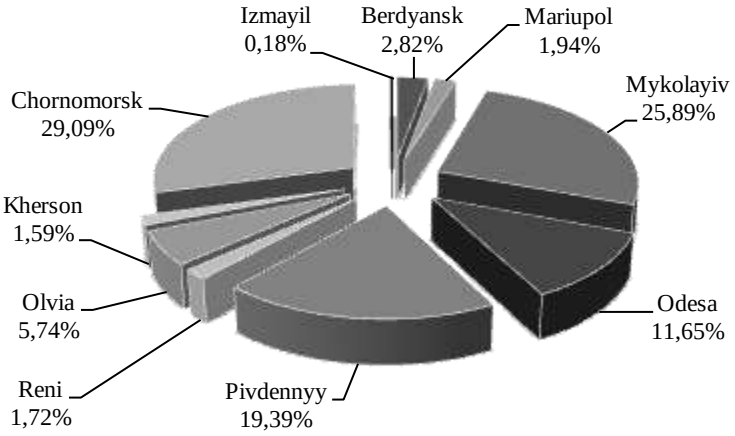

Fig. 1. Shares of Ukrainian seaports in total volume of grain cargo transshipment in 2021

Over the past 7 years, the share of grain cargo in the total volume of transshipped cargo has increased significantly in the ports of Berdyansk (by 64.5%), Reni (35.8%), Chornomorsk (by 27.4%) and Olvia (by 20.5%) . and grew in the ports of Mariupol (by 9.3%), Kherson (by 7.2%) and Mykolaiv (by 3.9%). Against the backdrop of a drop in the flow of grain cargo in the ports of Izmail (by 1.1%), Yuzhny (by 2.0%) and Odesa (by 7.9%) over 7 years, it was possible to increase this flow of cargo by 6.7%. At the same time, the ports located on the Sea of Azov increased the grain cargo traffic by 17.4%.

The presented analysis shows that there is an urgent need to increase the capacity of elevators for the ports of the Sea of Azov, as well as for the ports of Chornomorsk, Reni and Olvia. Therefore, investment development and construction of a new elevator in the port of Mariupol is a reasonable and timely strategic decision.

Forecasting the size of transshipment of grain cargo in seaports. To assess the change in the flow of grain cargo passing through the seaports of Ukraine, according to [13], we present in graphical form information on the transshipment of this type of cargo in ports over the past 7 years (Fig. 3).

It is clearly seen that two groups of seaports can be divided in terms of grain transshipment volumes – with large volumes in the range of 5–16 million tons per year (Mykolaiv, Chornomorsk, Yuzhny and Odesa) and significantly more than 3,000 thousand tons (all the rest 6 ports are indicated in figure 3). There is also a large variability in grain transshipment volumes over the years. For example, we can note the increase in the volume of grain transshipment in Chornomorsk from 5 to 15 million tons, that is, three times.

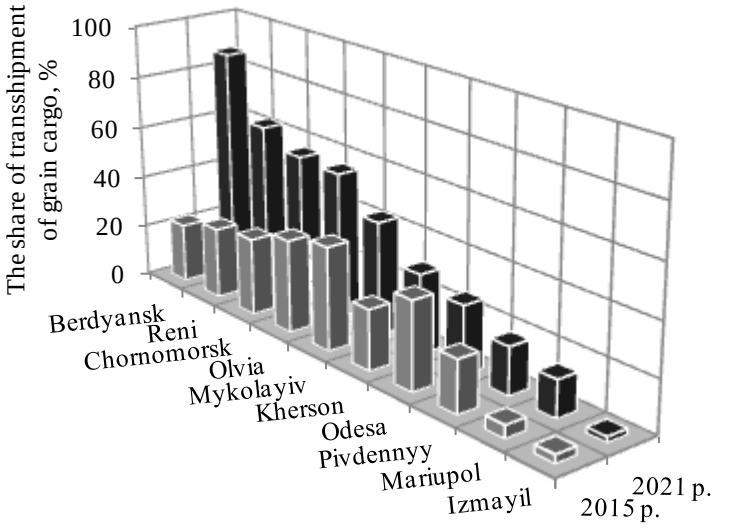

Fig. 2. Shares of grain cargoes of seaports of Ukraine in the total volume of transshipped cargoes in 2015 and 2021

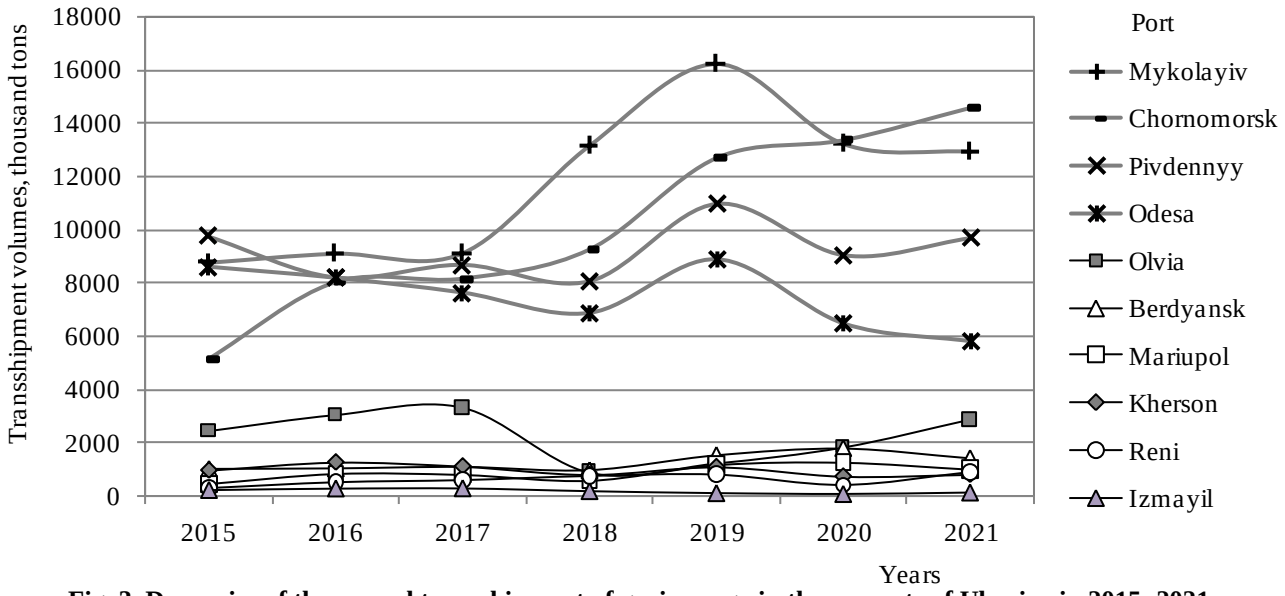

Fig. 3. Dynamics of the annual transshipment of grain cargo in the seaports of Ukraine in 2015–2021

To predict the volumes of grain transshipment in seaports, it is necessary to develop mathematical models (trend equations) that accurately approximated the observational (reporting) data and could give close to real medium-term forecast values of grain transshipment volumes for the next few years. Due to the presence of a significant number of different types of equations that can be used as mathematical models (trend equations), we analyzed all standard types of trend one-factor equations provided in MS Excel.

Such an analysis of the MS Excel approximation (trend) lines, carried out for two ports of the Sea of Azov (Mariupol and Berdyansk), showed that linear equations give determination coefficients of 0.56–0.59, in exponential equations the determination indices (coefficients) are 0.55–0.61, for logarithmic – 0.56–0.59, which are considered low. Polynomial types of equations (trends) have higher indices (coefficients) of determination: from 0.59 (a second-degree polinom) to 0.94–1.00 (for 4th–6th degrees of polynomials). However, despite the much greater accuracy of describing the volumes of grain transshipment by polynomial trends within the studied years 2015–2021, forecasts for them for the next few years give completely unrealistic results – either negative or too large values. So, for example, the forecast for the port of Mariupol for 2023 according to the 6th degree polynomial gives an increase in grain transshipment volumes by 75 times compared to 2021, which is nonsense.

Subsequent analysis of other types of equations showed that the modified exponential equation [8] can be used as temporary trend models

$$\tilde{y} = k + a\exp(-bx), \qquad (1)$$

where $\tilde{y}$ – estimated value of grain transshipment, thousand tons;

k, a, b – are empirical coefficients determined by the least squares method;

x – the time factor (year).

The coefficients k, a, b in the proposed modified exponential equation have a certain geometric content. Thus, the graph of function (1) as $\tau\to\infty$ approaches the horizontal asymptote $y = k$. Most often, equations are used as trends when $a<0$ (i.e., the asymptote is located above the trend curve), and $b<1$ (i.e., when the increments in y are constant and decrease with increasing τ).

As practice shows, the use of the numerical value of the year as a time factor in trend time series can lead to significant discrepancies between the observational data and the data predicted by the obtained equation. This is due to the significant remoteness of the current values of years in relation to the initial ("zero") reference point of the time factor (years). Therefore, instead of years, it is more expedient to take the ordinal numbers of the time scale (series of years) as a time factor. Using this approach and reporting (observational) data on annual volumes of grain cargo transshipment in 2015–2021 [13], we obtained trend equations describing the generalized nature of deregulation changes in annual grain flows in the ports of Berdyansk and Mariupol:

– for Berdyansk

$$\tilde{y} = 1388{,}89 - 1085{,}48\exp(0{,}188849x),\ R^2=0{,}589; \qquad (2)$$

– for Mariupol

$$\tilde{y} = 25551{,}3 - 24758{,}9\exp(0{,}00471517x),\ R^2=0{,}573, \qquad (3)$$

where x – serial number of the year (2015 year – 1; 2016 year – 2 etc).

R^2 – index (coefficient) of determination.

The numerical values of the empirical coefficients of the trend equations were determined by the least squares method using the procedure “Search for solutions”.

The assessment of the adequacy of the obtained trend models and their suitability for forecasting the volumes of grain transshipment was carried out according to the above simplified method [10], for which the following statistical criteria were calculated:

– correlation coefficient r_{xy} to estimate the tightness of a series of observed data with a trend curve;

– autocorrelation coefficient of M. Ezekiel and K. Fox r_{ai} and D-test of Durbin-Watson DW to assess the absence of autocorrelation of residuals;

– the average relative approximation error A for estimating the accuracy of the forecast.

Using the formulas given in the sources [10, 8],

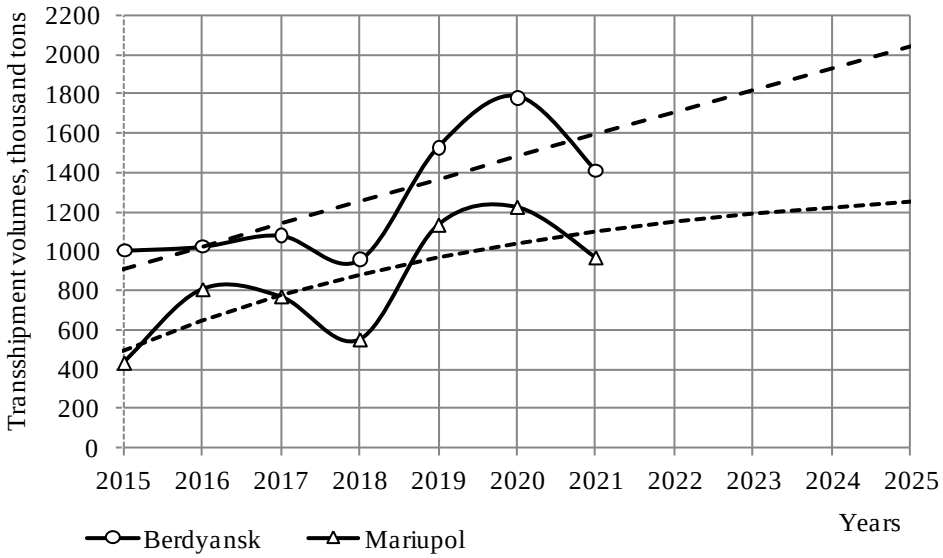

Fig. 4. Trend models for the forecast of transshipment of grain cargo in the seaports of the Sea of Azov for the period 2015-2025

the following values of the necessary statistical criteria were obtained:

– for Berdyansk

r_{xy} = 0,77; r_{ai} = –0,147; DW = 2,126; A = 12,54%;

– for Mariupol

r_{xy} = 0,76; r_{ai} = –0,263; DW = 2,432; A = 19,44%.

An analysis of these data showed that for both ports, the annual volumes of grain transshipment and serial numbers of the considered 2015–2021 years have correlations within 0.76–0.77, which is estimated as a high level according to the Chaddock scale [10] (0.7–0.9) and allows you to use trend models for forecasts.

The low values of the autocorrelation coefficients r_{ai} indicate the possibility of using trend equations for forecasts. However, the final conclusion was given by a comparison of the Durbin-Watson DW criteria with their critical limits d_1 and d_2, determined from the table [12] for the number of observations n=7, the number of independent variables in the model m=1 and the accepted significance level α=0.05. For these characteristics, the critical values of the D-criterion are – the lower limit d_1=0.700, the upper limit d_2=1.356. Considering that the autocorrelation coefficients r_{ai} have a minus sign, according to [10], the following relations can be written:

– for Berdyansk

DW = 4–2,126 = 1,874 > d_2 = 1,356;

– for Mariupol

DW = 4–2,432 = 1,568 > d_2 = 1,356,

which indicate the absence of autocorrelation of residues.

Average relative approximation errors equal to 12.54–19.44% do not exceed the recommended [10] allowable limits of 10–20%.

Thus, according to the set of requirements, confirmed by the corresponding statistical characteristics, the trend models obtained by us can be used for point and interval forecasts.

Using the obtained adequate equations (2)–(3), graphs of changes in the annual volumes of transshipment of grain cargo and trend lines were constructed, which are generalized and give an idea of the indicative medium-term forecast values for the period 2022–2025 (Fig. 4).

From the data analysis of fig. 4, we can conclude that the trends in the transshipment of grain cargo in the ports of the Azov Sea of Ukraine are now in the process of growth. The medium-term forecast for the next 2–4 years is optimistic – given a good grain harvest, which will grow in these seasons, the transshipment of grain cargo by 2025 in the ports of Berdyansk and Mariupol can reach about 2,000 and 1,300 thousand tons, respectively, i.e. year by 1.5 and 1.3 times.

Table 3 – SWOT analysis of the Mariupol seaport as of 2021

	STRENGTHS	**WEAK SIDES**
Internal environment	– Proximity to large places of localization of the production of ferrous metals – directly within the city, next to the port, there are powerful metallurgical enterprises of Ukraine – MMK im. Ilyich and MK "Azov-stal". – Proximity to large places of localization of coal mining, clay. – Versatility of berths. – Quality and speed of customer cargo handling.	– Small depths of the approach sea channel; – Limited capacity of the transport infrastructure (railways and railway station, highways). – Lack of specialized transshipment facilities for grain and bulk (oil) cargo. – The possibility of expanding the territory of the port through close proximity to the residential areas of the city and the recreational zone is limited.
	OPPORTUNITIES	**THREATS**
External environment	– Expansion of additional volumes of processing grain and sunflower oil. – Use of a very favorable geographical location of the port for the export and transit direction of goods. – Renewal of technological equipment and application of new technologies.	– Since 2014, there has been a difficult political and economic situation in the South-Eastern region of Ukraine, where the port is located. – Slowdown in the economic development of the region. – Decrease in demand for metallurgical products in the world markets.

Fig. 5. Modern silos of the grain terminal of the Mariupol Sea Port [16]

SWOT-analysis of the Mariupol seaport.

Even under the most pessimistic scenario of the development of events, the news about the construction of new elevator capacities will encourage producers to increase the sowing of grain crops and increase their export.

The analysis of the data of the map of elevators of the South-East region, including port ones, given in the source [14], showed that the capacities of the elevators existing in this region (Mariupol 20, Zaporiyia 21, Berdyansk 12, etc.) are still not enough to meet all the needs of grain producers and grain traders, especially the Mariupol seaport. This can be seen from the SWOT analysis of the Mariupol seaport.

When comparing the ports of the South-Eastern region of Ukraine with the most competitive ports of the Black and Azov Seas, it can be summarized that the Mariupol port has the following weaknesses:

– small depth of approach channels;

– high wear of hydraulic structures and berths;

– high wear and tear of the port fleet, crane equipment and other technological equipment;

– limited warehouse space;

– limited capacity of the transport infrastructure (roads, railways and railway station).

Outdated technological equipment reduces the efficiency of loading and unloading cargo, and also increases the risk of accidents. Of the 60 portal cranes available in the Mariupol port, 30 of them are older than 30 years, 16 cranes are older than 20 years. More than 40% of forklifts are operated beyond the standard period.

To mitigate these risks, separate technological lanes are being built in the Mariupol port for new and the introduction of obsolete (subrogation) equipment.

The final SWOT analysis of the Mariupol seaport is given in Table. 3.

The main measures aimed at increasing the competitiveness of the Mariupol port should be: construction of complexes for transshipment of grain, containers, vegetable oil; dredging, construction of hydrotechnical bank protection structures; reconstruction of port berths No. 2-4, 14-15; as well as the reconstruction of the nearby railway station Mariupol-Port. The said works on modernization of transshipment of grain cargoes are already underway. Thus, according to [15], the construction of a modern grain terminal continues in the Mariupol Commercial Sea Port, the decision to build which was made back in 2016 [16]. But due to a number of objective reasons, the deadlines for implementation were delayed. At present, the project is more than 60% completed and the modern grain transshipment complex (Fig. 5) is scheduled to be completed in March 2022.

Conclusions

1. A fairly uneven loading of the Mariupol port during the year has been shown. August and all summer months are especially critical, when both industrial and agricultural goods need to be exported from the nearby region at the same time. The urgent need to increase the capacity of elevators, the ports of Chornomorsk, Reni and Olvia, as well as the ports of the Sea of Azov, in particular, the construction of a new elevator in the port of Mariupol, which is a timely strategic decision, has been substantiated.

2. It is shown that at present most of the seaports of the country are expected to increase the transshipment of food cargo of all kinds. To predict the volumes of grain cargo transshipment at the Berdyansk and Mariupol seaports, based on the analysis of data from the state enterprise "Administration of the Sea Ports of Ukraine", forecast models (trends) are proposed that will contribute to the growth of production capacities and competitiveness of agricultural products of the adjacent agro-industrial region. It is shown that the forecast for the next 2–4 years is optimistic – subject to a good grain harvest, the transshipment of grain cargo by 2025 in the Berdyansk and Mariupol ports can reach 2,000 and 1,300 thousand tons, respectively, that is, increase compared to 2021, respectively, 5 and 1.3 times.

3. The conducted SWOT-analysis made it possible to identify and evaluate all the factors influencing decision-making on the possibility of developing the Mariupol seaport. On the basis of analytical data, a long-term forecast was made for the further development of the transport and logistics component of the seaports of the South-East region of Ukraine, which will expand and improve port services aimed at increasing its throughput. Among the most important measures is the construction of an elevator in the Mariupol seaport, which will help

increase the quality and safe transportation of agricultural products in the chain from the producer to the end consumer.

4. The main measures aimed at increasing the competitiveness of the Mariupol port were identified, including: construction of complexes for transshipment of grain, containers, vegetable oil; dredging, construction of hydrotechnical bank protection structures; reconstruction of port berths No. 2-4, 14-15; as well as the reconstruction of the nearby railway station Mariupol-Port.

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ПРОГНОЗУВАННЯ ПЕРЕВАЛКИ ЗЕРНОВИХ ВАНТАЖІВ НА ПОРТОВИХ ЕЛЕВАТОРАХ ПІВДЕННО-СХІДНОГО РЕГІОНУ УКРАЇНИ

Анотація

Наведено результати дослідження стану та можливостей збільшення потужностей перевалки зерна у портах України та обґрунтування на основі розроблених трендових моделей прогнозних обсягів перевалки зернових вантажів у Бердянському та Маріупольському морських портах Південно-Східного регіону України до 2025 року. У дослідженнях встановлено характеристик потоків зернових вантажів у морських портах України, у SWOT-аналізі виявлено сильні та слабкі сторони, переваги та загроза Маріупольського морського торгівельного порту, розроблено трендові прогнозні моделі обсягів перевалки зерна у портах Південно-Східного регіону України та обґрунтовано прогнозні обсяги перевалки на них зернових вантажів до 2025 року. Показано досить нерівномірне завантаження Маріупольського порту протягом року. Особливо критичними є серпень і всі літні місяці, коли з прилеглого регіону одночасно потрібно вивозити і промислові і аграрні вантажі. Обґрунтована нагальна потреба в нарощуванні потужностей елеваторів для портів Чорноморськ, Рені і Ольвія, також портів Азовського моря, зокрема будівництва нового елеватору в порту Маріуполь, що є своєчасним стратегічним рішенням. Відмічено, що наразі у більшості морських портів країни очікується зростання перевалки харчових вантажів всіх видів. Для прогнозування обсягів перевалки зернових вантажів на Бердянському та Маріупольському морському портів, основі аналізу даних державного підприємства «Адміністрація морсь-

ких портів України» запропоновані прогнозні моделі (тренди), які сприятимуть зростанню виробничих потужностей та конкурентоздатності сільськогосподарської продукції прилеглого агропромислового регіону. Показано, що прогноз на найближчі 2-4 роки є оптимістичним – за умов хорошого врожаю зернових, перевалка зернових вантажів до 2025 року у Бердянському та Маріупольському портах може досягти відповідно 2000 та 1300 тис. тонн, тобто зрости порівняно з 2021 роком відповідно у 1,5 та 1,3 рази. Проведений SWOT-аналіз дозволив виділити та оцінити чинники, що впливають на прийняття рішень з можливості розвитку Маріупольського морського порту. На основі аналітичних даних складено перспективний прогноз подальшого розвитку транспортно-логістичної складової морських портів Південно-Східного регіону України, що дозволить розширити та поліпшити послуги порту, спрямовані на підвищення його пропускної спроможності. Серед найбільш важливих заходів є будівництво елеватору в Маріупольському морському порту, що сприятиме збільшенню якісного та безпечного транспортування аграрної продукції в ланцюгу від виробника до кінцевого споживача. Визначено основні заходи, спрямовані на підвищення конкурентоспроможності Маріупольського порту, серед яких: будівництво комплексів з перевалювання зерна, контейнерів, олії; днопоглиблювальні роботи, будівництво гідротехнічних берегозахисних споруд; реконструкція 2-4 та 14-15 причалів порту; реконструкція прилеглої залізничної станції Маріуполь-Порт.

Ключові слова: регіон, морський порт, зернові вантажі, інновації. елеватор, статистичний аналіз, трендова модель, прогноз.

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INFLUENCE OF GRAIN QUALITY INDICATORS ON THE FLOUR QUALITY INDICATORS AT THE LABORATORY MILLING

Abstract

In the conditions of high competition in the flour market, the development of models that allow to predict the quantitative and qualitative indicators of flour during grain milling and to understand the correlation between grain and flour quality indicators is extremely relevant and requires efforts in this direction. 64 samples of wheat grain from mills situated in different regions of Ukraine, grown in 2019 and 2020 and straight flour obtained from this wheat in the laboratory at the mill MLU-202 were investigated. The data obtained confirmed great variability of grain and flour quality indicators which can depends on many factors: from agro-climatic condition and variety features to milling flow diagram and tempering conditions before milling. Wheat quality indicators are shown next results: test weight values ranged from 727 to 845 g/l, vitreousness – from 25 to 83%, initial moisture content – from 10.4 to 13.7%, protein content – from 11.3 to 17.2%, ash content – from 1.35 to 1.73%, gluten content – from 17.6 to 38.3%, gluten deformation index – from 46 to 96 units and Falling Number – from 309 to 500 seconds. Analyzing of correlations between grain quality indicators and flour quality indicators shown: the direct extra high correlation between grain protein content and flour protein content (r=0.95) and also between grain gluten content and flour gluten content (r=0.87); average correlation between ash content of grain and ash content of flour (r=0.68). According to milling properties was found: average correlation of initial grain moisture content and flour yield (r=0.52), a direct high correlation between grain vitreousness and the ratio of reduction and break flour (r=0.70), and an inverse average correlation of test weight with ratio of break and reduction bran (r=–0.61). It has been established that the flour strength W is affected by a set of grain quality indicators: grain protein content with high coefficient correlation (r=0.70), grain gluten content and grain Falling Number with average correlation coefficients – r=0.53 and r=0.56, respectively. For other rheological indicators, such as stability, water absorption capacity and P/L, no high correlation coefficients were found, since their values depend on a complex of various indicators of grain. The obtained correlations can be used to improve the efficiency of grain blending before milling, to substantiate the modes of tempering, grinding, and flour mixing stage in existing mills, as well as to design a milling flow diagram for new mills.

Keywords: wheat, grain, flour, laboratory milling, test weight, vitreousness, protein content, quality indicators

Introduction

Milling of wheat is a physical or mechanical process of separating the peripheral parts of the grain (shells and germ) from the internal endosperm and turning the latter into flour. Complete separation is never achieved, but when milling due to special methods of preparation and milling, try to achieve the greatest possible release of endosperm into flour – to carry out the so-called "selective grinding" [1].

The most important factor that determines the consumer properties of flour is the quality of grain, which is determined by the chemical composition and technological properties. The concept of "quality" is an integrated indicator that evaluates the physical, biochemical and flour-milling properties of grain, as well as the baking properties of flour obtained from it. In the technology of flour-milling production, "high-quality" grain is understood as the grain from which the maximum yield of grade flours with high whiteness, low-ash, high-gluten, high-elasticity and stretchable flour is obtained, which allows to obtain the best quality bread [2].

The quality of wheat depends on a complex number of factors that depend on how it grows, grinds and adapts to end use in any of the many products. Wheat

is the main raw material, which has changes in composition and usefulness depending on the variety and growing conditions in a particular geographical location during the year of its growth and production. Complex and diverse processing methods and a variety of products made from wheat have created significant requirements for wheat, which has specific quality characteristics and nutritional value [3].

When choosing grain before milling and forming a milling batch by blending of grain of different quality, the question often arises as to how well it is possible to predict the real commercial quality of processing of this grain and what quality indicators of finished products could be. This can be done by laboratory milling of a small amount of grain, considering how different laboratory milling flour will be from flour obtained in industrial conditions.

Literary review

One of the most common and simplest criteria for wheat quality is test weight and 1000 kernel weight. These indicators have influence on the potential yield of flour because larger grains usually have a higher ratio of endosperm to peripheral parts.

The test weight and 1000 kernel weight depend on the differences in the genetic makeup of wheat variety, growing location, different growing and environmental conditions prevailed during growing periods of wheat in each region [4, 5], using an artificial irrigation [6], particularly high temperature during the final phase of grain filling [7]. Ultimately, high values of test weight and 1000 kernel weight are determined by the wheat grain size and shape of individual grains [8], surface condition, grain density, which, in turn, is determined by the biological structure of the grain, its chemical composition [9]. The grain is rounded, even in size, denser in consistency, has a higher test weight and 1000 kernel weight, and they have affected end-use quality and market price [10].

Some authors considered, that the 1000 kernel weight may been used as an good parameter of wheat milling value [10]. Some authors have the opinion that 1000 kernel weight affects the milling properties only in the case of very low or very high value. [11]. Other considered, that 1000 kernel weight is strongly heritable in wheat and 1000 kernel weight as an index of milling value should be used only for the same wheat varieties, but cultivated under different agro-environmental conditions [12].

Agro-environmental conditions are also a determining factor of the initial moisture content of wheat grains after harvesting, in the future this indicator may vary depending on storage conditions due to the hygroscopic properties of the grain [4, 13].

The main indicator of quality, which determines the type of flour, is the ash content. This indicator in grain is influenced by various factors such as wheat variety, geographical location, crop years. Interactions among these factors determine flour ash content, flour color value and flour extraction yield [14, 15]. At the same time, the ash content of flour is a very variable indicator due to the large differentiation of the ash content of the endosperm [16].

The next important criteria of grain quality are hardness and vitreousness. Grain hardness is arguably the most important single determinant of wheat grain quality and utilization, it forms the basis of differentiating world trade of wheat grain [17]. The hardness of wheat determines the grain milling properties and the end use of its processed products [18]. Hard wheat varieties have higher protein content than soft ones. Hard wheat has a compact homogeneous structure of the endosperm with predominantly small starch granules firmly linked to the surrounding protein matrix.

Vitreousness is natural kernel translucence and a means of describing the appearance of wheat grains [19]. Vitreous kernels have a dark, translucent, glassy appearance, as opposed to mealy kernels which have a light, opaque appearance. Usually vitreous kernels are harder and have higher protein content that mealy kernels, but hard wheat kernels may look like non-vitreous, and, conversely, yellow-sided grains with viscous endosperm after soaking, when visually inspected, look like vitreous grains – the so-called false vitreousness [20]. Hard and generally vitreous grains are more difficult to grind during milling with increased energy per mill, requiring more grinding systems [21].

The protein content is closely related to grain hardness – it is a very important quality indicator for bread-making quality and end-use of flour [5]. Protein content is inversely proportional to grain yield [9], directly proportional to the amount of nitrogen fertilization [22], while the protein quality is determined primarily by the wheat genotype [23]. On the other hand, both indicators – the quality and the protein content are affected by the climatic conditions during wheat maturation [24].

The main feature of wheat proteins is the ability of those proteins to form viscoelastic networks, i.e. gluten [25]. The gluten proteins have very low extractabilities in water or salt solutions and consist of gliadins (extractable in aqueous ethanol) and glutenins (unextractable in aqueous ethanol). Gliadins are a heterogeneous polypeptide mixture, while glutenins consist of peptide polymers connected by di-sulphide bonds [26]. Gluten is responsible for physical dough properties. It has been generally accepted that any increase in total protein content of the flour results in an increase in the gluten content, increase the strength of flour and the bread volume [27]. The quality of gluten is a genetically determined trait, but growing conditions also have a strong influence on it. In this case, the most important factors are temperature and humidity, especially in the grain filling period [28], as well as the provision of plants with nitrogen [29].

Precipitation during harvest period has an impact on the quality indicator such as Falling Number [30]. Low Falling Number in wheat grain means high α-amylase activity, which causes poorer wheat quality [31]. But for Ukraine in past seasons the opposite situation is typical, due to an increase in average annual temperatures, especially in summer, and a small amount of precipitation, the grain has a low amylolytic activity [32].

To ensure the required quality of flour, when processing wheat at flour mills, the principle of forming a milling batch before milling is used, which is based on blending grain with known indicators and predicting flour quality indicators after processing [32].

Full understanding of the features of the change in the quality indicators of grain in modern conditions under the influence of changeable agro-climatic factors, as well as the prediction of the flour-milling properties of grain and dough properties of flour, is an urgent and important practical task [33, 34].

Purpose and objectives of the analysis

The purpose of this work was to establish the relationship between grain quality indicators and laboratory milling indicators, flour quality indicators and indicators of physical properties of the dough. For this purpose, the following objectives were achieved:

– determining the indicators of grain quality and the establishment of a correlation between themselves;

– determining the milling properties, indicators of flour quality and indicators of the physical properties of the dough and establishment a correlation relationship between themselves;

– establishing a correlation relationship between indicators of grain quality and milling properties, indicators of flour quality and physical properties of the dough.

Materials and methods

Samples. 64 samples of wheat grain from mill plants situated in different regions of Ukraine, grown in 2019 and 2020, and straight flour obtained from this wheat in the laboratory at the mill MLU-202.

Grain tempering. The grain was tempered according to AACC 26-10A for 16-18 hours (depending on the sample vitreousness) before milling to permit uniform distribution of the moisture. Tempering (Water–thermal processing stage) of the hard type wheat grain with vitreousness >60% was carried out with moistening to 16.0% within 18 hours, while wheat with vitreousness <40 % was tempered within 16 hours to 16.0% tempering moisture.

The required water quantity to raise the moisture content of grain to 16.0% was calculated using following equation:

$$\text{Amount of water} = \text{grain weight} \cdot \left[\frac{\text{grain tempering moisture} - \text{grain moisture}}{100 - \text{grain tempering moisture}}\right] \quad (1)$$

Before milling moisture content of grain was controlled by AquaMatic 5200-A and if moisture content was less required value, the grain was additionally moistened. The amount of water was calculated according to formula 1.

Experimental milling.

Buhler MLU-202 mill (Buhler Industries, Uzwil, Switzerland) was used to mill the wheat samples according to AACC International Approved Method 26-21.02, and the flour extraction was determined as the percentage of straight-grade flour produced on a product basis. A 10xxx polyamide screen (132 μm) was used for obtains flour. With a standard procedure, as a result of grinding, you get:

– break flour – from three break systems on which corrugated rolls are installed;

– reduction flour – from three reduction systems on which smooth rolls are installed;

– break bran (large);

– reduction bran (small).

The total flour yield was determined as the sum of all 6 flour streams (B1, B2, B3, C1, C2, C3) relative to the mass of grain taken for milling (weight of grain was 3 kg).

To evaluate the efficiency of milling, the following criteria were used:

$$\text{Flour ratio} = \frac{\text{Reduction flour yield}}{\text{Break flour yield}} \quad (2)$$

$$\text{Bran ratio} = \frac{\text{Break bran yield}}{\text{Reduction bran yield}} \quad (3)$$

Grain and Flour quality analysis. Evaluation of grain and flour quality indicators was performed by:

– physical-technological and chemical-technological indicators of grain (moisture performed by air-thermal direct method according to ISO 712, test weight according to ISO 7971, vitreousness according to GOST 10987, protein content according to ISO 20483, ash content in accordance with ISO 2171, wet gluten was washed out according to GOST 27839 – by manually washing of dough from 25 g of flour with 14 ml of water, the gluten deformation index (GDI) – on the IDK-M device. Falling Number method performed according to ISO 3093);

– indicators of laboratory milling (total yield of flour, the ratio of bran and flour from break and reduction systems – according to formulas 2 and 3);

– physical-technological and chemical-technological indicators of flour (moisture according to ISO 712, protein content by Kjeldahl method according to ISO 20483, ash content according to ISO 2171, gluten content and gluten deformation index (GDI) according to GOST 27839, Falling Number (FN) according to ISO 3093, starch damage content by the SDmatic amperometric method (AACC 76-33));

– physical properties of the dough on Alveograph PC following the method ISO 27971 (flour strength W and P/L ratio) and on Mixolab device (Simulator Protocol) which determine the parameters (water absorption capacity (WAC) and stability (St) described in the method ISO 5530.

Statistical evaluation. All the evaluation data was statistically processed by employing the least significant difference (LSD 0.05) at a 95% probability level and the correlations were calculated using the statistical processing built-in Microsoft Excel Software. In the correlation analysis, it was determined whether the quality indicators have a correlation with each other and to what extent in accordance with the following division: extra high – $0.85 < |r| \leq 1.00$; high – for $0.70 < |r| \leq 0.85$; average – for $0.50 < |r| \leq 0.70$; low – for $0.30 < |r| \leq 0.50$; have no correlation – at $0 < |r| \leq 0.30$.

When analyzing the variation of quality indicators, the range was divided into 5 groups and the obtained variation histograms were compared with the normal distribution law of the random variable.

Results and its discussion

Based on the results of quality indicators shown in Table 1, it can be seen that the average indicators of wheat, received for processing at flour mills, indicate

Table 1 – Physical-technological and chemical-technological properties of wheat grain (n=64, p=0.95)

Quality indicator	TW (grain)	V (grain)	MC (grain)	PC (grain)	AC (grain)	GC (grain)	GDI (grain)	FN (grain)
Minimum	727	25	10.4	11.3	1.35	17.6	46	309
Maximum	845	83	13.7	17.2	1.73	38.3	96	500
Average	794	53	12.1	13.9	1.55	27.2	73	423

Note to Table 1, 3, 4: TW (grain) – test weight, g/l; V (grain) – vitreousness, %; MC (grain) – initial moisture content, %; PC (grain) – protein content, %; AC (grain) – ash content, %; GC (grain) – gluten content, %; GDI (grain) – gluten deformation index, units; FN (grain) – Falling Number, seconds.

relatively high initial grain quality indicators. In these 2019 and 2020 harvest years in Ukraine (except for some southern regions) there were favorable conditions for growing wheat and, according to FAOSTAT data, record wheat yield of 28.3 million tons were grown in 2019 and 24.9 million tons in 2020.

Although there were wide fluctuations in quality indicators due to various agro-climatic conditions and varietal characteristics of grain grown in different regions, but only 6 of 64 grain samples had a test weight with less than 760 g/l, 12 samples had low vitreousness (less than 40%), 9 samples in terms of protein content and 7 samples in terms of gluten content had insufficient indicators for the subsequent processing of grain for bread. Most of the samples (30 of 64) had an ash content of 1.51 to 1.60%, which is typical for Ukrainian wheat grown today (Figure 1).

GDI and FN indicators – the indicators characterizing the quality of the protein-protease and carbohydrate-amylase complexes, as well as indirectly characterizing the enzymatic activity of the corresponding enzymes of proteolytic and amylolytic action. According to GDI, only 8 samples were insufficient values for bread (with considering the relationship of this indicator with flour [35]), when for the Falling Number only 3 samples belonged to the group with normal amylolytic activity. The remaining samples were characterized by insufficient amylolytic activity to obtain bread of good volume, which is a feature of the quality of Ukrainian wheat in recent times, which is associated with an increase in average annual temperatures and a decrease in the amount of rain in the spring and summer period [36].

Analyzing the type of histograms, it can be concluded that the variation in test weight, vitreousness, ash content, GDI were close to the normal distribution of a random variable with an average value in the central group, then in terms of moisture content, protein content and gluten content, quality indicators are distributed relatively evenly across groups without a pronounced predominance of the central group. This suggests that these indicators are more influenced by agro-climatic conditions, agro-technological conditions (fertilization), genetic characteristics of grain.

The standard laboratory milling process assumes 70% flour yield. According to our results was obtained lower indicators which associated with quality and varieties of wheat samples and features of laboratory milling (Table 2).

Due to the fact that bran finishers were not used in laboratory conditions for additional flour extraction, bran yield was high, especially break bran yield, so the ratio between break bran and reduction bran was more than 3:1, although in industrial conditions usually 2:1. This feature of laboratory milling also affected such indicators as flour ash content, starch damage, and, as a result, WAC, which are much higher for industrial flour – 0.48-0.60% for ash content, 20-22 UCD – for starch damage, 58-60% – for WAC.

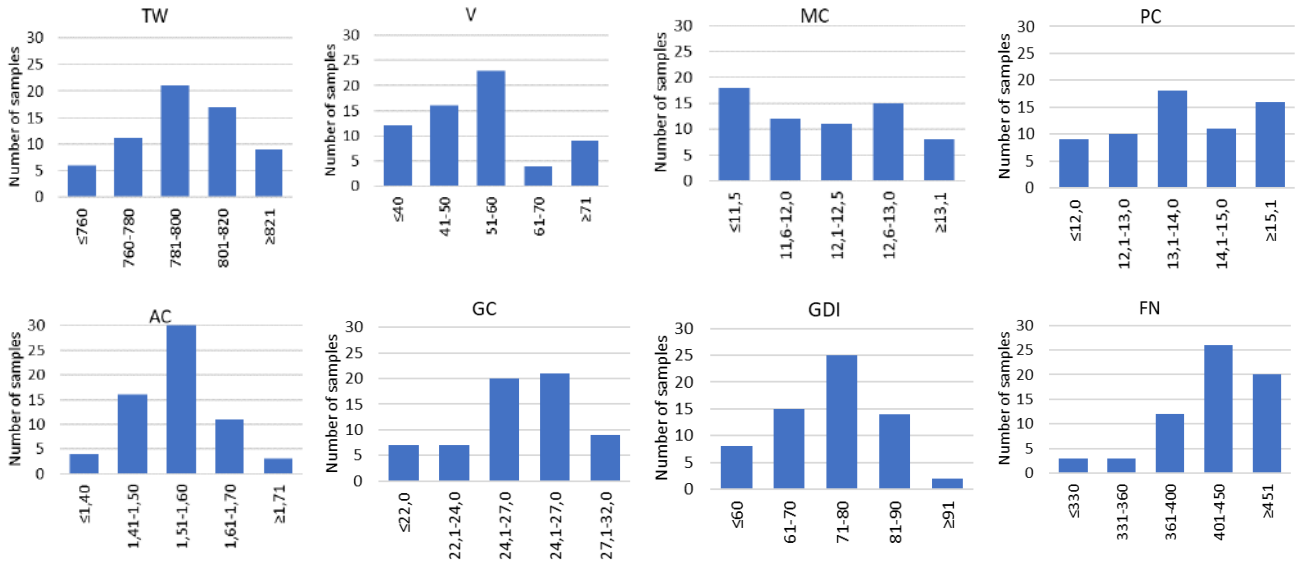


Fig. 1. Histograms of distribution of grain quality indicators by groups

Table 2 – Milling properties, flour quality indicators and rheological properties of the dough (n=64, p=0.95)

	FY	FR	BR	PC	AC	GC	GDI	FN	SD	WAC	St	W	P/L
Minimum	63.1	2.4	1.7	9.7	0.31	21.8	45	333	10.8	51.3	1.0	173	0.31
Maximum	72.5	5.9	7.5	15.8	0.55	36.8	82	501	21.1	57.7	25.4	393	3.15
Average	68.4	3.3	3.2	12.2	0.41	28.1	65	402	15.7	54.2	3.3	261	0.98

Note to Table 2, 4, 5: FY – flour yield, %; FR – flour yield ratio reduction to break; BR – bran yield ratio break to reduction; PC – protein content, %; AC – ash content, %; GC – gluten content, %; GDI – gluten deformation index, units; FN – Falling Number, seconds; SD – starch damage, UCD; WAC – water absorption capacity, %; St – dough stability, min; W – strength of flour, 10^{-4} J; P/L – configuration ratio.

For other quality indicators, on average, good results were obtained, but their wide variability in obtained flour indicates its high instability. In order to increase the stability of the quality of the produced flour in the future, or to predict these indicators, it is desirable to establish which quality indicators of the initial grain predetermine one or another flour quality indicator. For this, a correlation analysis was carried out between grain quality indicators among themselves (Table 3) and grain quality indicators with milling properties, flour quality indicators and rheological properties of dough (Table 4). For convenience, all missing correlations (r≤0.3) are extracted from the Tables.

According to the obtained data results shown in Table 3, test weight has a good direct correlation with vitreousness and average inverse correlation with initial moisture content of grain. The average correlation coefficient of test weight and vitreousness (r=0.45) can indicate the presence of influence of the agroclimatic conditions, due to the rather hot weather in crop years, but not dry, because test weight has shown high values. Test weight and moisture content of grain correlation (r=-0.51) indicating larger grains are less hydrated and more moisture remains in the peripheral layers, thereby reducing flour moisture. Low inverse correlation between test weight and grain ash content (-0.37) is observed by considering the finer grain with a wrinkled surface and a large proportion of surface shells. In addition, dust can settle on a wrinkled surface, which also increases the ash content.

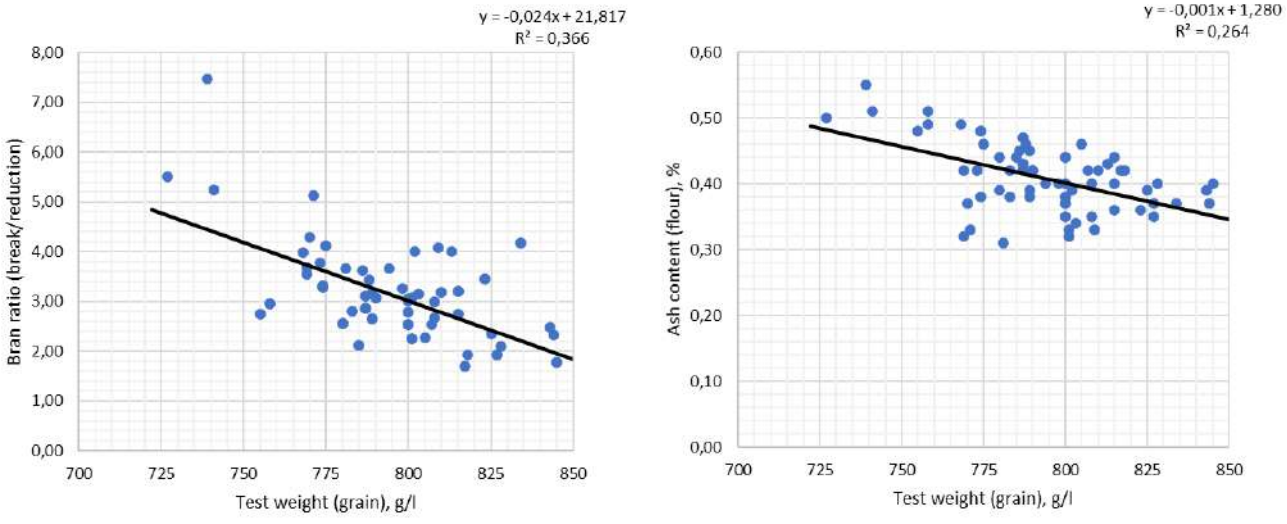
The vitreousness indicator of grain has a weak correlation with most of the studied quality indicators of grain, except average inverse correlation (r=–0.54) with moisture content. This can be explained by the fact of influencing of hot weather on hardness and vitreousness of grain. Consistently, the high vitreousness means that the consistency of the endosperm is harder and the distribution of moisture is poorer. Obviously, these same fac-

Table 3 – Correlation of grain quality indicators among themselves

	TW (grain)	V (grain)	MC (grain)	PC (grain)	AC (grain)	GC (grain)	GDI (grain)	FN (grain)
TW (grain)	1	0.45	**-0.51**		-0.37			
V (grain)		1	**-0.54**	0.48				0.45
MC (grain)			1					
PC (grain)				1		**0.87**		**0.53**
AC (grain)					1			
GC (grain)						1	**0.54**	0.42
GDI (grain)							1	
FN (grain)								1

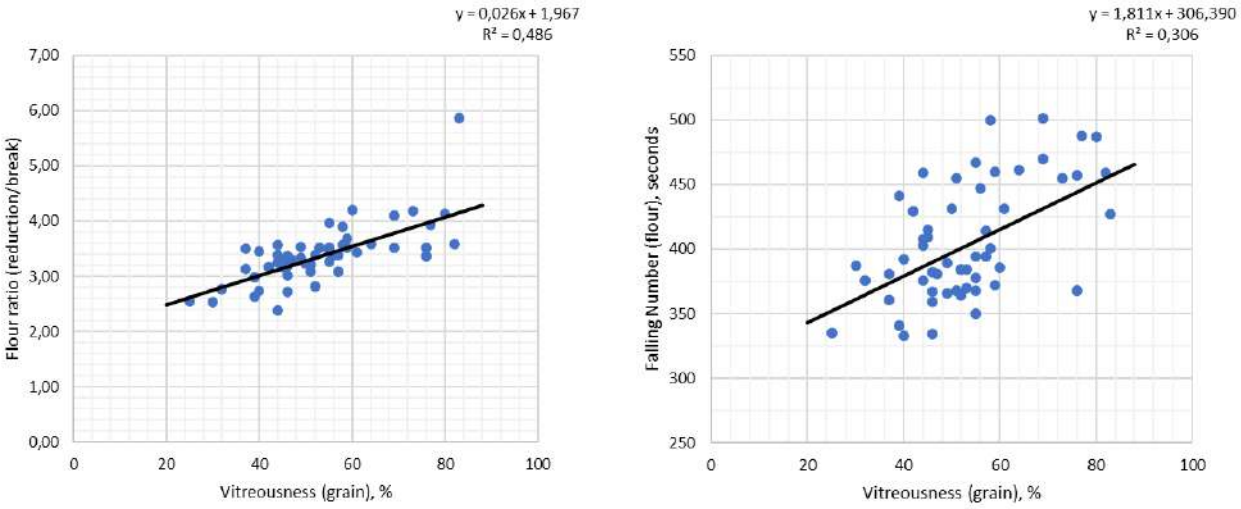
Table 4 – Correlation between grain quality indicators and milling properties, flour quality indicators and rheological properties

	FY	FR	BR	PC	AC	GC	GDI	FN	SD	WAC	St	W	P/L
TW (grain)	-0.31	0.35	**-0.61**		**-0.51**				0.39	0.40	0.47		0.38
V (grain)		**0.70**		0.47		0.32		**0.53**		0.40	0.40	0.41	
MC (grain)	**0.52**	-0.35	0.45					-0.43	-0.45	-0.35	-0.41		-0.41
PC (grain)		0.38		**0.95**		**0.80**	0.40	0.35	-0.34	0.42	0.35	**0.70**	
AC (grain)					**0.68**								
GC (grain)				**0.87**		**0.92**	0.42		-0.39	0.38	0.42	**0.53**	
GDI (grain)				0.31		**0.58**	**0.59**						
FN (grain)		0.35		**0.58**		0.44		0.47		0.39	0.43	**0.56**	



2A **2B**

Fig. 2. Impact of grain test weight on bran ratio (2A) and ash content (2B)



3A **3B**

Fig. 3. Impact of grain vitreousness on the flour ratio (3A) and flour FN (3B)

tors cause a direct low correlation between the vitreousness and grain protein content (r=0.48) and the grain Falling Number (r=0.45).

Protein content of grain have a direct extra high correlation with gluten content of grain, that it is generally accepted that the direct relationship between vitreousness and protein content has [37]. Direct average correlation of protein content with FN (r=0.53) could be related to growing weather conditions, since warm and sunny weather influences the high amount of protein, which in turn reduces the chance of sprouting and the amylolytic activity of the grain. Gluten content showed direct average correlation with GDI (r=0.54), which is associated with an increase in the proportion of the hydrophilic gliadin fraction of gluten during protein accumulation [38], and direct low correlation with FN (r=0.42).

Test weight has an inverse average correlation with bran ratio (r= –0.61), which is explained by the fact that with an increase in test weight, grain completion and the amount of endosperm increase. As a result, there is an increase in the amount of break bran results which leads to a decrease in bran ratio (Figure 2A). Contrariwise test weight had a low correlation with flour yield and flour ratio (r= -0.31 and r=0.35 respectively), which is associated with a short milling flow diagram of laboratory milling and tempering conditions. As can be seen from Figure 2B, test weight leads to a decrease in amount of ash content in flour, which is related to increase of yield of break flour, which contains less bran amount.

The only quality indicator that has a high correlation (r=0.70) with grain vitreousness is the ratio of reduction and break flour (Figure 3A). This fact can be considered when projecting flow diagram of new flour mills or for improving the stage of formation of flour grades in existing mills. And there is direct average correlation between grain vitreousness and grain FN (r=0.53) (Figure 3B), which is related to the weather conditions in the grain filling stage, as described above [28, 30].

As can be seen from the Table 4, the vitreousness of the grain has a low correlation with most of the studied indicators of flour quality: WAC of flour, stability of the dough during kneading and strength of flour (W), i.e. processing of high vitreousness grain does not mean guaranteed quality of finished products. Although the tendency to improve all indicators of flour with increasing vitreousness of grain exists, which is described in source [38], and the absence of the effect of vitreous-

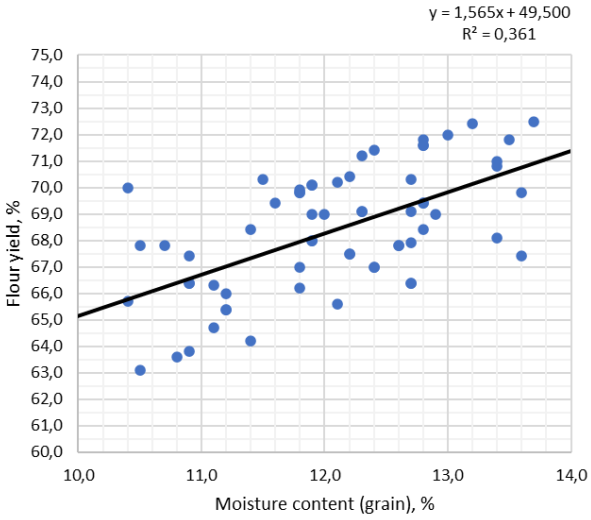
ness on flour yield is consistent with data [36].

It is noteworthy that there is no correlation between grain vitreousness and starch damage (SD) in laboratory milling flour, which is probably due to the lack of mechanical action of roller mills in a short laboratory milling flow diagram.

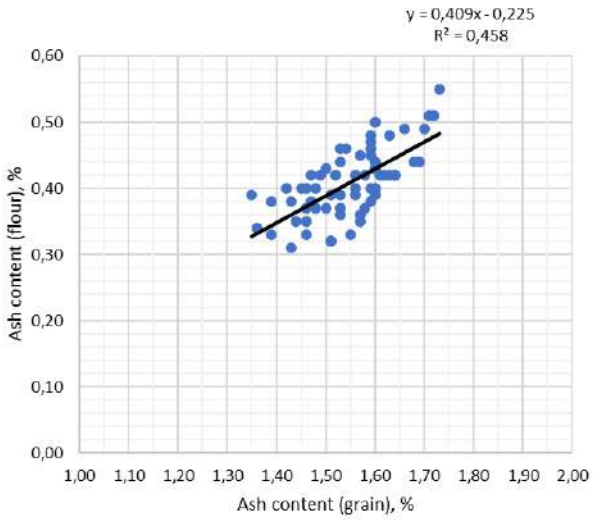
A direct average correlation was obtained between initial moisture content of grain and flour yield (r=0.52) (Figure 4A), which appears to be related to the tempering and milling conditions in the laboratory. Because according to the experimental method, the grain moisture content before milling was constant 16.0%, and the difference in the duration of moistening of high vitreousness and low vitreousness grain was only 2 hours, this did not contribute to the effective penetration of moisture into the central part of the grain (endosperm) when tempering grain with low initial moisture. Although, the total grain moisture differed from the specified one by no more than ±0.1%. As a result, the grain did not soften so much, due to the same gaps between the roller mills, the grain was more difficult to grind to the particle size of flour and larger endosperm particles fell into the bran, reducing the overall flour yield [39].

The higher the ability of the grain to give a greater yield of flour with a lower ash content (greater whiteness) is, the higher the flour milling properties of the grain will be. At the same time, it is important to provide certain functional properties in flour that are suitable for a particular bakery or flour confectionery product. According to the source [40], the higher the initial ash content of grain is, the higher the ash content of flour will be. Therefore, it shows a correlation coefficient between ash content of grain and ash content of flour (r=0.68) (Figure 4B).

It is a known fact that the protein content of grain directly affects protein content of flour (r=0.95). Roughly 80% of the crude protein of wheat flour is gluten [41] which corresponds with strong correlation between protein content of grain and gluten content of flour (r=0.80), between gluten content of grain and protein content of flour (r=0.87) and gluten content of grain and gluten content of flour (r=0.92) (Figure 5B, 6A, 6B).

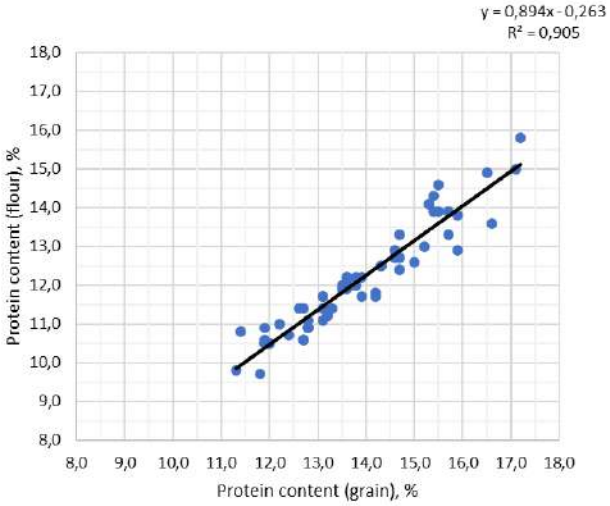


4A

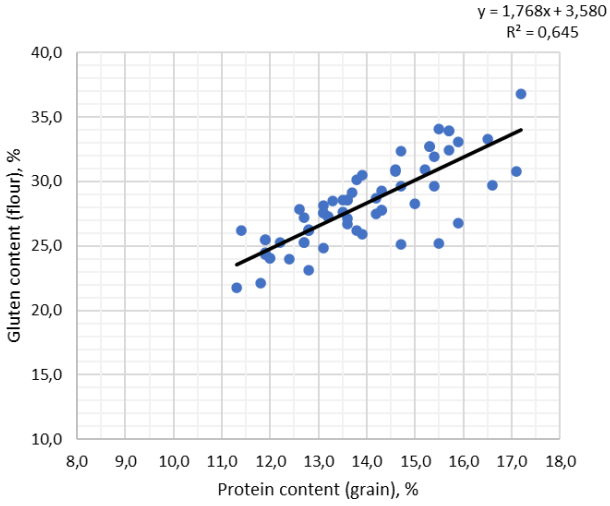


4B

Fig. 4. Impact of moisture content of grain on the flour yield (4A) and ash content of grain on the ash content in flour (4B)



5A



5B

Fig. 5. Impact of protein content of grain on the protein content of flour (5A) and gluten content of flour (5B)

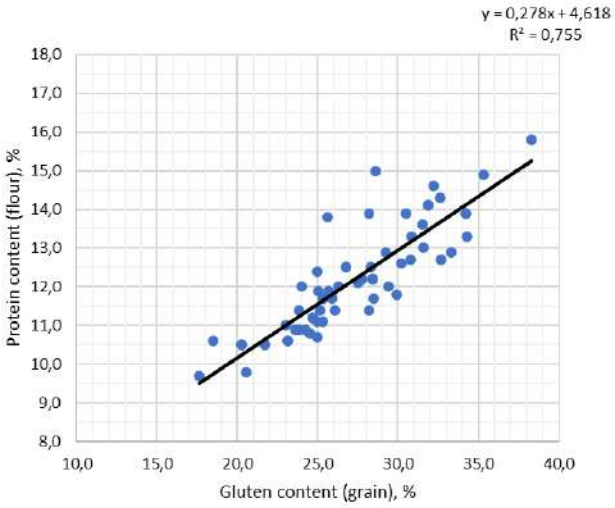
Most importantly, a high correlation was found between protein content and gluten content of grain and strength of flour W (r=0.70) and (r=0.53), respectively (Figure 7A, 7B), which is consistent with the data [42]. A lower correlation with protein content is apparently associated with different hydrophilic properties of the gliadin fraction of proteins in the studied samples and the effect of the degree of starch damage on flour strength.

Gluten quality is determined by its composition, by the presence or absence of specific protein types and their concentrations, in a result direct average correlation showed GDI of grain with gluten content (Figure 8A) and GDI of flour (r=0.58 and r=0.59 respectively), but no correlation was found with flour strength W and other indicators of the physical properties of the dough, that will not allow using this indicator as a predictor of flour strength without considering the influence of other indicators.

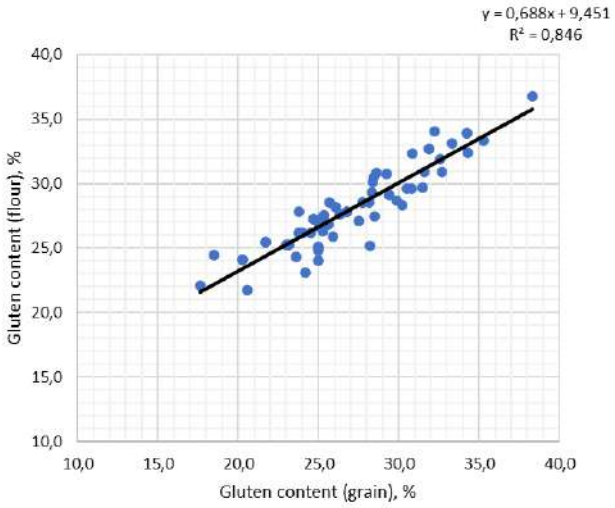
The lower the amylolytic activity of grain enzymes is, the more executed and larger grain will be. This is due to an increase in average annual temperatures, especially in summer, and a small amount of precipitation, the grain has a low amylolytic activity. Respectively, FN has an average effect on the protein content of flour (r=0.56) and flour strength W (r=0.58) (Figure 8B).

The main criterion for the end use of flour is the physical properties of the dough and the indicators of trial baking. Rheological properties of the dough are a complex indicator that describes the condition and behavior of the dough during kneading and throughout the baking process. Good bread-making properties is generally associated with strength of flour (W) and coefficient configuration (P/L), that based on the flour gluten quality and flour gluten content.

According to the data obtained (Table 5), the protein content, gluten content and WAC have the greatest effect on flour strength (W). Our results shown that flour protein content has direct strong correlation with flour strength W (r=0.70) and confirmed research concluded that flour protein content is a primary factor contributing to dough strength [43]. Gluten content of grain influenced on W with direct average correlation coefficient (r=0.53).

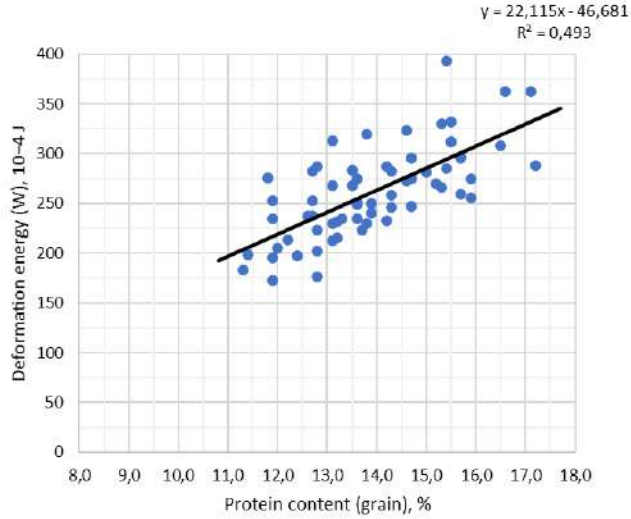


6A

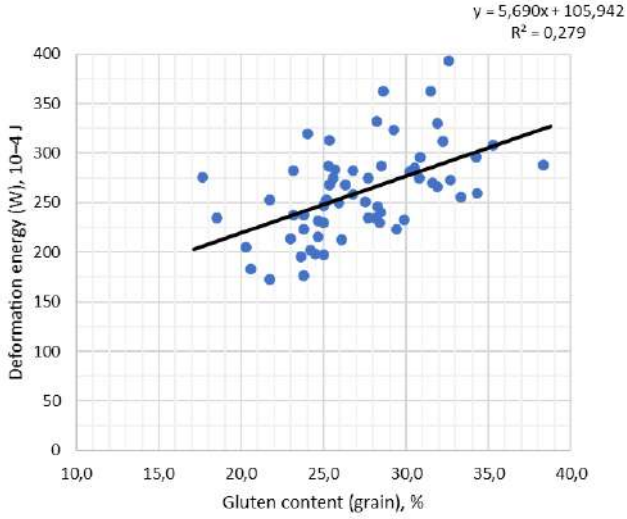


6B

Fig. 6. Impact of gluten content of grain on the protein content of flour (6A) and gluten content of flour (6B)

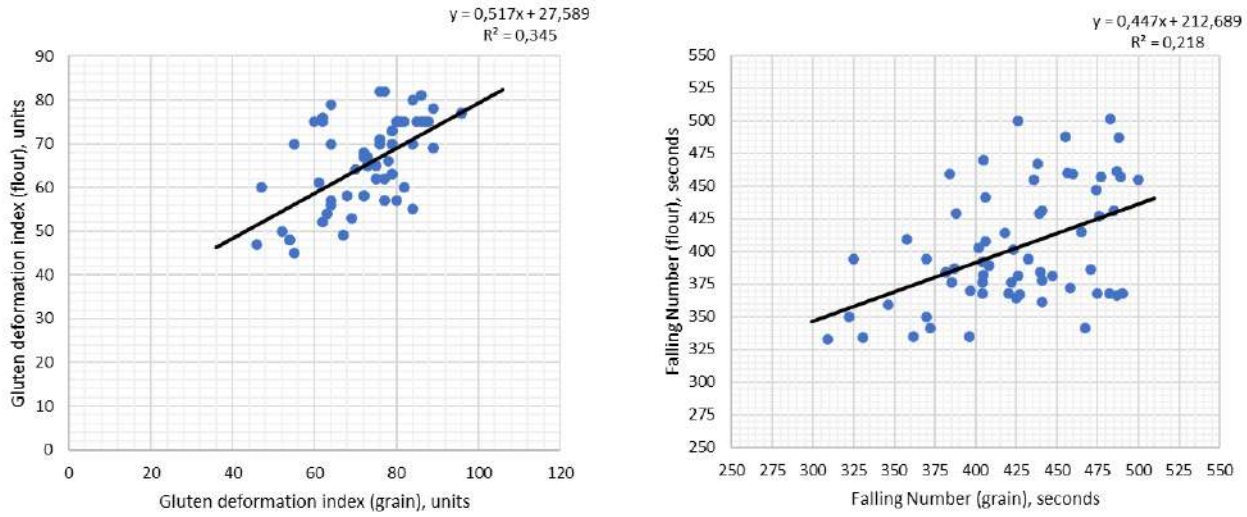


7A



7B

Fig. 7. Impact of grain protein content on the strength of flour (7A) and gluten content of grain on the strength of flour (7B)



8A **8B**

Fig. 8. Impact of GDI of grain on the GDI of flour (8A) and FN of grain on FN of flour (8B)

Table 5 – Correlation between milling properties, flour quality indicators and rheological properties among themselves

	FY	FR	BR	PC	AC	GC	GDI	FN	SD	WAC	St	W	P/L
FY	1		0.38						-0.40				
FR		1	0.36	0.36				0.43		0.34		0.38	
BR			1		0.32				**-0.58**		0.30		-0.35
PC				1		**0.85**	0.47	0.42	-0.30	0.41	0.46	**0.70**	
AC					1					-0.36			
GC						1	0.49					**0.53**	
GDI							1						
FN								1		0.34		0.44	
SD									1				
WAC										1		**0.55**	
St											1	0.40	
W												1	
P/L													1

WAC have positive average correlation with strength of flour W (r=0.55) by means of which the increasing of WAC is stronger flour. Also, standard alveograph test is designed for WAC≈53% and variations in this indicator in one direction or another will also affect the value of W. No significant correlations with coefficient configuration (P/L) were found due to the fact that the P and L indicators depend on various factors and their influence in total does not correlate with the P/L indicator.

Low correlations were obtained between flour ratio, flour protein content, flour ash content and WAC, which is related to the short laboratory milling flow diagram, in which flour had lower SD and WAC values. Protein content (r=0.41) has a slightly greater effect on water absorption capacity which partially confirms the studies [44] in which the authors identified four flour components affect WAC: protein, intact starch, damaged starch, and pentosans.

Conclusions

According to the achieved results, the quality indicators of grain harvested in 2019 and 2020 and the flour obtained from it, were found that quality indicators vary greatly in their values, which depends on many factors: from the differences in the genetic properties of wheat variety, growing location, different growing and environmental conditions prevailing during growing periods; to milling flow diagram and tempering conditions before milling. Wheat quality indicators are shown next results: test weight values ranged from 727 to 845 g/l, vitreousness – 25-83%, moisture content – 10.4-13.7%, protein content – 11.3-17.2%, ash content – 1.35-1.73%, gluten content – 17.6-38.3%, gluten deformation index – 46-96 units and Falling Number – from 309 to 500 seconds. Such a range in indicators led to their different behavior during the laboratory milling process and to different quality indicators of flour.

During the study of the influence of grain quality on its milling properties, the following results were obtained. The flour yield was affected only by initial grain moisture content (r=0.52), which is explained by the features of the short laboratory milling flow diagram and tempering conditions before milling. It was found a direct high correlation (r=0.70) of grain vitreousness with the ratio of reduction/break flour, and an inverse average

correlation of test weight with the ratio of break/reduction bran (r=–0.61), which is explained by the influence of these indicators on the amount and structure of the grain endosperm.

When establishing the dependences of grain quality indicators and flour quality indicators, we can conclude that protein and gluten content of grain are good predictors of protein and gluten content of flour with high correlation coefficients (r>0.80). At the same time, the protein content of grain correlates with the protein content of flour with a coefficient (r=0.95), and the gluten content of grain correlate with gluten content of flour with a coefficient (r=0.92). Average correlation was obtained between ash content of grain and ash content of flour (r=0.68), which says that the higher the initial ash content of grain is, the higher the ash content of flour will be. Another indicator that correlated with flour ash content is test weight (r=–0.51), it leads to a decrease in amount of ash content in flour, which is related to increase of yield of break flour, containing less bran amount. Direct average correlation was found between GDI of grain with gluten content and GDI of flour (r=0.58 and r=0.59 respectively).

Rheological properties of flour, such as water absorption capacity, stability, strength of flour W and coefficient configuration (P/L) – the main criteria for the end use of flour and behavior of dough during kneading. Our results shown that protein content of grain has direct strong correlation with strength of flour W (r=0.70), which confirms that protein content is a good predictor of strength of flour. Gluten content of grain and Falling Number of grain have positive average correlation with strength of flour W (r=0.53 and r=0.56 respectively). No significant correlations with stability, water absorption capacity and coefficient configuration (P/L) of flour were found due to the fact that these indicators depend on complex of various factors.

The obtained correlations can be used to improve the efficiency of grain blending before milling, to substantiate the modes of tempering, grinding, and flour mixing stage in existing mills, as well as to design a milling flow diagram for new mills.

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ВПЛИВ ПОКАЗНИКІВ ЯКОСТІ ЗЕРНА НА ПОКАЗНИКИ ЯКОСТІ БОРОШНА ЛАБОРАТОРНОГО ПОМЕЛУ

Анотація

В умовах високої конкуренції на ринку борошна розробка моделей, які дозволяють прогнозувати кількісні та якісні показники борошна при помелі зерна та розуміти співвідношення між показниками якості зерна та борошна, є надзвичайно актуальним завданням та потребує зусиль у цьому напрямку. Досліджено 64 зразки

зерна пшениці з млинів з різних регіонів України, вирощених у 2019 та 2020 роках, та борошна, отриманого з цієї пшениці в лабораторії на млині МЛУ-202. Отримані дані підтвердили велику варіабельність показників якості зерна та борошна, що залежить від багатьох факторів: від агрокліматичних умов і особливостей сорту до технологічної схеми подрібнення та умов темперування зерна перед подрібненням. Показники якості пшениці представлені наступними результатами: натура змінювалась від 727 г/л до 845 г/л, склоподібність – від 25 до 83%, початкова вологість – від 10,4 до 13,7%, вміст білка – від 11,3 до 17,2%, зольність вміст – від 1,35 до 1,73%, вміст клейковини – від 17,6% до 38,3%, індекс деформації клейковини – від 46 до 96 одиниць і число падіння – від 309 до 500 секунд. Аналіз кореляції між показниками якості зерна та показниками якості борошна показав: пряму надвисоку кореляцію між вмістом білка в зерні та вмістом білка в борошні (r=0,95), а також між вмістом клейковини в зерні та вмістом клейковини в борошні (r=0,87); середню кореляцію між зольністю зерна та зольністю борошна (r=0,68). За мукомельними властивостями встановлено середню кореляцію початкової вологості зерна та виходу борошна (r=0,52), пряму високу кореляцію між склоподібністю зерна та співвідношенням розмелювального та драного борошна (r=0,70) та обернену середню кореляцію натури зерна з відношенням драних та розмелювальних висівок (r=–0,61). Встановлено, що на силу борошна W впливає такі показники якості зерна: вміст білка з високим коефіцієнтом кореляції (r=0,70), вміст клейковини та число падіння із середніми коефіцієнтами кореляції – r=0,53 та r=0,56, відповідно. Для інших реологічних показників, таких як стабільність, водопоглинальна здатність та P/L, високих коефіцієнтів кореляції не виявлено, оскільки їх значення залежать від комплексу різноманітних показників зерна. Отримані співвідношення можуть бути використані для підвищення ефективності змішування зерна перед помелом, для обґрунтування режимів етапів темперування, подрібнення та змішування борошна в існуючих млинах, а також для складання технологічної схеми помелу для нових млинів.

Ключові слова: пшениця, зерно, борошно, лабораторний помел, натура, склоподібність, вміст білка, якісні показники.

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APPLICATION OF PROCESSING PRODUCTS OF VEGETABLE RAW MATERIAL IN MARSHMALLOW PRODUCTION

Abstract

The article examines the main trends in obtaining new types of confectionery products with a balanced composition and functional properties, the production of which is based on the use of a product of plant raw materials processing - carob. Studies on increasing the nutritional value and reducing the energy intensity of marshmallow-type whipped products with the use of carob and the sugar substitute isomalt are given. Information on the functional properties of carob, the effect of the roasting process on its quality indicators, and the possibility of using carob in the production of confectionery products to expand the range of raw ingredients and increase their nutritional value were considered. A comparative description of the nutritional and energy value of medium-roasted carob and cocoa powder is given. The article examines the influence of the product of the processing of plant raw materials of carob on the nature of the formation of the structure of marshmallow masses of reduced energy content, and their main structural-mechanical, physico-chemical and organoleptic indicators are determined. Based on the determination of the structural and mechanical properties of marshmallow masses, such as critical shear stress, degree of general deformation and density of the mass, it is proposed to reduce the duration of their whipping by increasing the rate of structure formation of the mass when using carob powder, so the complete replacement of cocoa powder with carob leads to an increase critical shear stress by 51.83 Pa and an increase in mass density by 171 kg/m3 compared to the control sample. As a result of a complex of conducted studies of physico-chemical and organoleptic quality indicators, the expediency of using the product of the processing of plant raw materials of carob in reduced-energy marshmallow products with 75% isomalt has been proven, it is recommended to completely replace cocoa powder with carob at the stage of whipping the mass. The calculated nutritional and energy value of the new marshmallow products showed a decrease in the total content of fats and carbohydrates in the developed products, an increase in the content of vegetable dietary fibers by 28% and a decrease in the energy value by 55.65 kcal. Enrichment of marshmallow products with minerals, in particular calcium, sodium and vitamins B6 and E, was noted.

Key words: marshmallows, whipped confectionery, carob, isomalt, density, nutritional value.

Introduction

Whipped confectionery products are in demand among consumers due to their delicate light consistency and the useful protein and pectin substances contained in them. Marshmallow or "air marshmallow" is an aerated confection consisting mainly of gelatin, sugar solutions, glucose syrup, and foaming agents such as egg albumin. Marshmallow products are most often white and have various shapes (round, square, cylindrical, in the form of colored bundles), glazed with chocolate or caramel glaze, or with nuts [1].

A promising direction in the production of whipped marshmallow products is to increase their nutritional value, reduce energy content, and impart functional properties. Modern consumers care about their health and prefer products with a balanced composition, which contain significant amount of dietary fibers, biologically active substances, vitamins, and minerals [2, 3]. Therefore, the development of new marshmallow-type whipped products with increased nutritional value and reduced energy content using the products of processing plant raw materials (carob and isomalt) is relevant and promising.

Analysis of recent research and publications

Carob is a sweet powder made from the pulp of the fruits (pods) of the carob tree, a plant of the legume family. In its wild form, the carob tree is often found in Palestine, and it is this country that is considered its homeland. Currently, the plant is cultivated in India, Brazil, Argentina, Mediterranean countries, and other subtropical regions. Raw carob pods are collected, laid out in the sun and dried. In the process of drying, the fruits become sweet and suitable for consumption. After drying, the pods are processed into powder: carob. Well-roasted pods taste similar to dark chocolate [4]. Carob can be used as a natural substitute for cocoa powder in confectionery recipes. Carob is classified as a functional food product due to its preventive properties, which are due to its chemical composition: most of the pulp consists of sugars (mainly sucrose, glucose, and fructose), and dietary fibers. Carob fruits contain gum, which has the properties of a stabilizer and thickener. Due to this substance, carob is used as an ingredient that gives the product thickness, shine, and viscosity. There are few proteins in the pods, but they contain an almost complete set of amino acids, including essential ones. A

distinctive feature is the high content of arginine [5, 6]. In addition, carob contains pinitol (5-7%), condensed tannins (18-20%), ash (mineral elements) 2-3%, as well as fats (0.2-0.6%). Carob tannins bind toxins, thus deactivating them [7-9].

Carob is a functional product and has a wide range of therapeutic and preventive effects on the human body. There are 10 times less fats in carob than in cocoa. Sucrose and fructose provide sweetness, which gives carob the right to be considered dietary. The fiber contained in the powder improves digestion, and together with antioxidants removes harmful substances from the body, including toxins. Carob is sweeter than cocoa powder, so diabetics should use it with caution (Table 1). Raw and fried carob have certain differences. Non-roasted powder is the sweetest, it has a light pink-beige shade, and the taste is different from chocolate. Lightly roasted powder has a light caramel taste. Medium-roasted carob has dark chocolate color and characteristic smell. The taste gains some bitterness characteristic to dark chocolate. It is necessary to pay attention to the degree of roasting, since the sugar content in the roasted powder is lower than in the raw one. The energy value of carob is almost two times lower than that of cocoa powder, while a large number of calories are accounted for by sugar. The nutritional and energy value of medium-roasted carob and cocoa powder is shown in Table 2 [10].

Table 1 - Comparative characteristics of carob and cocoa powder

Indicators	Cocoa	Carob
Taste	Bitter	Sweet
Color	Dark brown	Light brown (raw); brown (roasted)
Allergy	Causes	Does not cause
Effect on the central nervous system	Invigorates, can cause migraines and insomnia	Does not affect
Vitamins	Beta-carotene, A, B_9, PP, B_6, E	Cholin, PP, B_5, E, C, B_2, B_1, B_6
Caffeine	Contains	Does not contain
Mineral substances	Calcium, zinc, sulfur, phosphorus, molybdenum, copper, chlorine, iron, manganese, potassium, magnesium	Copper, selenium, calcium, manganese, zinc, phosphorus, potassium, magnesium, sodium, iron

Table 2 - Nutritional and energy value of carob and cocoa powder, g/100 g

Components	Cocoa powder	Medium-roasted carob
Proteins	27	4.6
Fats	11	0.6
Carbohydrates, including	54	49
Sugars	0.5	40.5
Energy value	1789 kJ (428 kCal)	929 kJ (222 kCal)

Carob, the product of processing plant ingredients, is used in the manufacture of cookies, flour desserts, craft candies, dark and white glaze, without changing the original color and aroma of the final product. The use of carob improves the sensory qualities of products, particularly taste and aroma, and enriches them with vegetable dietary fibers, vitamins, and minerals [5, 11-12] .

Studies were conducted regarding the use of raw and roasted (at +110°C and +130°C for 20 min) carob powder in the production of beverages and the use of carob concentrate in the production of confectionery products. According to the results of sensory evaluation, the use of carob concentrate in the manufacture of toffee, jelly candies, and Turkish delights in the amount of 5%, 20% and 10% of the sugar mass, respectively, led to an increase in the antioxidant activity of these confectionery products. Research results have proven that carob concentrate can be used for the production of functional and healthy food products [13].

The purpose and goals of the research

The purpose of the research is determining the expediency of using carob, the product of processing plant ingredients,, in the technology of marshmallow whipped products with low energy value, establishing its effect on the type of the marshmallow mass structure formation, physical, chemical, and sensory properties.

To achieve the goal, the following tasks have been set:

1. To investigate the influence of carob, the product of processing plant ingredients, on the structure formation type of the whipped mass of marshmallows with reduced energy content.
2. To establish the main physical, chemical, and sensory properties of the developed products.
3. To determine the nutritional and energy value of marshmallows with carob and sugar substitute isomalt.

Research materials and methods

Research materials used were white crystalline sugar according to DSTU 4623:2006; starch molasses (DSTU 4498:2005); food gelatin (GOST 11293-89); citric acid (DSTU 908:2006); isomalt (TM "IRCA"); medium-roasted carob powder from the company "Manteca" (Lviv) TU U 10.6-2949619066-001-2019.

The density of the whipped mass was determined by the volumetric method: the relation of the research object mass to the mass of water, which occupies the same volume and has the same temperature. Research on the critical shear stress of marshmallow samples was carried out by the penetration method: immersion of a cone with 60° angle at the top with a constant penetration force into the product using an automated penetrometer AR-4/1 [14]. Physical and chemical properties were determined by generic methods. Sensory properties (taste, smell, color, consistency, structure, shape, and

surface appearance) had to meet the requirements of DSTU 6441-2003.

A chocolate marshmallow recipe, where 50 to 100% of cocoa was replaced with carob and 75% of sugar was replaced with isomalt was chosen as a control sample. The expediency of replacing 75% of sugar with isomalt in the marshmallow recipe was proven in previous studies [15]. To obtain marshmallows, gelatin mass is prepared first. For this, pre-swollen gelatin and molasses are gradually heated in an open pot to a temperature of +80-90°C. The resulting mixture is cooled to a temperature of +60-65°C, then isomalt and citric acid are added and mixed. The resulting mass is filtered through a sieve with a hole diameter of no more than 3 mm.

Preparation of foamy marshmallow mass is carried out in a whipping unit. First, the gelatinous mass is fed to the installation, then powdered sugar with a particle size of no more than 260 μm is loaded. Carob is added to this mixture and whipped for 5-6 minutes at a speed of 340 rpm. The marshmallow mass is formed by depositing it in the form of bundles on a surface covered with a polymer film. The products are proofed indoors at a temperature of +18-20 °C for 55-65 minutes. Then the formed clusters are cut into separate products of the required length. The technological scheme of making marshmallows with isomalt and carob is presented in Fig.1.

Results and their discussion

During the production of whipped marshmallow products, two processes take place in succession: foam and jelly formation. Foamy whipped masses are dispersed systems consisting of cells filled with air and separated from each other by films of the dispersion medium. The hydrocarbon component of the dispersion medium significantly affects its rheological properties, which in turn depend on the type of structure formation. In order to determine the effect of carob on the formation type of the marshmallow mass structure, structural and mechanical properties were determined by penetration, which is characterized by such indicators as the critical shear stress, the degree of general deformation, and the density of the marshmallow mass. The obtained research results indicate that increasing the amount of carob in marshmallows with isomalt leads to a slight increase in the critical shear stress of all the studied samples (Fig. 2). When increasing the amount of carob from 50 to 100%,

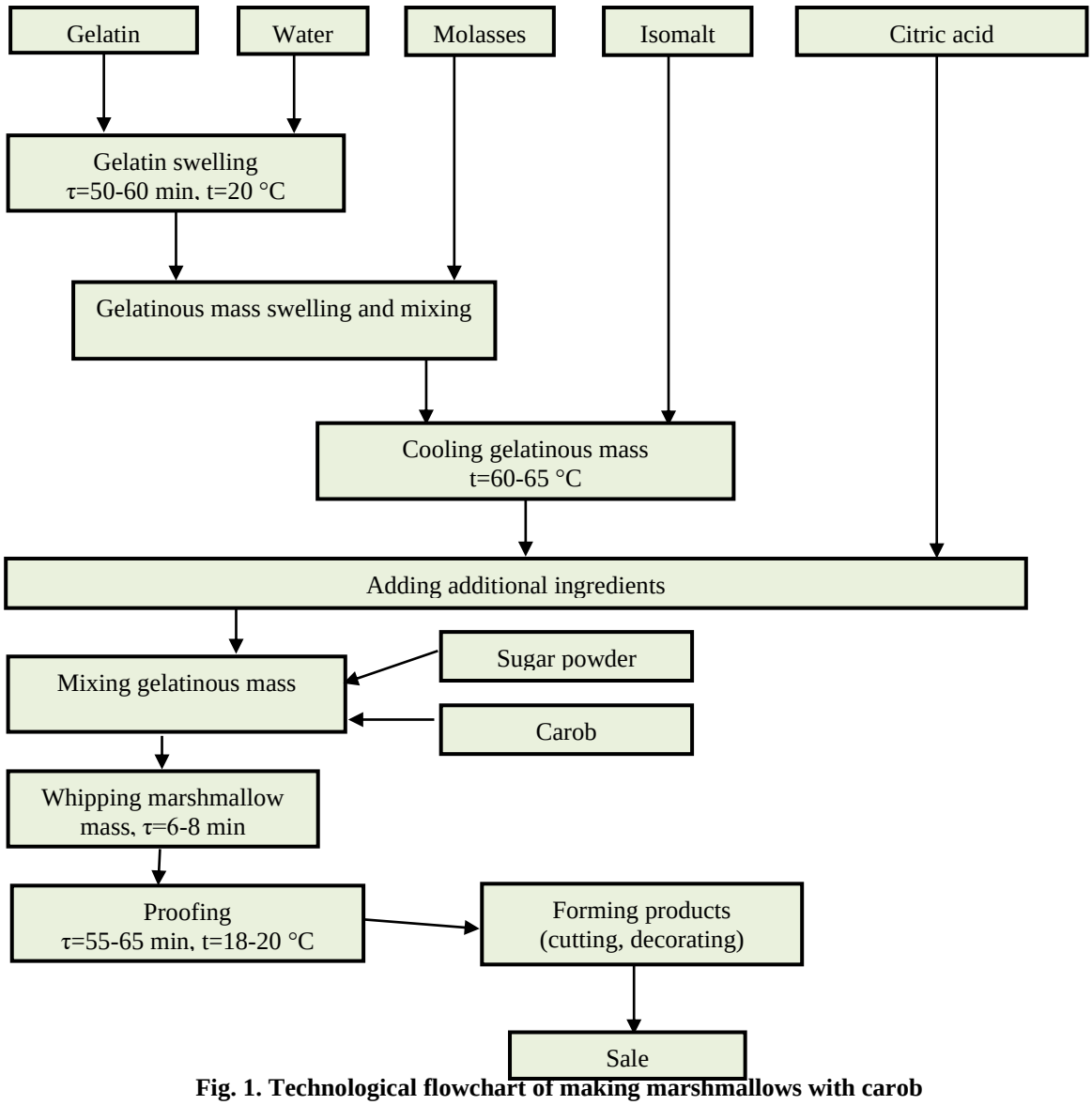

Fig. 1. Technological flowchart of making marshmallows with carob

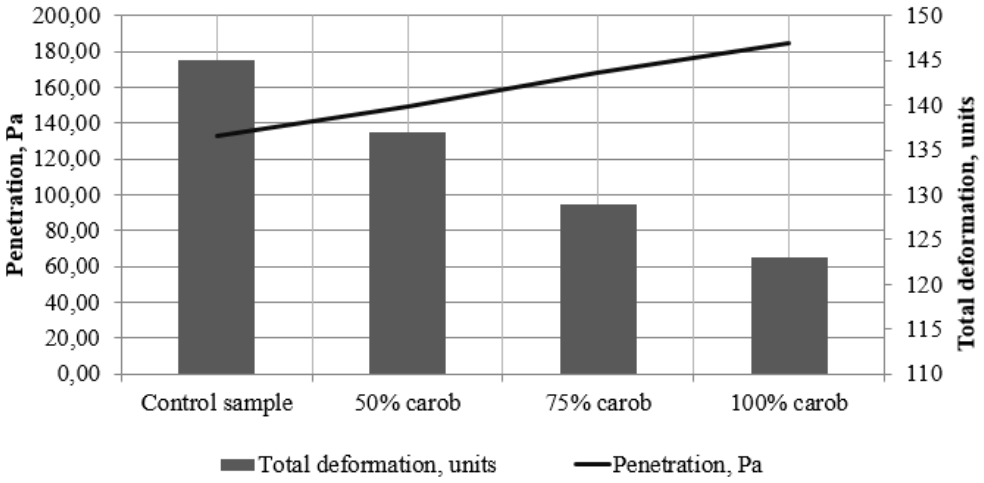

Fig. 2. Dependence of the penetration of marshmallow masses on the amount of carob

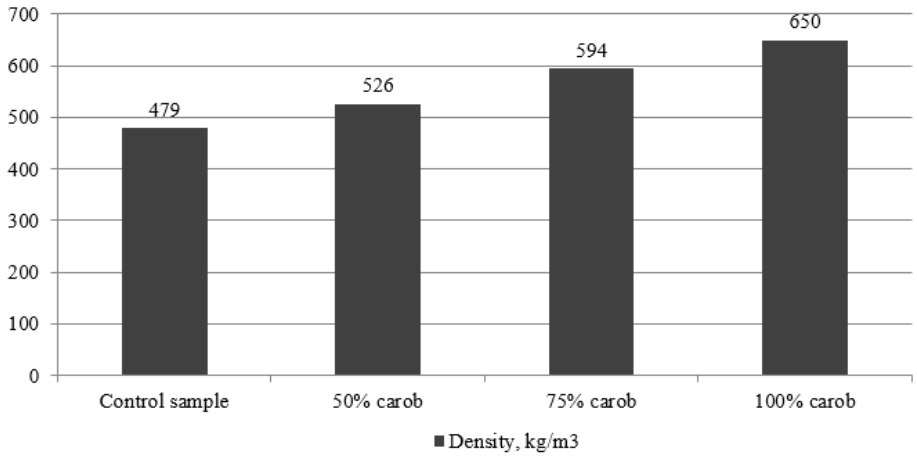

Fig. 3. Dependence of the density of marshmallow masses on the amount of carob

the mass of marshmallows becomes denser, so the penetration indicators increase by 51.83 Pa for the sample with 100% carob compared to the control. At the same time, there is a decrease in the total deformation, so for the control sample, the value of the total deformation is 144 units, and for a sample with 100% carob it is 123 units.

Density is one of the main factors that determine the quality of whipped confectionery products. As a result of whipping, a mass is formed, with that part of volume occupied by the gas phase. The degree of saturation of the whipped mass with air can be characterized by its density. Conducted studies on determining the mass density of marshmallows with isomalt and carob powder showed that the density of the investigated samples increases with an increase in the carob amount due to the additional filling of the spatial frame around the bubble with powder particles. Thus, when adding 50% carob, the density of marshmallow masses increases slightly by 47 kg/m^3, and when cocoa

powder is completely replaced by carob, the density increases by 171 kg/m^3 (Fig. 3). This is due to the fact that carob powder has moisture-retaining properties, i.e. the ability to bind and retain moisture in the studied samples.

The quality of finished marshmallow products with carob and reduced energy content was studied by their physical, chemical, and sensory properties. As can be seen from the data in Table 3, when the amount of carob increases from 50 to 100%, the amount of marshmallow dry matter increases, which may be related to the moisture-retaining properties of the additive. Thus, for the sample with complete replacement of cocoa powder with carob, the amount of dry substance increases by 3.82% compared to the control. The introduction of carob helps to slightly reduce the acidity of the products. As the amount of carob increases, the number of reducing sugars in the samples increases as well, which may be related to the chemical composition of carob powder. The duration of whipping the products is reduced by 2 min compared to the control for a sample with 100% carob due to an increase in the density and speed of structure formation of the mass when using carob powder.

Sensory properties include quality parameters that determine consumer properties of products, such as appearance, shape, taste, consistency, and color. The sensory properties of low-energy chocolate marshmallow with carob were converted using the Harington scale into relative units and presented in the form of a profile diagramm (Fig. 4).

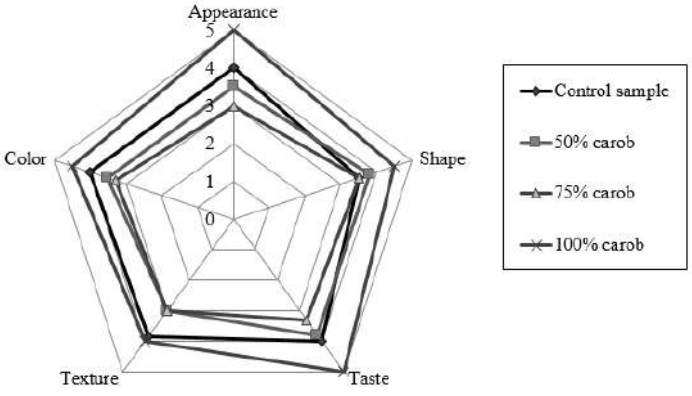

Fig. 4. Quality profile diagramm of low-energy marshmallows with carob

When increasing the amount of carob from 50 to 100%, samples of marshmallows with isomalt acquire rich chocolate color, and the taste becomes more pronounced,

Table 3 – Physical, chemical, and sensory properties of marshmallows with carob

Properties	Control sample	Carob amount, %		
		50%	75%	100%
Mass fraction of dry substances, %	81.88	83.05	84.25	85.7
Acidity, degrees	0.68	0.65	0.66	0.66
Mass fraction of reducing substances, %	25.84	28.26	29.97	32.0
Duration of whipping, min	8	8	7	6
Sensory properties				
Taste and aroma	Typical for marshmallows, with a hint of chocolate		The taste and aroma of bitter chocolate intensifies	
Color	Brown			Rich brown
Texture	Foamy, homogeneous, porous			

Table 4 - Marshmallow recipes

Ingredients	Amount of ingredients per 1 ton of semi-finished product, kg	
	Control sample	Marshmallow "Chocolate Bear"
Sugar	671.0	167.1
Isomalt	-	510.8
Molasses	94.6	94.6
Cocoa powder	38.7	-
Carob	-	40.5
Gelatin	29.5	29.5
Water (for soaking gelatin)	177.0	177.0
Citric acid	7.7	7.7
In total	1018.5	1027.2
Yield	1000.0	1000.0

with bitterness characteristic of chocolate. The texture of the products is uniform, the sample where cocoa powder is completely replaced with carob is denser than the control sample. Products have a smooth surface and uniform porosity. According to the sensory evaluation of the studied samples, 100% of carob additive to the mass of cocoa powder was recognized as optimal.

As a result of evaluating physical, chemical, and sensory properties of chocolate marshmallows with reduced energy content, the possibility of completely replacing the cocoa powder with carob in the studied products has been proven, while all quality indicators were within normal parameters. Based on the conducted research, the “Chocolate Bear” marshmallow recipe with 75% isomalt and 100% carob has been developed and recommended for implementation in production (Table 4).

Data on the nutritional and energy value of the developed marshmallows showed that adding 75% isomalt and carob, the product of processing plant ingredients, allows to reduce the total content of fats by 89%, carbohydrates by 16%, increase the amount of dietary fiber by 28%, which will have a positive effect on the human body. The enrichment of marshmallows with mineral substances, particularly calcium, sodium, and vitamins B6 and E, was also determined. The energy value of marshmallows "Chocolate Bear" decreased by 55.65 kcal compared to the control sample.

Conclusions

Structure formation type of the marshmallow masses with reduced energy content with added carob, the product of processing plant ingredients, has been studied. Based on the determined structural and mechanical properties of marshmallow masses, it is proposed to reduce the duration of their whipping by increasing the rate of mass structure formation when using carob powder, so the complete replacement of cocoa powder with carob leads to an increase in the critical shear stress by 51.83 Pa and an increase in the density of the mass by 171 kg/m^3 compared to the control sample.

As a result of conducted studies on physical, chemical, and sensory properties, the expediency of using carob, the product of processing plant ingredients, in the technology of marshmallows with reduced energy content with 75% isomalt has been proven. It is recommended to carry out a complete replacement of cocoa powder with carob at the stage of whipping the mass. The use of products of processing plant materials in marshmallow technology allows to expand the range of ingredients for the production of whipped confectionery products, increase their nutritional value, and enrich them with plant dietary fibers, vitamins, and minerals.

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ЗАСТОСУВАННЯ ПРОДУКТІВ ПЕРЕРОБКИ РОСЛИННОЇ СИРОВИНИ ПРИ ВИРОБНИЦТВІ МАРШМЕЛЛОУ

Анотація

У статті розглянуто основні тенденції отримання нових видів кондитерських виробів зі збалансованим складом та функціональними властивостями, виробництво яких засновано на використанні продукту переробки рослинної сировини - керобу. Наведені дослідження по підвищенню харчової цінності та зниженню енергоємності збивних виробів типу маршмеллоу з використанням керобу та цукрозамінника ізомальту. Розглянуто інформацію щодо функціональних властивостей керобу, впливу процесу обсмажування на його якісні показники та можливості використання керобу при виробництві кондитерських виробів для розширення асортименту сировинних інгредієнтів і підвищення їх харчової цінності. Наведено порівняльну характеристику харчової та енергетичної цінності керобу середнього ступеню обсмажування і какао-порошку. У статті досліджено вплив продукту переробки рослинної сировини керобу на характер формування структури мас маршмеллоу зниженої енергоємності, визначено їх основні структурно-механічні, фізико-хімічні та органолептичні показники. На підставі визначення структурно-механічних властивостей мас маршмеллоу, таких як гранична напруга зсуву, ступінь загальної деформації та густина маси, запропоновано скорочення тривалості їх збивання за рахунок підвищення швидкості структуроутворення маси при використанні порошку керобу, так повна заміна какао-порошку на кероб приводить до підвищення граничної напруги зсуву на 51,83 Па та збільшення густини маси на 171 кг/м^3 у порівнянні з контрольним зразком. У результаті комплексу проведених досліджень фізико-хімічних і органолептичних показників якості доведено доцільність використання продукту переробки рослинної сировини керобу у виробах маршмеллоу зниженої енергоємності з 75% ізомальту, рекомендовано проводити повну заміну какао-порошку на кероб на стадії збивання маси. Розрахована харчова та енергетична цінність нових виробів маршмеллоу, встановлено зниження загального вмісту жирів та вуглеводів у розроблених виробах, підвищення вмісту рослинних харчових волокон на 28% та зменшення енергетичної цінності на 55,65 ккал. Відзначено збагачення виробів маршмеллоу мінеральними речовинами, зокрема кальцієм, натрієм та вітамінами В6 та Е.

Ключові слова: маршмеллоу, збивні кондитерські вироби, кероб, ізомальт, густина, харчова цінність.

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STUDIES OF THE NUTRITIONAL VALUE OF COMPOUND FEED FOR STURGEONS

Abstract

Aquaculture is one of the fastest growing food industries in the world today. The share of aquaculture in world fish production is growing every year. Over the past 50 years, the volume of fish farming in the world has increased by more than 50 million tons, while the growth in the volume of world fish catch stopped in the 80s of the last century. Aquaculture is one of the most promising and at the same time underestimated areas of economic activity in the agro-industrial complex of Ukraine, which, with the rational use of water resources, is able to provide consumers with a wide range of fish and fish products in a short time. A certain increase in the production of aquaculture products, especially the cultivation of sturgeon and salmon in Ukraine, is due to the use of imported feed, which has a high cost. However, its further development cannot rely on imported feed products, at the same time, the development of industrial fish farming methods is impossible without full-fledged balanced feeding of cultivated objects. Due to the aquatic environment, the need of fish for energy, nutrients and biologically active substances has its own specificity, in comparison, for example, with warm-blooded agricultural animals: it is the need for a high level of protein, another, a special ratio of protein and total energy, fat and polyunsaturated fatty acids, sensitivity to an excess of carbohydrates. Thus, in natural feed for fish, more than 60% of the gross energy falls on protein, about 36% - on fat and only 4% - on carbohydrates. The development of domestic feed for sturgeon is an important task of the feed industry in Ukraine. The paper investigates the current state of fish farming in the country, the relevance and volume of production of compound feed for sturgeon fish, provides the advantages of growing sturgeon fish in Ukraine, analyzes the needs of sturgeon fish in nutrients, micro- and microelements and vitamins, analyzes the physical properties of compound feed for sturgeon fish recipes, an analysis of existing ones was carried out and a proprietary program for feeding stur-

geon fish was developed. The developed sturgeon feeding program allows industrialists of the feed industry in Ukraine to use this information when calculating compound feed for sturgeon and their production.

Key words: aquaculture, sturgeon fish, compound feed, feeding programs, sturgeon feeding, feed ingredients.

Introduction

According to the recommendations of the World Health Organization, a person should consume at least 20 kilograms of fish annually[1].The Ukrainians have not yet succeeded in reaching this norm. One of the reasons: 80% of fish in Ukraine is imported, which means it is expensive. Today fish consumption in Ukraine is 12-14 kg per person [2].

More than 70% of the total global aquaculture production is dependent upon the supply of external feed inputs. Global aquaculture feed sales rose 4 percent to reach 41 million tonnes in 2019, according to the 2020 Alltech Global Feed Survey [3].In 2018 Alltech Global Feed Survey shows that the aquafeeds sector grew by 4 percent[4]. Production volumes are growing for the sixth consecutive year, following an increase in consumption of aquaculture products. The most notable growth over the past year has occurred in Europe, which accounts for 9% of world production. 75% of the world production of compound feed for aquaculture falls on the countries of the Asia-Pacific region, 10% - in Latin America, 5% - in North America, 1% - in the Middle East and Africa [5].

According to the results of aquaculture production of 2020 year, the best results were shown by the fisheries of Sumy (2.9 thousand tons), Cherkaska (2.6 thousand tons), Vinnitsa (1.9 thousand tons) and Kirovograd (1.5 thousand tons) regions. In these regions (as well as throughout Ukraine), the main objects of aquaculture are carp and herbivorous species. This trend has remained unchanged for a long time [6].

Sturgeons are fish species of biological and economic importance. Sturgeon species are grown more by fish farms located in the Zaporozhie, Cherkaska, Odesa, Chernivtsi and Kiev regions [7]. The development of sturgeon farming in Ukraine in recent years is also associated with the development of recirculating aquaculture, to a lesser extent with the development of horticultural fish farming. Leading farms of Ukraine that are engaged in the cultivation of sturgeon fish species: LLC "Sturgeon" (Kiev region), PE "NPSP" Bester "(Kiev region), PJSC" Chernigovrybkhoz "(Chernihiv region), LLC" Ukrainian service company "(Kiev region)), Private Enterprise "Fortuna-XXI" (Kiev), LLC "Kind fish" (Kiev region), "Odessa sturgeon complex" (Odesa region), FH "Ishkhan" (Chernivtsi region), LLC "Oasis Bisan" (Nikolaev region)), GC "Aquasvit", LLC "Aqua Top" (Odessa), LLC "Scientific and Production Center" Trout "(Volyn region), State Enterprise" Irklievsky fish nursery "(Cherkasy region), LLC" Brig LTD "(Zaporozhye region), LLC "Biosila" (Kiev), LLC "Olesya" (Kherson region).

At the state level, the restoration of the sturgeon population is carried out by the S.T. Artyuschik Dnieper experimental production sturgeon fish hatchery(Kherson region). This state-owned enterprise was created back in 1984 - specifically to revive the stocks of Russian sturgeon, stellate sturgeon, beluga, sterlet, etc. Since then, more than 50 million sturgeon young have been released in the lower reaches of the Dnieper. In particular, in 2018, the fish factory introduced 1.6 million Russian sturgeon, sterlet and stellate sturgeon. In Ukraine, there are fifteen farms engaged in the cultivation of sturgeon fish species. In 2018, more than 200 kilograms of black gourmet caviar were supplied to the domestic domestic fish market. They have exported 67 kg of black caviar[8]. Over the past few years, more than ten sturgeon farms for the production of caviar have opened in Ukraine, therefore, the competition is already high on the market. In addition, active Chinese exporters in Ukraine are dumping at prices for caviar. If in Ukraine the prices for sturgeon caviar harvested by the classical method start at $ 800 / kg, now a lot of Chinese caviar at $ 250-300 has appeared on the market.One kilogram of feed for fry costs more than 300 UAH (11.5 US dollars), and for adult fish - more than 55 UAH. The farm needs a ton of this feed per week.

A certain increase in the production of aquaculture products, especially the cultivation of sturgeon and salmon in Ukraine, is due to the use of imported feed, which has a high cost[9]. However, its further development cannot rely on imported feed products, at the same time, the development of industrial fish farming methods is impossible without full-fledged balanced feeding of cultivated objects.

The aquatic feed produced in the world is mainly intended for feeding carp (32%), shrimp (21%), sturgeon (12%) and salmon (12%) (table1). Although certain segments of the aquaculture industry, such as salmon, face sustainability challenges with terrestrial feed sourcing, the share of global animal feed used as aquafeed is small—estimated at 4% (compared with roughly 40% for poultry, 30% for swine, and 25% for ruminants) [10].

Purpose and objectives of the analysis

The objectiveof this review is to provide information on sturgeon feeding programs and provide a basis for recommendations for future research and use by fish feed manufacturers of the developed own sturgeon feeding program.

Results and its discussion

Sturgeons mainly live in temperate waters (from subtropical to sub-Arctic) of the Northern hemisphere; some grow and sexually mature in marine and brackish waters but migrate to freshwater to spawn, while others are land locked in freshwater for their entire life cycle[12].

Sturgeon production volume doubled between 2009 and 2018. An increase was recorded in all the main producing countries (Italy, Poland, Bulgaria, France and Germany). The **rise** of production was particularly significant in Poland where production was five times higher in 2018 than in 2009 and in Bulgaria where production doubled. The sector-wide increase in aquaculture production can be explained by restrictions on the exploitation of wild sturgeon at EU level. However, the production for meat remains limited as they are produced mainly for caviar (fig. 1, 2) [23].

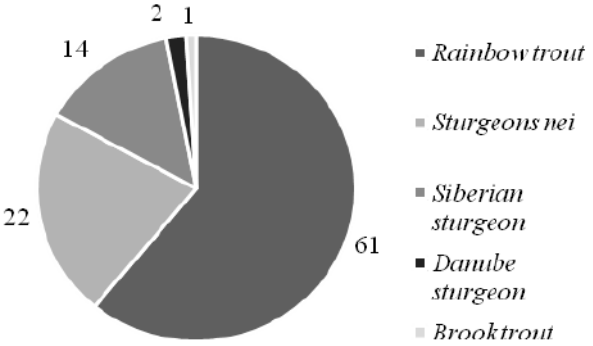

Fig. 1. Breakdown of EU production of fish eggs for human consumption in 2018 in volume

In fact, the sturgeon gender can be determined after three years of rearing, thus only after this period can females be selected for further rearing and eggs production and males are harvested for the consumption market (fig. 3)[23].

These species belong to the phylum Chordata, superclass Osteichthyes, class Actinopterygii, order Acipenseriformes and family Acipenseridae. There are 27 species in the Acipenseridae family, but 4 species are extinct. The 23 extant species are grouped into 4 genera with 2 species in Huso, 2 species in Scaphirhynchus, 3 species in *Pseudoscaphirhynchus* and 16 species in Acipenser[13]. Technologies for the commercial culture of various sturgeon species have been established over the last 20-30 years and they are now available for fish farmers (fig. 4, 5) [23].

Table 1 - Top fish and crustaceans fed commercial feeds in 2019

Top fed species	Tones (Mt)	% on feeds	Economic FCR	Feed use (Mt)
Chinese carp	14.35	59	1.7	14.39
Shrimp	6.55	86	1.6	9.02
Catfishes	6.26	82	1.3	6.68
Tilapia	6.19	94	1.7	9.90
FW crustaceans	3.47	59	1.8	3.69
Marine fish	3.19	84	1.6	4.29
Salmon	2.87	100	1.3	3.73
Other MFW/D fish	2.50	45	1.6	1.80
Milkfish	1.54	54	1.6	1.33
Trout	0.94	100	1.3	1.22
Eel	0.27	98	1.5	0.40
Total fed species production (Mt)	48.15	Total feed use (Mt)		56.45

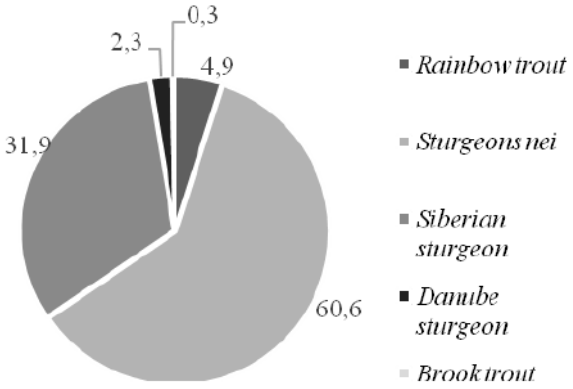

Fig. 2. Breakdown of EU production of fish eggs for human consumption in 2018 in value

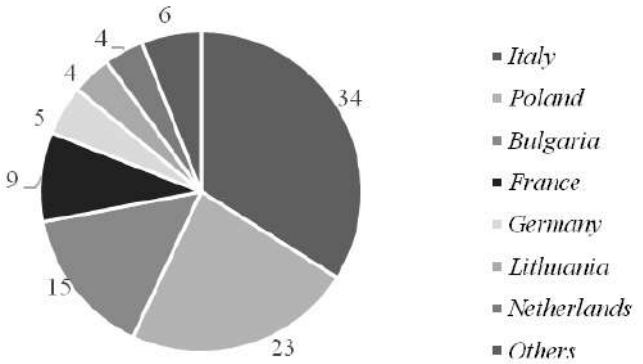

Fig. 3. Sturgeons main EU producers – 2018

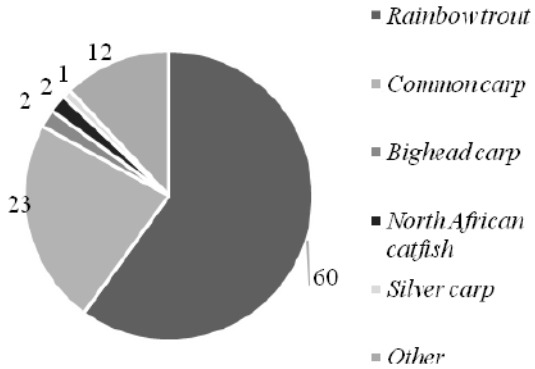

Fig. 4. Main farmed species in the EU member states in 2018 in volume

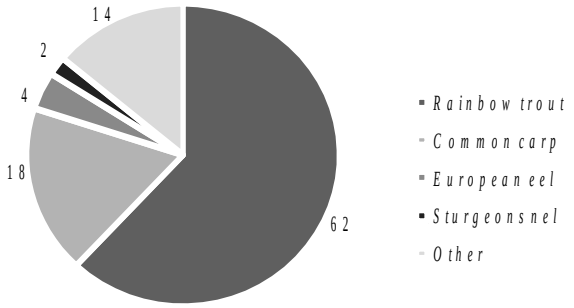

Fig. 5. Main farmed species in the EU member states in 2018 in value

The production of sturgeon meat for human consumption has begun more recently. White sturgeon The production of sturgeon meat for human consumption has begun more recently. White sturgeon (A. transmontanus) and Russian sturgeon (A. gueldenstaedtii) and various sturgeon hybrids showed an increase weight between 1 and 2 kilograms and 100% survival. Pelleted feeds were daily given 3-6% of body weight, and food conversion ratio (FCR) was relatively at 4.5-5.0, likely generating a high load of wastes. At temperatures of 21-23°C, market size (1.0 - 1.3 kilograms) was attained in 12 months.

Physical properties of compound feeds for sturgeon. The habits of this fish are taken into account in the production of compound feeds. For sturgeon feed should be floating, because this species of fish feeds on the surface of the water, as a rule [14]. The physical properties of compound feed for fish are characterized by such indicators as size, moisture, fragility, bulk density, angle of natural slope, etc[15]. Today, compound feed for sturgeon, as well as for other fish species, is produced in extruded and pelleted form, which is very popular today. Paste-like compound feed for fish was produced in the 70s of the 20th century, but due to the high (up to 50%) leaching of nutrients by water, they were abandoned[16].

The pellet length for all group numbers must be less than 1.5 times the diameter. The fragility of granules is not more than 8%, water resistance is not less than 25 minutes. The size of the granules (crumbs) of compound feed depends on the body weight of the fish. Also, evaluating the quality of compound feed for sturgeon, indicate the mass fraction of protein, fat, ash, fiber, calcium, phosphorus, lysine, methionine and cysteine, some vitamins, the presence of metal-magnetic and harmful impurities, pest infestation [16].

Nutritional value of compound feed. Fish, like warm-blooded animals, need up to 40 different components, which are contained in 5 groups of nutrients: nitrogenous substances, fats, carbohydrates, vitamins and minerals [15]. Feeding it is necessary to ensure not only the amount of nutrients and biologically active substances, but also their ratio.

Sturgeon compound feed recipes are usually composed by combining individual components according to their chemical composition. Since the chemical composition and nutritional value of individual feed types differ, it becomes necessary to combine feeds with each other in certain proportions. In practice, this happens in the formulation of feeding rations. The chemical composition of compound feed gives a general idea of its potential biological value. The actual value of the compound feed is determined after adjusting for the inevitable losses arising in the processes of digestion and assimilation of nutrients of compound feed in the fish organism [17].

Young fish, having a high growth rate, require a higher concentration of protein in the feed than older age groups, which is associated with a decrease in the potential for growth of fish with an increase in body size.

Optimum dietary protein at 40.5%, 40%, 40% to 45%, 40% and 37% has been reported for the maximal growth of white, Siberian,Chinese, Persian and hybrid sturgeons, respectively [18].

To provide fast-growing larvae with a sufficient amount of essential and non-essential amino acids, starter feeds should contain 50-65% protein. At the same time, the amount of water-soluble protein fraction, by analogy with natural food, should be sufficiently high. The specific needs of the larvae can be satisfied by including various types of hydrolysates, microbial products that contain degraded protein components in the starting feed of fish.

The main feature of the needs of the larvae of most sturgeon fish is the need for increased availability of protein components. The original feed requires the presence of digested protein products containing low molecular weight peptides and free amino acids [17]. Requirements of sturgeon in amino acids and vitamins are shown in table 2 [19].

Table 2 – Requirements of sturgeon in amino acids and vitamins [19]

% Protein	1993 year	2011 year
Arginine	1.20	4.8
Histidine	0.60	2.3
Isoleucine	0.80	3.0
Leucine	1.30	0.2
Lysine	1.60	5.4
Methionine	0.60	2.0
Cysteine	0.90	0.2
Phenylalanine	0.07	3.0
Tyrosine	1.60	2.3
Threonine	0.70	3.3
Tryptophan	0.20	0.3
Valine	0.80	2.3
Thiamine	-	60-120
Riboflavin	-	80
Vitamin A, mg/kg	-	2.5
Vitamin D, mg/kg	-	100
Vitamin E mg/gk	-	90
Vitamin K mg/gk	-	35

The importance of fats in sturgeon feeds is determined by their high calorie content in comparison with other nutrients, however, this does not exhaust their biological significance. The physiological value of fats depends on the composition and availability of fatty acids and vitamins. Since energy and plastic metabolism are two sides of the same process, the requirements for fat and protein are interrelated - the higher the protein content in the feed, the more fat should be.

The most important element of a balanced diet is the presence of the required level of essential highly unsaturated fatty acids with 4-6 double bonds in the lipids

of the feed, which are recruited on diets with a large amount of yeast or bacterial mass, i.e. growth and development. Analysis has showed that dietary lipid requirement for maximum growth of juvenile hybrid sturgeon was at 11.1% [18].

Table 3 shows the Requirements of 1993 and 2011 years of sturgeon fish in minerals according National Research Council [19]; they have changed with new scientific research.

Table 3 – Requirements of sturgeon fish in minerals[19]

Macroelements, %	1993	2011
Calcium	1E	-
Chlorine	0.9E	-
Magnesium	0.05	0.05
Phosphorus	0.60	0.70
Potassium	0.70	-
Sodium	0.6E	-
Microelements, mg/kg		
Copper	3.0	3.0
Iodine	1.10	1.10
Iron	60	-
Manganese	1.3	12
Selenium	0.3	0.15
Zink	30	15

On the next stage of the work we have analyze the experience of leading sturgeon feed producers and their feeding programs. Compound fishfeed for the world market is represented by foreign manufacturers such as Biomar, Likra Skreting, Aller Aquaetc, which occupy the bulk of the market and are popular for both foreign and domestic consumers due to high-quality raw materials used and the latest technologies. A thoughtful feeding program involves taking care of different sizes of different species in their own niches in the pond. Commercial fish feeds from Aller Aqua are the result of comprehensive testing and evaluation, they have own research and development department and trial station in Germany, Aller Aqua Research. Accordin official information Aller Aqua use in sturgeon feeds fish meal, fish oil, grain products, vegetable proteins, vitamins and minerals as ingredients.

The paper considers the feeding programs of such foreign manufacturers as Biomar and Aller Aqua, they are presented in table 3, 4, 5. As can be seen from the tables, the nutritional value of compound feed depends on the purpose of the fish, for obtaining caviar or for obtaining fillets from the fish. EFICO Sigma 844 is specially designed for mature sturgeon females as a finishing feed for the final stages of caviar production. In collaboration with top sturgeon farms in France, BioMar's caviar finishing feed is designed to promote high yields of quality caviar.

As can be seen from table 4, sturgeon feeds require higher crude fat compare to feeds for fillet purpose Table 5. AlsoBioMar has aquafeeds for fish in stress conditions; they have higher crude protein content [22]. BioMar has over 20 years of experience with sturgeon feed production. BioMar’s sturgeon feed is produced with high quality raw materials. It is suitable for both recirculation and flow-through systems in a variety of climates for optimum growth performance and cost-effective fish farming.

BioMar uses the following ingredients: feather meal, fish meal, hemoglobin, meat bone meal animal fat, rapeseed, rapeseed oil, soybeans, concentrated sunflower protein, triticale, vitamins and minerals, wheat.

Potential alternative include meals and oils from plants (the greatest source of protein and edible oil on earth), fish processing waste, yeast, bugs and other special meals, and even seaweed. Potential alternative ingredients already in use include soybeans, barley, rice, peas, canola, lupine, wheat gluten, corn gluten, other various plant proteins, yeast, insects and algae.

Based on the analysis of the feeding programs (table 5, 6, 7) and recommendations from foreign sources and research, our own sturgeon feeding program was developed, it shown in Table 8. The main impotent indicators were chosen: crude protein, crude fat, crude fiber, crude ash, lysine, methionine, phosphorus, gross energy, vitamin E and vitamin C. As can be seen from the table 8, starting sturgeon feeds should have higher crude protein content (minimum 48.0 %) and less crude fiber content (maximum 1.1 %), lysine and methionine content (% of protein) not less 5.4 and 2.0 respectively.

After analyzing the feeding programs of the presented manufacturers, it can be noted: the presented feed manufacturers use feeding programs that differ in the

Table 4 - Feeding program of BioMar company for obtaining caviar from sturgeon [20]

Indicator	EFICO Sigma 844	EFICO Sigma 844	EFICO Sigma 844
Pellets size, mm	3.0…4.5	6.5… 9.0	12.0…15.0
Crude protein, %	47.0	44.0	43
Crude fat,%	14.0	18.0	18.0
Crude fiber,%	4.0	4.0	3.7
Crude ash, %	8.4	7.9	7.7
Phosphorus %, not less	1.2	1.1	1.1
Gross energy, not less, MJ / kg	20.7	21.4	21.6
Vitamin E, mg/kg, not less	200	200	200
Vitamin C, mg/kg, not less	300	300	400

growing periods and nutritional value of the compound feed; modern feeding programs mainly divide the period of sturgeon rearing into prestart, starting, growers and productive (finishing); for fish of the same age, within the same manufacturer, compound feeds are produced that differ in nutritional value, indicating the difference in feed (for example, economy and increased nutritional value); in the programs of different companies, at the beginning of productive cultivation, different weights of fish correspond.

Table 5 – BioMar feeding program for feeding for fillet purpose [22]

Indicator	EFICO Sigma 811R	EFICO Sigma 811R	EFICO Sigma 811R	INICIO Plus 805 (stress conditions)
Pellets size,mm	3.0…4.5	6.5…9.0	12.0…15.0	12.0…15.0
Crude protein, %	46.0	44.0	44.0	51.0
Crude fat,%	14.0	16.0	16.0	16.0
Crude fiber,%	5.0	5.3	5.3	2.4
Crude ash,%	6.3	6.6	6.6	8.7
Phosphorus %, not less	0.9	1.0	1.0	1.3
Gross energy, MJ / kg	21.8	21.9	21.9	18.0

Table 6 – Aller Aqua feeding program for sturgeon for fillet purpose [21]

Indicator	Aller Performa	SturgeonALLER IVORY EX, 2 MM Fry feed to 50 g	Sturgeon ALLER BRONZEGrower Feed	Sturgeon ALLER BRONZEGrower Feed
Pellets size,mm	1.5	2.0	5.0	11.0
Crude protein, % not less	48.0	54.0	45.0	45.0
Crude fat, % not less	21.0	20.0	15.0	15.0
Crude fiber, % notmore	1.1	0.9	3.2	3.2
Crude ash, %	8.7	8.2	6.5	6.5
Phosphorus %, not less	1.2	1.1	1.2	1.1

Table 7 – Sturgeon feeding program [22]

Feeding period	Fish size, mm	Pellets size,mm	Crude protein, %	Crude fat	Crude fiber	Gross energy	Phosphorus
Prestrating	3-15	1.3-1.5	58.0	17.0	0.9	21.6	1.2
Starting	15-50	2.0	54.0	20.0	0.9	22.2	1.1
Grower	50-7000	38.0	45.0	15.0	3.2	21.2	1.1
Finishing	more 7000	11.0	45.0	15.0	6.5	21.2	1.1

Table 8 – Feeding program for sturgeon (developed)

Indicator	Feeding periodof sturgeon		
	Starting	Grower	Finishing
Pellets size,mm	1.5	1.5	5.0
Crude protein content, % not less	48.0	48.0	45.0
Crude fat content, % not less	21.0	21.0	15.0
Crude fiber, % notmore	1.1	1.1	3.2
Crude ash, %,	8.7	8.7	6.5
Lysine, % of protein, not less	5.4	5.4	5.4
Methionine, % of protein, not less	2.0	2.0	2.0
Phosphorus %, not less	1.2	1.2	1.2
Gross energy, not less, MJ / kg	20.0	20.0	21.2
Vitamin E, mg/kg, not less	200	200	200
Vitamin C, mg/kg, not less	300	300	400

Conclusions

The current state of fish farming and the relevance of the production of compound feed for sturgeon fish have been investigated. In recent years, the new sturgeon farms have been opened in Ukraine. The increase in sturgeon cultivation is partly due to the use of the highly efficient foreign-made compound feeds. In Ukraine, for the effective development of aquaculture, it is necessary to pay close attention to the efficiency and quality of compound feed. Unfortunately, the quality and nutritional value of domestic compound feeds are inferior to foreign ones due to the use of outdated requirements and programs for years of valuable fish species.

The article analyzes the physical properties of compound feed for sturgeon fish and the peculiarities of the formulation of foreign manufacturers. The need of sturgeon fish in micro- and microelements, vitamins is shown. The analysis of existing feeding programs Biomar and Aller Aqua was carried out. Based on the analysis, we have developed our own sturgeon feeding program. The developed sturgeon feeding program will divide the period of fish development into initial, growth and final periods and meets the needs of sturgeon fish according to the latest recommendations.

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ДОСЛІДЖЕННЯ ПОЖИВНОЇ ЦІННОСТІ КОМБІКОРМІВ ДЛЯ ОСЕТРОВИХ

Анотація

Сьогодні аквакультура є однією з найбільш швидкозростаючих харчових галузей у світі. Частка аквакультури у світовому виробництві риби з кожним роком зростає. За останні 50 років обсяг рибного господарства у світі зріс більш ніж на 50 млн тон, тоді як зростання обсягів світового вилову риби припинилося в 80-х роках минулого століття. Аквакультура є одним із найперспективніших і водночас недооцінених напрямів господарської діяльності в агропромисловому комплексі України, який при раціональному використанні водних ресурсів здатний забезпечити споживачів широким асортиментом риби та рибопродуктів за короткий час. Певне збільшення виробництва продукції аквакультури, особливо вирощування осетрових та лосося в Україні, зумовлено використанням імпортних кормів, які мають високу вартість. Проте його подальший розвиток не може спиратися на імпортні кормові продукти, водночас розвиток промислових методів рибництва неможливий без повноцінної збалансованої годівлі об'єктів вирощування. Через водне середовище потреба риб в енергії, поживних і біологічно активних речовинах має свою специфіку, в порівнянні, наприклад, з теплокровними сільськогосподарськими тваринами: це потреба у високому рівні протеїну, особливе співвідношення протеїну і загальної енергії, жирів і поліненасичених жирних кислот, чутливість до надлишку вуглеводів. Так, у природних кормах для риб більше 60% загальної енергії припадає на протеїн, близько 36% - на жири і лише 4% - на вуглеводи. Розробка вітчизняних кормів для осетрових є важливим завданням комбікормової промисловості України. У роботі досліджено сучасний стан рибництва в країні, актуальність та обсяги виробництва комбікорму для осетрових риб, наведено переваги вирощування осетрових риб в Україні, проаналізовано потреби осетрових риб у поживних речовинах, мікро- та мікроелементах та вітамінів, проведено аналіз фізичних властивостей комбікорму для рецептів осетрових риб, проведено аналіз існуючих та розроблено власну програму годівлі осетрових риб. Розроблена програма годівлі осетрових дає змогу промисловцям комбікормової промисловості України використовувати цю інформацію при розрахунку комбікорму для осетрових та їх виробництва.

Ключові слова: аквакультура, осетрові риби, комбікорми, програми годівлі, годівля осетрових, компоненти комбікормів.

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INSECTS ARE A SOLUTION TO THE PROBLEM OF PROTEIN SUPPLY OF MIXED FODDER'S

Abstract

In the materials of this article, the problems of protein deficiency in the production of compound feed are considered, and ways to solve them due to the use of alternative, non-traditional protein components - insects that have high nutritional properties, provide rapid accumulation of biomass, serve as sources of biologically active substances and are safe from from the point of view of issues of veterinary medicine and ecology. It is predicted that up to 15% of additional protein will be provided by insects in 2050, and their market will be estimated at $1.2 billion. The characteristics of the black lion fly (Hermetia illucens) and its larvae, peculiarities of cultivation and chemical composition are presented. Larvae mostly consist of protein and fat, and also contain 7.0% chitin, 5.0% calcium, 1.5% phosphorus and iron. The amino acid composition of the protein demonstrates the presence of a wide range of amino acids and a relatively high content of lysine, which makes it possible to use them in the development of new components of complete feed for farm animals and poultry. A method of introducing dry larvae of the black lion fly into the compound feed through granulated and extruded mixtures with a mass fraction of larvae from 10 to 50% has been developed. The structural scheme of the introduction of larvae in the production of compound feed is presented, which includes cleaning of grain raw materials, grinding, sieving, mixing the passing fraction of the sieve with dry larvae in a certain ratio, and subsequent granulation and extrusion of the mixture. The results of the study of the physical properties of the samples of the molded mixtures are given, and it is established that the sample with 15% dry larvae has the best physical properties. With an increase in the content of dry larvae in the mixture by more than 25%, the samples at the exit were characterized by significant fragility and fatness and required an additional drying operation, which would significantly increase the cost of the finished compound feed. Calculated recipes of complete ration compound feed for adult laying hens using larvae from 15 to 20%, which made it possible to exclude expensive feeds of animal origin (fish meal, meat and bone meal) and partially replace soybean meal (up to 12%), which significantly reduced the cost of finished compound feed.

Key words: compound feed, Black lioness larva, recipe, physical properties, granulation, extrusion, technology.

Introduction

The development of new components of combined feed for farm animals and poultry is one of the topical directions of the modern combined feed industry. The feed base, which determines the largest item of expenditure, is represented by various ingredients of plant and animal origin, as well as feeds obtained with the help of microbiological synthesis.

Considerable attention is paid to their protein supply when balancing complete ration compound feeds, therefore, the search for new sources of protein is quite an urgent issue. So, let's consider the problems of lack of protein in modern fodder production and the possibility of its replenishment. To understand why the creation of alternative proteins is generating so much interest in the animal feed industry, we need to first appreciate the context in which this new industry has emerged over the past decade. High-protein components are necessary to ensure the animal's need for protein, its balance, and therefore, for the full development of the body.

First, the grain and legume group (barley, oats, wheat, corn, soybeans, peas) serves as raw material for the production of not only compound feed, but also food products for humans, which causes competition for these sources of protein. large areas of arable land that could be used for food production.

Secondly, the geographical isolation of fish production and the decline of global fish stocks can contribute to the shortage of fish meal, which is almost the main full-fledged source of animal protein in animal nutrition, forcing technologists around the world to invent new sources of raw materials. In addition, fish meal is a rather expensive type of raw material, in addition, there is a significant amount of counterfeiting of this compound feed component on the feed raw material market.

Thirdly, such protein components as soybean meal, fodder yeast, dry amino acid preparations are also characterized by high cost and falsification.

One of the areas of use of new alternative protein components is non-traditional types of raw materials, which can reduce the intensity of these problems and expand the possibilities of the compound feed industry.

Literary review

The base of non-traditional feeds is expanding every year, which makes it necessary to conduct experiments with various biological objects, to study the possibilities of their use as feed ingredients, to identify the most promising ones from an economic point of view. Such objects must have high nutritional properties (primarily in terms of protein and fat content), provide rapid accumulation of biomass, serve as sources of biologically active substances and be safe from the point of view of veterinary and ecological issues. These requirements are met by insects, in particular the black lionfly (Hermetia illucens) and its larvae [1].

The work of both foreign and domestic scientists, who proved the expediency of their use from both a productive and an economic point of view, is devoted to the issue of the prospective use of insects in the production of compound feed [1, 2, 3]. Therefore, one of the most promising alternative proteins for compound feed for animals is currently considered to be insects. The very first modern studies on the cultivation of flies and larvae of the Black Lioness (Hermetia Illucens) were conducted by three researchers Furman, Young and Catts back in 1959. According to forecasts, it is expected that by 2050 (Fig. 1), insects can provide 15% of the additional protein that will be needed by that time [1, 4-6].

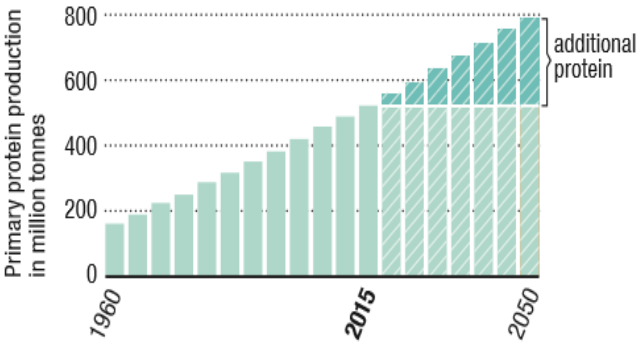

Fig. 1. Prospects for providing protein through the use of insects

The use of edible insects and the animal protein produced from them is rapidly gaining momentum around the world. According to UN forecasts, this market will be valued at $1.2 billion in two years [1, 6]

In China, EU countries, and especially in the USA, insect protein is actively used for the production of compound feed: in particular, in 2020, a subsidiary of Nestle Purina began producing such feed [7]. This is quite an important event, because previously large transnational holdings showed a rather restrained interest in alternative protein. If one of the global giants enters this market, it can be expected that others will follow. This means that production and the range of available products will grow exponentially in the foreseeable future.

Black soldier fly (Hermetia illucens, or Black Soldier Fly) is a large American fly from the family Stratiomyidae (Fig. 2), whose natural range is North and South America [1, 2]. The insect is one of the few species of invertebrates capable of fully developing in pure culture in a confined space of artificial conditions, which allows the species to be used for biotechnological purposes.

A variety of sources serve as a feed substrate for the larvae of this type of insect: manure, substandard grain and processed products of the agricultural and food industry, food waste. Every day, up to a third of the volume of produced products is thrown away as food waste, a large part of which is of plant origin (the remains of fruits and vegetables, which is connected with the complexity of their storage and transportation). The products quickly decompose and become unsuitable for further use. Bioconversion of waste when growing larvae on it partially solves the problem of utilization and allows obtaining a high-quality protein fodder product [8, 9].

Fig. 2. Black lioness fly and larvae

When breeding Black lion flies, the main factors that affect the growth, development and production of fodder biomass are lighting, humidity, temperature regime, fodder substrate, chemical factors, which include the gas composition of the air, mineral composition of water, acidity, mechanical and chemical composition the environment in which the insect develops, its air penetration and density, as well as noise, gamma radiation and electromagnetic oscillations [10, 11]. But, despite the entire range of necessary factors of the distribution environment, the insect is unpretentious, and its larvae (Fig. 2) are omnivorous and able to develop in a wide range of temperatures (+20-50°C) and relative air humidity (40-90%) [9, 10].

The Black Lionfly and its larvae have gained great popularity in the last decade due to its introduction as a fodder for reptiles, poultry and other domestic and farm animals [12-14]. First of all, this is due to the high nutritional value of larvae grown on organic waste, which contains proteins (≈40%) and fats (≈40%) [10]. In fig. 3 shows the chemical composition of the larvae of the Black lioness fly grown on pig droppings.

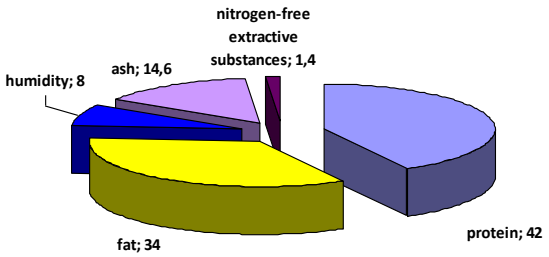

Fig. 3. Chemical composition of the larvae of the Black lioness fly

As can be seen from the diagram, the larva's body consists mostly of protein and fat. When conducting research, it was found that the protein content in the larva is not affected by the composition of the feed substrate, while the amount of fat and ash varies depending on the type of feed - for fat 20-45%, for ash 3-20% [1, 2, 3] In the composition of fatty acids, lauric acid accounts for 50% [3]. Omnivorousness and nutrition is determined by the ability of Black lioness larvae to eat any solid organic waste without exception and as a result accumulate in their body a complex of macro- and microelements, the percentage of which depends on the diet. On average, the larva contains 7.0% chitin, 5.0% calcium, 1.5% phosphorus and iron. In the table 1 shows the results of the study of the amino acid composition contained in the dry flour of fly larvae [1-3].

The amino acid composition of the protein in the larva shows the presence of a wide range of amino acids and a relatively high content of lysine (Table 1). In addition, it contains useful organic compounds that have commercial and industrial value.

Table 1 – Amino acid composition of flour from the Black lioness

№	Amino acid	Content, %
1	*Lysine*	3.37
2	*Threonine*	0.55
3	*Methionine*	0.86
4	*Valin*	3.41
5	*Leucine*	3.53
6	*Isoleucine*	1.96
7	*Tryptophan*	0.20
8	*Phenylalanine*	2.20
9	*Arginine*	2.24
10	*Histidine*	1.91
11	*Aspartic acid*	4.56
12	*Serine*	0.12
13	Glutamic acid	3.81
14	Proline	3.26
15	Glycine	2.88
16	Alanine	3.69
17	Cystine	0.06
18	Tyrosine	2.51
	A total of	40.12

Formulation of the problem

In this regard, the goal of the work was to find, characterize and process the possibility of alternative protein raw material - larvae of the Black lioness, as a component of compound feed for agricultural poultry.

Materials and methods

The object of the study was dried larvae of the Black lioness, as well as granulated and extruded mixtures of grain with larvae. The mass fraction of dry black lionfish larvae in the mixtures was 10, 15, 25, 35, 50%.

In the work, standard analytical, physical and chemical research methods were used to evaluate chemical and physical properties.

The mass fraction of moisture was determined by the accelerated method, by drying the weight of the sample in a drying cabinet at a temperature of +130°C for 40 minutes. Volumetric mass using a liter flask with a falling load and laboratory scales of the 2nd accuracy class. The angle of the natural slope was determined according to the degrees applied to the side surface of the special device R.L. Zenkova by pouring the product from a watering can. Average particle size by sieving a portion of bulk product through a sieve with openings of a specified size and weighing the residue on the sieve. Flowability by measuring the flow rate of the product through an opening of a certain diameter. Granule fragility according to the granule abrasion index in the PPG 2 apparatus. To obtain molded mixtures - technological methods of granulation and extrusion.

Results of the study and their discussion

Taking into account the high content of fat in the larvae, as well as the satisfactory physical properties of the dry larvae of the Black Lioness, when introducing them into the compound feed, a method of their use has been developed (Fig. 3), which includes cleaning the grain raw material - corn grain, grinding it with subsequent sifting through a sieve PR No. 30-40, mixing the passing fraction of the sieve with dry larvae in a certain ratio and subsequent granulation and extrusion of the mixture under the following technological modes:

- granulation in a press granulator of the OPG 150 brand (the number of pressing rollers - 2 pcs., the diameter of the die of the matrix 4.0 mm; the mass fraction of moisture of the mixture that is fed to granulation – 16...18%; the temperature of heating the matrix – + 90 ± 5ºC; pressure – 2-3 MPa; temperature of granules at the exit from the press – + 70 ± 5 ºC);

- extrusion in an EZ-150 extruder (the diameter of the die at the exit 10.0 mm, the mass fraction of moisture of the mixture that is fed to granulation is 16...18%; the temperature in the working area is + 120 ± 5ºC; the pressure is 1 MPa; the temperature of the extrudate at the exit is + 100 ± 5ºC).

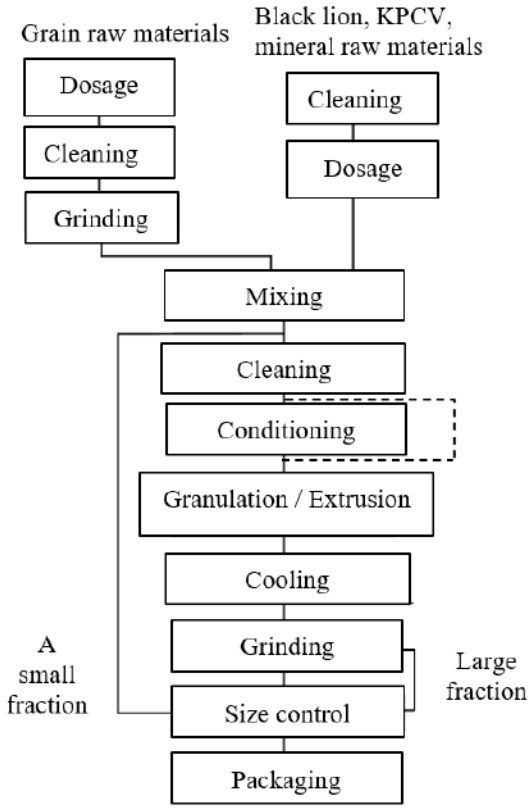

Fig. 3. Structural diagram of the introduction of Black Lioness larvae during the production of compound feed

The physical properties of the obtained samples of the obtained molded mixtures in the form of granules and extrudate (Fig. 4) were investigated. The best physical properties were in the sample of the mixture, which included 15% of dry larvae (Table 2).

When the mass fraction of dry black lionfish larvae in the composition of the mixture was increased to more than 15%, the effect of its extrusion (swelling) was not noted, as a result of the increase in fat content and the acquisition of a more plastic shape by the product due to this. With an increase in the content of dry larvae in the mixture by more than 20%, the samples at the exit were

Fig. 4. Granulated and extruded mixtures of grain with larvae (maize grain:larvae)

Table 2 - Physical properties of compound feed

Index	Dry insects	Granules	Extrudate
Mass fraction of moisture, %	45.6	14.0	15.3
Volumetric mass, kg/m^3	315	580	429
Thickness, mm	12	3 mm, l = 4 mm	2.1
Angle of natural slope, degree.	48	40	41
Flowability, cm/s	1.75	4.2	3.54
Brittleness of granules, %	-	9.8	-

Table 3 – Recipes of whole grain feed for laying hens

Ingredient	% complete ration compound feed		
	№-1-1	№-2-2	№-3-3
Wheat	31.00	28.00	36.70
Corn	24.00	16.00	
Barley	-	13.23	15.00
Bran	-	-	2.60
Millet without films	-	-	25.10
Soy meal SP46%	-	11.30	-
Sunflower SP36%	13.00	10.50	5.00
Black Lioness	19.00	15.00	12.24
Monocalciumphosphate	8.00		
Fodder chalk	2.00	-	-
Limestone flour	1.56	3.90	1.90
Kitchen salt	0.25	0.10	0.26
Baking soda	-	0.70	-
Lysine 98%	0.13	0.10	0.10
Dl-Methionine 98.5%	0.06	0.17	0.10
P1-1	1.00	1.00	1.00

characterized by significant fragility and fatness and required an additional drying operation, which would significantly increase the cost of the finished compound feed.

Taking into account the chemical composition of the larvae of the Black lioness, we calculated recipes for adult laying hens using larvae up to 20% of the input, which are presented in the Table. 3, which made it possible to eliminate expensive feed of animal origin (fish meal, meat and bone meal) and partially replace soybean meal (up to 12%), which significantly reduced the cost of ready-made compound feed.

The obtained extruded/granulated mixture can be used in the future for the production of complete ration compound feed with increased fat content, with lines for the preparation of grain raw materials, preparation of FPFI, Black Lion, and other mineral raw materials, the main mixing and forming line, size control and packaging of finished products.

Conclusions

The technology of organic waste processing by black lioness fly larvae is a natural and innovative method of obtaining natural and complete feeds and their components, quick replenishment of soil fertility, as well as effective methods of fighting for environmental safety and improving green technologies.

The fodder market of vermiculture (insects, larvae) is at the initial stage. Based on the literature review and the results of experimental studies, it is advisable to use the larvae of the Black Lioness insect as an alternative to proteins of animal origin and vegetable crops (cakes, meal). A method of introducing the larvae of the Black Lioness into compound feed as part of grain raw materials has been developed.

The appearance of black lionfish larvae on the feed market of Ukraine makes it necessary to evaluate the biological effectiveness of this feed product as part of compound feed for poultry, pigs, fish and domestic animals.

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КОМАХИ – ВИРІШЕННЯ ПРОБЛЕМИ БІЛКОВОГО ЗАБЕЗПЕЧЕННЯ КОМБІКОРМІВ

Анотація.

В матеріалах статі розглянуті проблеми білкового дефіциту при виробництві комбікормів, та шляхи їх вирішення за рахунок використання альтернативних, нетрадиційних білкових компонентів – комах, які володіють високими пожив-ними властивостями, забезпечують швидке накопичення біомаси, служать джерелами біологічно активних речовин і є безпечними з точки зору питань ветеринарії та екології. Наведено прогноз забезпечення до 15 % додаткового білка у 2050 році за рахунок комах, а їх ринок буде оцінюватися в 1,2 млрд. $. Представлено характеристику мухи Чорна левина (Hermetia illucens) та її личинки, особливості вирощування та хімічного складу. Личинки в більшій мірі складаються з білка і жиру, також містять 7,0 % хітину, 5,0 % кальцію, 1,5 % фосфору і заліза. Амінокислотний склад білка демонструє при-сутність широкого спектра амінокислот і відносно високий вміст лізину, що дає можливість їх використання при розробці нових компонентів повнораціонних комбікормів для сільськогосподарських тварин і птиці. Розроблено способи введення сухих личинок мухи Чорна левина до складу комбікормів через гранульовані та екструдовані суміші з масовою часткою личинок від 10 до 50 %. Представлено структурну схему введення личинок при виробництві комбікормів, яка включає очис-тку зернової сировини, подрібнення, просіювання, змішування проходової фракції сита з сухими личинками у певному спів-відношенні та послідуюче гранулювання і екструдування суміші. Наведено результати дослідження фізичних властивостей зразків формованих сумішей, встановлено, що найкращі фізичні властивості у зразка з 15 % сухої личинки. Зі збільшенням вмісту сухої личинки у складі суміші понад 25 % зразки на виході характеризувалися значною крихкістю та жирністю і потребували додаткової операції сушіння, що значно підвищило б вартість готового комбікорму. Розраховані рецепти повнораціонних комбікормів для дорослих курей-несучок з використанням личинки від 15 до 20 %, що дозволило виключити дорогі корми тваринного походження (рибну муку, м'ясо-кісткову муку) та частково замінити соєвий шрот (до 12%), що значно зменшило вартість готових комбікормів.

Ключові слова: комбікорми, личинка Чорної левини, рецепт, фізичні властивості, гранулювання, екструдування, технологія.

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Ukrainian LiveStock Summit 2022

Ukrainian LiveStock Summit
Український Тваринницький Саміт – подія Міжнародного формату з ефективного тваринництва та птахівництва. Це event-платформа для обговорення сучасних трендів й проблемних питань розвитку тваринництва та птахівництва, місце зустрічі й обміну досвідом професіоналів з України та зарубіжжя.

Місце і дата проведення: Event Hall Golf Center, Україна, м. Київ, Оболонська набережна, 20, м.Київ. 11 Жовтня 2022 р.

Мета – залучити до обговорення проблем тваринництва України світову та вітчизняну спільноту , пошук шляхів збереження , відродження та стрімкого зростання тваринництва та корбікормовиробництва України.

Організатори: Асоціація Союз птахівників України, ГС «Міжрегіональний Союз Птахівників та Кормовиробників України», Спілка молочних підприємств України, ProAgro Group.
За підтримки : Уряду України

Саміт включатиме:

– Форум «Тваринництво та птахівництво України . Виклики воєнного часу та післявоєнної розбудови»;
– «Комбікормовий Форум»;
– Семінари з інноваційних технологій та продуктів;
– діалогові панелі та круглі столи з провідними фахівцями, експертами галузі;
– виставку обладнання та технологічних рішень у галузі тваринництва та птахівництва;
– VIP-зону для бізнес-переговорів;
– прес-конференцію;
– кава-паузи, фуршети.

Головні діалогові панелі:

- Головні виклики воєнного часу та ефективні рішення їх подолання
- Відновлення. До чого готуватись та з чого починати?
- Державна підтримка, Фіскальна політика, Міжнародні фонди та фінансові установи. Чого чекати, на що сподіватись?
- Кандидатство в члени ЄС — нові виклики і нові можливості
- Енергоефективність та енергобезпека — важливіший тренд післявоєнної розбудови
- Впровадження інноваційних технологій та продуктів — шлях до стрімкого зростання

UKRAINIAN LIVESTOCK SUMMIT

10:00 – 13:00 Панель I

Відкриття. Продовольча безпека людства – пріоритетна мета сучасного світу.
– Діалогова сесія: – Головні виклики воєнного часу та ефективні рішення їх подолання.
– Діалогова сесія: – Відновлення. До чого готуватись та з чого починати?

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- **Олександр Гайду**, голова Комітету Верховної Ради України з питань аграрної та земельної політики
- **Йоахім Берманн**, президент союзу — ЄВРОПЕЙСЬКИЙ СОЮЗ КОМБІКОРМНИКІВ
- **Ольга Шевченко**, заступник голови ДЕРЖПРОДСПОЖИВСЛУЖБА
- **Юрій Мельник**, заступник голови правління — МХП
- **Вадим Чагаровський**, голова спілки — Спілка молочних підприємств України
- **Роман Сластьон**, генеральний директор УКРАЇНСЬКИЙ КЛУБ АГРАРНОГО БІЗНЕСУ — ucab
- **Сергій Карпенко**, виконавчий директор — СОЮЗ ПТАХІВНИКІВ УКРАЇНИ
- **Сергій Бакум**, генеральний директор — EDINSTVO GROUP
- **Богдан Єгоров**, ректор ОДЕСЬКИЙ НАЦІОНАЛЬНИЙ ТЕХНОЛОГІЧНИЙ УНІВЕРСИТЕТ
- **Юлія Фльорова**, генеральний директор — ясенсвіт
- **Микола Кремезь**, директор «НВП» ГЛОБИНСЬКИЙ СВИНОКОМПЛЕКС — Глобино
- **Наталія Якименко**, голова спілки ГС «ВІВЧАРСТВО ТА КОЗІВНИЦТВО УКРАЇНИ»
- **Анатолій Незамай**, генеральний директор — ТВАРИНПРОМ

14:00 – 15:00 Панель II

– Діалогова сесія: – Торгівля і фінанси. Чого чекати, на що сподіватися?

Спікери:

- **Тарас Качка**, заступник Міністра економіки України – торговий представник України — Міністерство економічного розвитку і торгівлі України
- **Данило Гетманцев**, голова Комітету Верховної Ради України з питань фінансів, податкової та митної політики
- **Владислав Карпенко**, керівник напряму розвитку аграрних ринків — USAID
- **Галина Хейло**, віце-президент — АСОЦІАЦІЯ УКРАЇНСЬКИХ БАНКІВ
- **Дар'я Дідковська**, генеральний директор — APK-RESURS
- **Дмитро Кузьменко**, виконавчий директор Української Асоціації венчурного та приватного капіталу — UVCA

15:00 – 16:30 Панель III

– Діалогова сесія: – Енергоефективність та енергобезпека – важливіший тренд післявоєнної розбудови.

Спікери:

- **Сергій Кравчук**, генеральний директор — Gals Agro
- **Сергій Савчук**, директор із розвитку інновацій ГРУПА КОМПАНІЙ VITAGRO — VITAGRO
- **Іван Корженко**, генеральний директор — GRECO group
- **Георгій Гелетуха**, голова правління Біоенергетична асоціація України — UABIO
- **Іван Тракслер**, директор — МХП | Еко Енерджи
- **Сергій Сілін**, бренд-менеджер — ECOFLOW
- **Юрій Подоляк**, генеральний директор — IKNET

16:30 – 18:00 Панель IV

– Діалогова сесія: – Впровадження інноваційних технологій та продуктів – шлях до стрімкого зростання.

Спікери:

- **Вадим Шиян**, генеральний директор ГС «МІЖРЕГІОНАЛЬНИЙ СОЮЗ ПТАХІВНИКІВ ТА КОРМОВИРОБНИКІВ УКРАЇНИ»
- **Антон Водяник**, керівник проектів — СІЙ ДОБРО
- **Надія Бойко**, директор Науково-дослідного і навчального Інституту молекулярної мікробіології та імунології слизових оболонок — ТОВ «СГП «МБС»
- **Дмитро Коломоєць**, керівник технічного відділу — ТОВ «ФАБРИКА РУКАВНИХ ФІЛЬТРІВ»
- **Алла Ковалевська**, директор з розвитку бізнесу — LEDLIFE
- **Анатолій Міндель**, президент компанії — AgriGo

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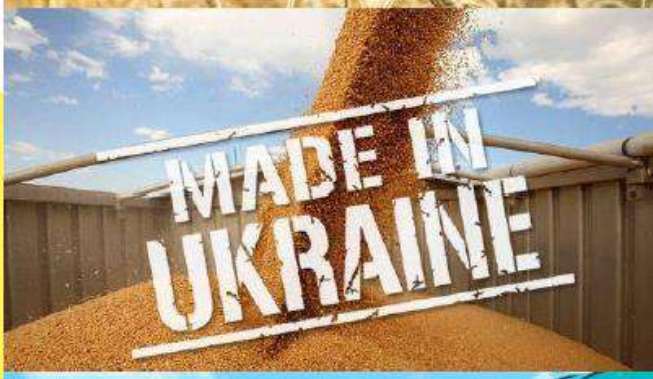
https://proagro.com.ua/events/date/2022/livestock_summit

ФАКУЛЬТЕТ
ТЕХНОЛОГІЇ ЗЕРНА І ЗЕРНОВОГО БІЗНЕСУ



ХАРЧОВІ ТЕХНОЛОГІЇ

Освітні програми:

- Технології та управління зерновим бізнесом;
- Технологія зберігання зерна та елеваторний бізнес;
- Технології та управління кормовим бізнесом;
- Технології та управління хлібопекарним і кондитерським бізнесом.

ПІДПРИЄМНИЦТВО, ТОРГІВЛЯ ТА БІРЖОВА ДІЯЛЬНІСТЬ

Освітня програма:

- Міжнародна торгівля зерном;

ГАЛУЗЕВЕ МАШИНОБУДУВАННЯ

Освітня програма:

- ІТ конструювання та обслуговування обладнання (Зернопереробної галузі).

Працевлаштування:

- Керівниками харчових та зернових підприємств (елеваторів, борошномельних, круп'яних, комбікормових заводів, кондитерських фабрик, хлібозаводів);
- Керівниками агропромислових підприємств;
- Керівниками машинобудівних заводів, комерційних структур технічного сервісу;
- Керівниками торгівельних, зерноторгівельних компаній та їх підрозділів;
- Керівниками підприємств малого бізнесу;
- Керівниками біржових структур та їх підрозділів;
- Фахівцями-аналітиками з дослідження товарних ринків і бірж;
- Технологами, головними інженерами, завідуючими лабораторіями, менеджерами з якості;
- Брокерами на товарних біржах;
- Фахівцями з логістики;
- Експертами з зовнішньоекономічних питань;
- Експертами з оцінки та прогнозування діяльності зерноторгівельних підприємств та ін.

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