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Determination of Rational Parameters of Pseudomixing by Complex Modelling of Work Processes

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Abstract. The area of improving the quality of the formation of mixtures upon mixing in the food industry is relevant since the improvement of technology and equipment for processing components by various methods, nature, and degree of influence is practically achievable for their improvement. The purpose of this study was to improve the design parameters and increase the efficiency of the mixer by creating conditions that will ensure the optimisation of the dissolution kinetics of a dispersed mixture of flour and liquid components during their pseudo-mixing in a suspended state. This study considered the properties of raw materials based on methods for determining their quality, laboratory methods and tools for conducting research were proposed with the established planning methodology with analysis of the results obtained, and the Flow Vision software package was used in plotting based on the laws of thermodynamics. The experimental data set was processed using a mathematical description of the process of forming the liquid flow and the dispersed flow of flour particles. The study used an incomplete multivariate model of the approximation of the experimental data of the function of three variables in the form of polynomials according to the three-level Box-Behnken plan with 13 experiments performed in 5-fold repetition. Periodic mixers were analysed, and the redistribution and transformation of deformations under optimal mixing modes was considered. The interaction of components and their flow dynamics while minimising energy consumption was established. The authors determined the influence of fluidisation and vibration during the dosing period of the components on the intensification of the interaction of the dispersed phase according to the principle of discrete-pulse energy input, which creates rapid changes in the movement of the components. The functional dependence of the uniformity of the formation of bubbles of the medium on three factors $\upsilon t=f(h, V, \upsilon_c)$ was obtained with the verification of the homogeneity of dispersions, the adequacy of the obtained functional dependence and the search for its optimum. The materials considered in this paper represent the practical value of the effective process of uniform distribution of recipe components in the working chamber of the mixer design under study, with the creation of favourable conditions for the formation of the foam structure

Keywords: mixer, mixture, fluidisation, vapour

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Introduction

This study evaluates the component of the technological process of the interaction of components in the working chamber of the machine with the possibility of effective mixture formation based on their redistribution with the creation of local zones.

In the conditions of a market economy, the best process and equipment will be those that optimise technological processes with lower energy and material costs. After all, the property of the interaction of component particles and the amount of surface tension depends in each case on the nature of the phases of the mixing process. The influence of the surface layer of the phase on its total costs is determined by the specific energy. The excess of free energy on the surface of the phase distribution is the main reason for the instability of the liquid consistency of the components (in the form of an emulsion) because according to the principle of thermodynamics, the most stable state of the system corresponds to the minimum value of the surface energy [1; 2]. The uniform concentration of the suspension in the entire volume of the mixer has an effect on the course of the technological process, and therefore, it is an important condition for all particles of a solid body to be in a liquid in a suspended state. Therefore, the need to create large liquid turbulence around the flour to reduce the thickness of the laminar layer at the liquid-solid interface remains relevant today.

For the most part, the equipment for mixing components is chosen considering the specific features of production, the specified productivity, the characteristics of raw materials, the quality indicators of the finished mixture and the economic capabilities of the enterprise. Mechanical mixing in the food industry is widely used due to the simplicity of the design of the working chamber and mixing working bodies. According to the authors [3], working bodies not only serve for mixing, but are devices in the process of homogenisation of non-Newtonian liquids. They have a uniform and intense mass exchange between the solid phase and the liquid.

Technological machines of different designs differ in the degree of impact on components [4]. This effect leads to the production of a final product with different structural and mechanical properties and finished products of different quality. Investigation of the influence of individual mixers on the properties of semifinished products allows searching for the most appropriate designs to determine the optimal mixing modes.

The authors [5] note that currently, when choosing such technological equipment or carrying out modernisation with appropriate parameters, the necessary microstructure of the semifinished product, which allows establishing high-quality contact interaction, is not considered. Therefore, a promising area for mixing a mixture of components is the use of a new generation of equipment, which would increase turbulence and flow circulation while reducing energy consumption and metal consumption.

The development of equipment design for the preparation of liquid water-flour semifinished products, emulsions, suspensions of Ukrainian production is practically absent today, and the existing ones are quite conservative and ineffective. In these machines, the requirements set by modernity are poorly solved. The action of the working body and the working chamber of the machine is partially absent or unbalanced, and the mixing mode is not regulated, which leads to increased heating of the medium with insufficient aeration [6].

Today, there is a constant search for improving the process. The authors of the studies and researchers are constantly seeking areas for continuous mixing, reducing time, improving the design and ease of maintenance [7]. This is one of the shortcomings of the existing mixers, which is why there was a need for an innovative design of the mixer using vibrating flour dosing and a device for dosing liquid components. The essence is to combine several processes to intensify mixing and then mix components without forming dead zones in the working chamber of the machine.

Scientific research in this area of knowledge opens ways to modernise the existing and develop innovative equipment designs with the necessary parameters. *The purpose of this study* lies in an optimisation of the kinetics of dissolution of a dispersed mixture of flour and liquid components during their mixing in a suspended state.

Literature Review

The problem of dissolving solid particles (flour) today is carried out by mechanical, pneumatic, combined mechanical with vibration, discrete-pulse mixing with a moving or stationary layer of solid and liquid phase [8].

It is known that flour is a high-molecular biopolymer in a crushed (dispersed) state and is a powdered adsorbent [8]. The specific surface area of diverse types of wheat flour ranges within 60...270 m^2/kg. Flour, especially from hard varieties of wheat, comprises discrete parts with a size (100...200 μm), and starch granules, e.g., have a size within (5...40 μm) and, usually, can be larger than protein molecules.

The main significance of the interaction of flour with liquid is their flow under conditions of shear deformation. Under the action of working bodies, there is a relationship between the physical and chemical properties of the components and the temperature and force applied. A special section of mechanics – rheology – considers the study of all aspects of medium deformation under the action of applied stresses [9].

The study [10] noted that the formation of a high-quality mixture depends on obtaining a uniform concentration of solid particles in a liquid over the entire volume of the apparatus. Therefore, the mixing process is considered as a purely mechanical process of mutual penetration. The purpose of penetration is aimed at obtaining the most uniform continuous medium. The interaction of particles of a continuous medium with some physical properties between particles of a continuous medium with other physical properties creates new properties that differ from the properties of mixed media [11].

The authors of scientific papers [12; 13] considered models of fluidisation of polydisperse suspensions. Based on the physical essence of the process, a set of equations for modelling a polydisperse system was proposed. In the work based on research, these equations are presented based on grapho-analytical dependencies, but these developed equations do not fully consider the movement of particles.

In the study [14], a mixer containing a cylindrical body with a bottom, a lid, a centrally vertically placed shaft with poppet working bodies is presented. The working cylindrical chamber has mounted brake blades. Thus, the study [15] states that the use of fluidisation and vibration during the dosing of components at the first stage of mixing intensifies the technological process with a dispersed phase. This approach, which is called the principle of discrete-impulse energy input (DIEE), is based on the effective use of the above-mentioned mechanical and other physical effects that occur in a fluidised medium of rapid changes in the movement of components and internal pressure.

The ideology of DIEE implies the presence of many evenly distributed flour particles and bubbles in the formed liquid phase. The behaviour of any individual particle is determined by the influence of the nearest other neighbouring particles. Dynamic characteristics at the local point of the liquid are considered, taking into account the influence of all particles of the dosing components. This leads to the formation within the liquid phase of chaotic, continuously variable in time and space fields of velocities and pressures. The microcurrent in the interphase space has a vortex nature. This creates pressure and velocity fields that resemble the corresponding fields in a turbulent fluid flow [16].

Consequently, the spatiotemporal structure of the flow during pulsed energy input constitutes a factor in the formation of the interface of the phases of concentrated energy dissipation zones. As a result, various powerful factors develop in the boundary layer, which intensify the transfer of heat and mass. All this leads to an increase in the intensification of heat and mass transfer and added mixing.

Apart from hydrodynamics, the kinetics of the process are important components of dissolution. The total dissolution component of the process is determined by the intensity of the kinetics and diffusion stages. They determine and establish the time course of the process with its speed of passage. Clearly, this determines the performance of mixers [17]. The development of mathematical models of process kinetics is based on research in the field of heterogeneous solution [18].

The rate of heterogeneous processes is affected by the size of the interfacial contact surface and diffusion. The authors in [19] note that the increase in the speed of the process occurs mainly due to the renewal of components on the surface of the phase contact, since the diffusion rate is insignificant. Continuing this process of heterogeneous reaction, in the work of the authors [20], the component of several consecutive stages between the liquid phase and flour particles was revealed. The resulting speed of the entire process is determined by the speed of phase interactions.

To facilitate the analysis of the mixing process and the establishment of stage rational parameters, the authors [21; 22] improved the proposed three-stage process model. The essence of the stage model proposed by Professor O.T. Lisovenko, which is also based on the developments of H.D. Cheishner, N. Quendt and other inventors, is discussed in detail in the paper of the authors [23].

An essential component in concentration studies is the speed of movement of a solid flour particle when dissolved in the liquid phase. In the study [24], researchers concluded that the rate of dissolution of a flour particle is proportional to the difference between the concentration of the formed solution and its saturated concentration. Mixing in a fluidised state and using rotating agitators is a process with a crucial influence of hydrodynamics on the state of the medium, product, and productivity [25]. The design parameters of the mixer are actively involved in the formation of the speed of turbulent and convective transfer at the stage of mixture formation. This stage directly affects the efficiency and determines the level of mixing, i.e., the dissolution of solid flour particles to form a homogeneous concentration. When mixing mutually soluble liquids and flour, the mixer design sets the duration of structure formation due to the hydrodynamics of the moving flow [25; 26].

Materials and Methods

Diverse types of flour are used to produce flour products. First-grade flour, yeast, salt, water, and auxiliary raw materials to produce foam were used in the research. Experimental and theoretical studies were carried out based on the Ivan Puliui Ternopil National Technical University. A mixture of first-grade wheat flour with a humidity of 13.9±0.2%, a raw gluten content of 24% and a stretchability of 14 cm was prepared. Water with a temperature of 32-35°C was used for mixing flour and pressed yeast. The temperature was measured using a TLS thermometer. The dose of the components was measured on an electronic scale with a measurement range of up to 0.1 g. The Benetech GM533A device was used to determine the temperature regimes during the preparation of the steam; quality of dispersion of components and their interaction with flour in a suspended state was used digital camera CANON EOS Wi-Fi 4000D 18-55 DC III (3011C004AA); the quality of the interaction of the components was determined using a My First Lab MFL-06 Duo-scope microscope.

Sampling was carried out according to DSTU 7045: 2009 [27]. Quality control of sourdough was carried out according to generally accepted methods [28]. FlowVision software [29] was used to determine the necessary parameters and operating modes, as well as modelling of the corresponding process. It is based on a finite-volume method for solving hydrodynamic equations based on a rectangular adaptive grid with local grinding. This allowed importing geometry from CAD (computer-aided design system) systems with information exchange with a finite element analysis system.

To conduct the study, the department staff developed and manufactured a new prototype of the mixer (Fig. 1). The basis of the mixing method is the moistening of dust-like flour particles in a suspended state with a jet of liquid under pressure and the interaction of components aimed at the intensity of the influence of heat and mass transfer in the model sourdough composition.

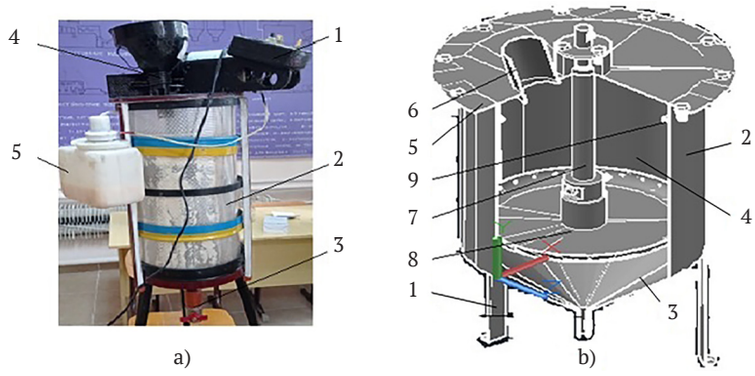

Figure 1. General view of the mixer a): 1 — control panel, 2 — cylindrical working chamber, 3 — nozzle for discharging the paste, 4 — flour vibratory dispenser, 5 — dispenser of liquid components; 3D model b): 1 – body, 2 – cylindrical and 3 – conical parts of the working chamber, 4, 5 – lid with an inlet 6 for flour dispensers, 7 – drive shaft with plate discs, 8, 9 – jet sprayers

The technological process of the stage formation of sourdough is based on the fact that a jet of liquid components accelerated in the air meets with sprayed flour particles in free fall. As a result of such interaction, the resulting mixture partially takes them away, hits the cylindrical wall of the working chamber 4 and the rotating disc-shaped 9 working body. The previously formed liquid mixture of components under the action of gravitational forces falls on the blades (1), is sprayed and receives an added speed. Such conditions contribute to the creation of a large surface of phase contact of wetted flour particles. This actively affects the formation of the mixture with some acceleration, where the speed decreases at the bottom of the chamber. Thanks to the kneading chamber configuration, the component jets swirl and automatically descend. They accumulate there and constantly receive mechanical action from the rotating kneading body.

To investigate the temperature field and uniformity of the mixture, a scheme for placing thermometers for measuring temperatures in the zone of the suspended state of interaction of metering components was developed. Using T_1 thermometers, temperatures were measured in coordinates Y=15 cm, Z=20 cm. T_1 was measured in the range of change X=10 cm, and T_2 in the range of change X=10...30 cm. The layout of temperature measurement zones and the interaction of components is presented in Figure 2.

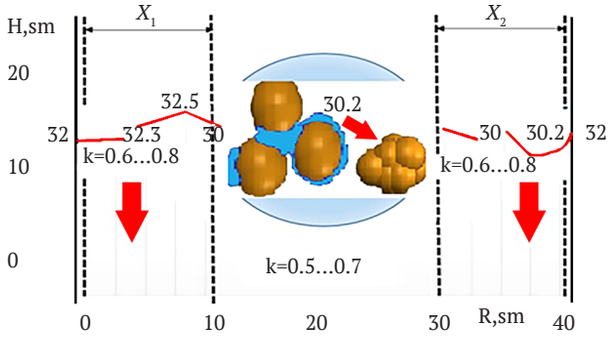

Figure 2. Calculation scheme of the pseudo mixing flow formation process

The study of the mixing process was carried out according to the Box-Behnken plan [30]. This allows getting the maximum amount of objective information about the influence of factors on the mixing process with the least number of experiments, i.e., they provide a regression model in the form of a full quadratic polynomial. Processing of experimental data was carried out using the "Statistica-12" application software package for a computer. The coefficients of the regression equation were determined using the standard method. The best modes were determined by substituting vectors of limited values in the target function under the conditions of sourdough preparation technology on a mixer. The data of experimental studies were processed using the Microsoft Office software package.

The limit of variation of the factors of the full factorial experiment type 3*k* was used. The homogeneity of variances, the adequacy of the obtained functional dependence and the search for its optimum were checked in the Maple computer mathematics environment [31].

Results and Discussion

Considering the mixing of components during vibration delivery and the outflow of liquid in a suspended state, the final effect of the working bodies on mixing is provided. The working chamber with cylindrical volume 2 (Fig. 1) and

the conical bottom 3 is placed on the frame of the housing 1. The cylindrical chamber, respectively, has a nominal volume for the fluidised bed process and a volume for mixing by working bodies. The level of mixing of liquid sourdough upon dosing components in the suspended state was determined by the height of the resulting mixture. Determining the height h_c of the resulting mixture allows establishing the design parameters of the mixer. Therefore, the height h_c of the resulting mixture was determined according to the following formula:

$$h_c = \frac{4\sum_{i=1}^{n} V_k}{\pi D_1^2} \quad (1)$$

where $4\sum_{i=1}^{n} V_k$ is the total loaded volume of mixed components, m^3; D_1 is the diameter of the cylindrical part of the working chamber of the mixer, m.

This allowed achieving uniformity during the mixing of sourdough at the established hydrodynamic flows of the forming mixture.

A distinctive feature of hydrodynamics is that within values 0⩽X⩽10 cm, components move with a constant K=0.8 (uniformity). In the zone of axial interaction 10⩽X⩽30, 3D surface mixing of components occurs at 30.2°C and at k=0.7. And at 30⩽X⩽40, the constant was also k=0.8, and the movement of the resulting mixture directed down the chamber wall is created.

Notably, such hydrodynamics of the interaction of components due to the increase in the zone of distribution of the liquid phase and flour ensured a mechanically symmetrical geometric shape of the temperature zone from 32°C to 32.2°C, at 10 mm from the wall of the working chamber. The authors in [32] covered the results of modelling the process of mixing components during the preparation of liquid vapours. The simulation was carried out based on the use of the energy of air and water flows under pressure. The basis of the method of making sourdough is the effect of a liquid jet on a dusty particle of flour in a suspended state. Accordingly, rational values of component feed rates were established, and energy dissipation in the device was investigated.

Therefore, the authors of this paper and the authors of [33; 34] believe that improving the energy efficiency of mixing is possible under the condition of rational parameters of the jet device and technological parameters of the mixing process. This result can be obtained by discrete-pulse dosing of components with the introduction of the ejector design of the nozzle system of the component mixer (jet device). The design of the device (nozzle) [35] is based on creating the maximum phase velocity difference. The resulting phase difference after leaving the nozzle creates conditions for dispersion, since there is a thermodynamic process of converting the potential energy of the flow into kinetic energy, which accompanies an increase in the speed and a decrease in the flow pressure. The level of binding of a small amount of liquid phase active hydrophilic groups of flour particles contributes to the formation of water shells. The interaction of the liquid phase with flour occurs not only on its surface, but also in volume. The process proceeds with the release and absorption of heat (exothermically). The amount of liquid phase retained by about 30% does not lead to a considerable increase in the particle volume (Fig. 2).

This fact is confirmed in studies [36; 37], which describe the method of dissolving components during pneumatic mixing. They established the advantages of pneumatic mixing, which are based on intensive mass transfer between the solid phase and the liquid. The use of compressed air for mixing simplifies the internal design of the device.

Thus, the water-absorbing capacity of flour is affected by its dispersion, i.e., the size of the particles from 0.015 to 0.003 m. Reducing the particle size to 0.012 g contributes to an 8% increase in the specific surface area per unit mass of flour. Therefore, more water can be adsorbed. Thus, the absorption of water by flour particles with small dimensions occurs 45 seconds faster. Hence, experimental studies of the proposed design of the discrete-pulse mixer on the uniformity of the supply of sprayed liquid components and the mass of flour dosed by the vibrodoser on their interaction in a suspended state constitute the area of the conducted research.

The experimental research conducted by the authors [38] determined the parameters of the screw-type conveyor-mixer under which the homogeneity of the mixture is formed (up to 96%). The impact of vibration on the process of movement of the feed mixture and the uniformity of its preparation was also noted.

Therefore, the basis of the method of mixing in a suspended state is the moistening of dust-like particles of flour with a jet of liquid under pressure under the condition of a thermodynamic model of the interaction of components aimed at the intensity of the influence of heat and mass transfer in the model steam composition. All these effects involve improving the kinetic and diffusion effects on the process and establishing the performance of the mixers [39]. Furthermore, of importance is the area of heterogeneous influence during the interaction of flour with liquid components [40].

Notably, the technological process of the preparation stage of the foam is because the jet of liquid components accelerated in the air hits the sprayed flour particles during free fall. Meanwhile, the time of interaction of flour and liquid components in the pre-mixing chamber until they reach the lower part of the chamber is $\tau 1$=5-10 s.

During the interaction of flour with a dispersed jet of the liquid phase, a mostly chaotic process takes place, i.e., their mixing interaction. Thus, in the case under study, under the influence of vibration and mixing in a suspended state by transformations of internal friction forces, the resulting mixture goes into a quasi-equilibrium state.

Therefore, the study considered the mathematical description of the process of forming an extended flow of liquid and a dispersed flow of flour particles, formed by a flour vibrator and a spraying nozzle. The objective function, which characterises the uniformity of the formation of a particle of a mixture of dosing components υ_t, is the coefficient of variation [1] of the time t_1 of its formation:

$$\upsilon_t = \sigma / T, \quad (2)$$

where σ is the mean square deviation of time t_1 of formation [13]; T is the mathematical average of time t_1 of formation [16].

The studies of the interaction of components at the stage of pseudomixing allow establishing the most influen-

tial controlling factors. The influence of control factors on the target function υ_t include:

– the relative height of the medium is formed by the interacting components in the working chamber of the mixer $h=H/D$, m;

– speed of movement of the medium V, s^{-1};

– coefficient of variation in the size of the medium bubble, υ_c %.

The coefficient of friction of the formed bubble in the medium was not considered as a controlled factor since the Archimedean repulsive force acts.

The variable influence of the control factors of the objective function is based on the use of factors at 3 levels. The level selection of factors and variation intervals was made based on theoretical justification, the results of earlier experimental studies (Table 1).

Table 1. *Variation of the factors of a complete factorial experiment of type 3k*

Indicators	Factors		
	h, mm	***V, s^{-1}***	***v_c, %***
Upper level	1.7	10	8
Zero level	1.5	15	5
Lower level	1.3	20	2

To increase the accuracy of response determination and to determine the absence of influence of uncontrollable and unmanageable factors, each experiment was performed in 5-fold repetition. The functional dependence of the uniformity of the formation of medium bubbles on three factors $\upsilon_t=f(h, V, \upsilon_c)$ was obtained. The limits of variation of the factors of the full factorial experiment of the 3*k* type are presented in Table 1.

Based on this, the obtained empirical model of the complete polynomial of the second degree allows revealing the functional dependence. This dependence characterises the change in the uniformity of the distribution of bubbles in the resulting mixture of sourdough components in the suspended state of the mixer, natural factors:

$$\upsilon_t=423.7+193.8\cdot h_2+0.34\cdot\upsilon_{c2}+0.04\cdot V_2-563.6\cdot h-6.6\cdot\upsilon_c-0.7\cdot V+4.04\cdot h\cdot V+0.03\cdot V\cdot\upsilon_c \quad (3)$$

A comparison of the estimated $F_{CALC}=4.9$ and tabular $F_T=19.3$ of Fisher's criteria allows accepting the hypothesis about the adequacy of the obtained mathematical model (3) with a 95 percent probability.

From the analysis of experimental data and the obtained dependence (3) (Fig. 3), it was established:

– the uniformity of the component feed should be a monotonous and increasing function of the change in the size of the medium bubble;

– for υ_c=3%, h=1.5 and a change in the dosing speed V from 10 to 13 m/s, the uniformity of interaction decreases from 9.4 to 9.1%, and then increases monotonically;

– the uniformity of the supply of components at υ_c=3% and the convex function of the speed of movement V acquires a value at h=1.4...1.5, and at the limits of variation h increases by 10...15%.

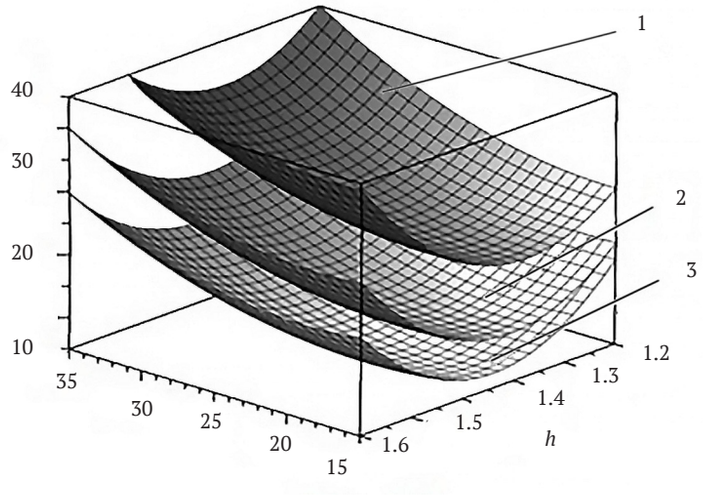

Figure 3. Dependence of the uniformity of the formation of the medium during the dosage of components on the relative height h, the speed of movement V and the coefficient of variation of the droplet sizes, υ_c *:1-*υ_c*=8%; 2-*υ_c*=5%; 3-*υ_c*=2%*

It is rational for the proposed design of the mixer and the technology of discrete-pulse dosing of components to occur under the uniformity of the supply of components. Thus, for υ_c=3%, the dependence of the uniformity of the dosage of components on the relative height *h* and the speed of movement *V* will have the following form:

$$\upsilon(\upsilon_c=3\%)=193.8\cdot h^2+0.039\cdot V^2-0.264\cdot h\cdot V-551.5\cdot h-0.62\cdot V+406.9 \quad (4)$$

The obtained expression of the differential function of the distribution of the number of particles by the angular scattering of the dosing components allows describing the structure of the dispersed flow formed during mixing in the pseudo-layer.

Nowadays, optimisation of mixing parameters is based on a detailed study of processes. Undoubtedly, at the same time, it is necessary to consider several influencing factors of this system on the viscous medium by choosing analytical methods in the presence of the necessary models, or their development. It is rational to approach the phenomena of rheology together with the postulate of thermodynamics and the transfer of information, precisely because of the energy connections of the processes during mixing. The technological process of using discrete-pulse energy input and the influence of the working body on the flow of a rheologically complex system, considering the design developments of the new mixer and theoretical models, involves the accurate calculation of characteristics aimed at optimising design and technological solutions.

Conclusions

Based on the obtained results of the process of mixing the components in the considered design of the mixer, it was established that the creation of favourable conditions for the formation of the foam structure is ensured by the uniform distribution of recipe components (flour, yeast, water) at a flour supply speed of 2 m/s and a liquid supply speed of 50 m/s.

The proposed mathematical empirical model in the form of a full polynomial of the second degree allows for an approximate calculation of the uniformity of the formation of the medium, which contributes to the determination of the rational geometric parameters of the mixer in a balanced state. The quality of the formation of the medium (sourdough) in a suspended state for this design of the mixer is ensured by the uniform supply of liquid components and dosing of flour at the set height *h* from 1.3 to 1.5 cm of the upper part of the working chamber and at the speed of movement of the formed mixture *V* from 25 to 35 m/s.

The formation of qualitative characteristics of liquid flour masses allows further predicting the process of interaction of fats with the constituent components. The mechanism of the process during kneading is determined by the parameters of this mixer and the quality of the flour. This practical issue of the mixing process cannot be solved analytically because its mechanism is complex. Therefore, the problem was solved in a planned experimental way using process models and mathematical statistics to obtain maximum results.

Undoubtedly, the temperature, humidity of the system, the intensity, and duration of mixing, the amount and composition of introduced fats constitute a study of structure formation, chemical composition, and properties of the physical state of the system under the action of a new mixer. The effect of fat dispersion in the form of droplets or balls, enveloping the flour proteins, prevents the penetration of water into the flour proteins. The design of the mixer allows predicting the reduction of their swelling by trapping air, which leads to a decrease in the density of the medium. Hence, further studies of the discrete-impulse effect on the components are expected to uncover these processes with justified optimisation.

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Визначення раціональних параметрів псевдозмішування шляхом комплексного моделювання робочих процесів

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Анотація. Напрям підвищення якості утворення сумішей при змішуванні в харчовій промисловості є актуальним, оскільки удосконалення технології й обладнання для здійснення обробки компонентів різними методами, характером та ступенем впливу практично досяжні для їх удосконалення. Мета дослідження – удосконалення конструктивних параметрів та підвищення ефективності роботи змішувача шляхом створення умов, що забезпечить оптимізацію кінетики розчинення дисперсної суміші борошна та рідких компонентів під час їхнього псевдоперемішування у зваженому стані. Розглянуто властивості сировини на методи її визначення якості, запропоновано лабораторні методи та інструменти проведення досліджень при встановленій методиці планування з аналізом отриманих результатів та використано програмний комплекс Flow Vision у побудові графіку на основі законів термодинаміки. Обробку експериментального масиву даних проведено математичним описом процесу формування потоку рідини та дисперсного потоку частинок борошна. Використано неповнофакторну багатовимірну модель апроксимації експериментальних даних функції трьох змінних у вигляді поліномів трирівневим планом Бокса-Бенкіна з 13 дослідами, виконаних у 5-кратній повторності. Проведено аналіз змішувачів періодичної дії, розглянуто перерозподіл і трансформацію деформацій при оптимальних режимах змішування. Встановлено взаємодію компонентів та їх динаміку потоків при мінімізації енерговитрат. Визначено вплив псевдозрідження та вібрації в період дозування компонентів на інтенсифікацію взаємодії дисперсної фази за принципом дискретно-імпульсного введення енергії, що створює швидкі зміни руху компонентів. Отримано функціональну залежність рівномірності утворення бульбашок середовища від трьох факторів $\upsilon_t=f(h, V, \upsilon_c)$ з перевіркою однорідності дисперсій, адекватності отриманої функціональної залежності та пошук її оптимуму. Розглянуті матеріали статті становлять практичну цінність ефективного процесу рівномірного розподілу рецептурних складових в робочій камері розглянутої конструкції змішувача із створенням сприятливих умов для утворення структури опари

Ключові слова: змішувач, суміш, псевдозрідження, опара

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Effectiveness of Using Beer Groats in the Technology of Semifinished Fish Products

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Abstract. The relevance of this study is conditioned upon the practical need to use beer groats as a structure-forming agent in the technology of fish moulded semifinished products. In this regard, this study is aimed at identifying the effectiveness of using beer groats in the technology of fish moulded semifinished products, namely the organoleptic and functional-technological properties of finished products. To solve the tasks set, generalisations, comparisons, and the following research methods were used: moisture content – by drying the sample to a constant mass; ash content – by the generally accepted weight method; fat content – by the Soxlet method; protein content determination – by the Kjeldahl method according to DSTU 8030, DSTU 8718; weight loss during heat treatment of samples was determined by weighing before and after heat treatment. This paper presents the results of studies of the physical and chemical parameters of minced meat from chilled and frozen common rudd, namely: water retention capacity, stability of the emulsion and weight loss upon heat treatment, which confirmed the need to use structure-forming agents to improve the functional and technological properties of minced meat. The results of studies of the viscosity and stickiness of minced fish indicate that the adhesive properties of muscle tissue are reduced when frozen. This can be explained by the fact that denaturation changes occur during freezing, which affect the protein structure. The paper presents the results of studies of the chemical composition of beer groats, depending on the degree of grinding. During the research, it was found that the composition of beer groats with a particle size of less than 0.73 mm is the best choice for adding as a structure-forming agent, more than 0.73 mm is advisable to use as breading. A comparative organoleptic evaluation of the quality of finished fish products with different breadings showed that breading fish cutlets in beer groats is promising, as it improves the organoleptic indicators of the quality of the finished product: the crispy crust gives the finished dish an attractive appearance and complements the taste. The practical value of this paper lies in the possibility of using research data in the brewing, fishing, and other branches of the food industry for effective, waste-free use of raw materials to produce high-quality goods

Keywords: minced fish, structure-forming agents, functional and technological properties, breading, fish cutlets

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Introduction

Analysis of the market of fish semifinished products in Ukraine indicates that the Ukrainian consumer is increasingly making a choice in favour of frozen semifinished products, which save time on cooking. The most common are cutlets, meatballs, chops, dumplings, and varenyky. The largest share falls on moulded semifinished products [1-3].

Ukrainian scientists – N.M. Oliinyk et al. have established that the frozen food market in Ukraine has quite a large potential. However, there are also problems that hinder the development of the entire industry. First, these issues include technological difficulties, seasonality of demand, the need to organise "cold logistics", weak quality control of raw materials, and the duration of return on investment [1].

The study by L. Peshuk et al. presents the results of the development of meat and fish moulded semifinished products for herodietic nutrition. To produce meat and fish semifinished products, poultry meat was used, as the most accessible raw material for the Ukrainian consumer, as well as sea fish – hake, pollock, oceanic – saithe, haddock [2].

However, to improve the consistency of finished products, it is relevant to introduce structure-forming agents into the recipe of minced fish and moulded semifinished products. Accordingly, the selection of an optimal, cost-effective structure-forming agent is an urgent task.

The use of plant-based additives in the production of moulded fish products allows not only regulating the structural properties of minced meat systems, but also improving their organoleptic parameters, nutritional and biological value, and enriching them with dietary fibre. These statements are supported by N.V. Holembovska, S. Ikram in their papers. The authors believe that currently the topical issue is the enrichment of the daily diet with biologically active substances contained in plant raw materials. They effectively eliminate the deficiency of vitamins, organic acids, and minerals [3; 4].

I.V. Dietrich et al. improved the technology of semifinished products based on hydrobionts using vegetable raw materials. Due to the modification of the recipe of fish-squid semifinished products, namely: adding pumpkin, a new product was obtained that has improved organoleptic properties, compared to the prototype [5].

Notably, Ukrainian breweries have a large amount of waste, 80-85% of which is beer groats, which contain vegetable protein, carbohydrates, fibre, macro- and microelements, lipids. According to its functional and technological properties, malt beer groats belong to food additives that improve the consistency of moulded semifinished products. This additive is used in various industries, namely petroleum, medical, construction, etc. However, research on its application in the food industry is quite limited. Yi-Ting et al. improved the technology of making cupcakes using beer groats flour. The authors note that today the use of flour in the production technology of cupcakes is relevant, since this additive is a valuable source of minerals, protein, and fibre. It is also proved that beer groats flour reduces the ability of wheat flour to form a gluten framework, weakens the elastic properties of gluten and limits its ability to swell [6].

In the production of minced fish and culinary moulded semifinished products, the task of improving their functional and technological properties arises, which can be solved by using various structure-forming agents.

The studies of Ukrainian researchers address the theoretical framework of the technology to produce moulded fish semifinished products using various food additives [7-9;]. However, there are no conceptual developments in the field of research of fish moulded semifinished products with the addition of beer groats, which determines the relevance and practical significance of this study.

The purpose of this study was to establish the feasibility of using beer groats in the production technology of minced fish and culinary moulded semifinished products, namely fish cutlets. To achieve this purpose, the following main tasks were set: to analyse the current state of the market of moulded semifinished products, to identify promising areas for research of beer groats in the technology of fish moulded semifinished products.

Materials and Methods

The study was conducted in May-August 2021 based on laboratories of the Faculty of Food Technologies and Product Quality Management of the Agro-industrial Complex. The objects of the study were formed fish semifinished products, namely cutlets based on minced meat from common rudd and champignons with the addition of beer groats (sample 1), cutlets based on minced meat with the addition of beer groats (sample 2). The control selected cutlets based on minced pollock.

The technological process of production of fish cutlets included the following stages: washing, chopping fish, cooking minced meat, forming the product, breading, heat treatment, preparation of added components, packaging, cooling, and storage. Dry beer groats were crushed and sifted into 2 fractions, then sent for breading and cooking minced meat. Beer groats were used as breading – 5%, structure-forming agent – 4%.

Moisture content – according to the method of drying the sample to a constant mass; ash content – according to the generally accepted weight method; fat content – according to the Soxlet method; protein content determination – according to the Kjeldahl method according to DSTU 8030, DSTU 8718 [10; 11].

Creating recipes for fish moulded semifinished products, cutlets were taken as a control sample, the recipe of which included minced pollock, onions, carrots, black pepper, salt, sugar, water, wheat bread, egg powder, milk powder, butter. Wheat flour was used as breading. The recipe of the developed sample No. 1 included minced meat from common rudd with the addition of beer groats and champignons, sample No. 2 – minced meat from common rudd with the addition of beer groats and sweet pepper. In prototypes No. 1 and No. 2, breading from beer groats was used.

Organoleptic quality assessment was performed according to the 5-point scale developed by the authors of this paper (Table 1).

***Table 1**. Rating scale for fish semifinished products*

Indicator	Feature	Points
Appearance	The structure is irregular in shape, without breading	1
	Partial breading, deformed structure	2
	Structure changed, partial breading	3
	The structure is normal, the breading is not uniform	4
	Regular shape structure, full breading	5
Product colour	Very modified, with grey inclusions	1
	Heterogeneous, with grey inclusions	2
	Normal, characteristic, with light grey inclusions	3
	Pleasant, characteristic of this type of product	4
	Homogeneous, characteristic of this type of product	5
Colour on the cut	Raw meat on the cut	1
	Uneven, colourless, grey	2
	Brown meat	3
	Light meat	4
	White meat on the cut	5
Smell	Unpleasant, very sharp	1
	Unpleasant, sharp	2
	Normal, slightly modified	3
	Nice, fishy	4
	Pleasant, harmonious	5
Taste	Unpleasant, repulsive	1
	Altered, unpleasant	2
	Normal, slightly modified	3
	Nice, fishy	4
	Harmonious, pleasant, fishy	5
Consistency	Brittle, hard, dry	1
	Slightly brittle, hard, dryish	2
	Not tender enough, not juicy	3
	Dense, slightly soft, tender	4
	Juicy, dense, tender	5
Juiciness	Fragile, decaying, with grey inclusions and voids	1
	Slightly disintegrates, with grey inclusions and breaks	2
	Preserved shape, slightly disintegrating, soft	3
	Well-preserved shape, not fragile, not falling apart, soft	4
	Fully preserved, undamaged shape, uniform	5

Stickiness and viscosity were determined by loading on a FUDOH type rheometer, using spherical steel indenters with a diameter of 5 mm and 10 mm, an indenter movement speed of 6 cm/min, at least 10 tests were performed for each sample. The depth of immersion was set to 10 mm.

Mass losses during heat treatment of samples were determined by weighing before and after heat treatment (after cooling to 40±2°C).

Results and Discussion

At the first stage of research, the functional and technological properties of minced meat from common rudd were determined, namely: emulsion stability (ES), water retention capacity (WRC), losses during heat treatment (LHT) (Table 2).

***Table 2**. Physical and chemical parameters of minced meat from chilled and frozen common rudd*

Type of fish	ES, %	WRC, %	LHT, %
Common rudd, chilled	88.4	66.3	11.3
Common rudd, frozen	82.9	63.3	15.5

The results of studies show that the physico-chemical parameters of minced meat from chilled common rudd have high values of emulsion stability and water retention capacity, which explains the low values of their LHT. However, in frozen fish, these indicators decrease, and LHT increases. Accordingly, it is necessary to use structure-forming agents to maintain the functional and technological properties of minced meat at a high level.

It is known that the viscosity of minced meat is one of the indicators that directly described the quality of minced meat [13]. The viscosity of minced meat from chilled common rudd is 37.4 Pa•s, frozen – 61.3 Pa•s. Notably, in minced frozen fish, the stickiness index changes, which indicates that the adhesive properties of muscle tissue decrease upon freezing (Table 3).

***Table 3**. Rheological indicators of minced meat from common rudd*

Type of fish	Viscosity, Pa·s	Stickiness, Pa
Common rudd, frozen	61.3	2300
Common rudd, chilled	37.4	2560

This is explained by the fact that denaturation changes occur upon freezing, which directly affect the protein structure [7; 8; 14]. To improve the consumer properties of fish cutlets, it is advisable to use various food additives.

Malt beer groats are a natural product, from light yellow to deep brown, with a specific bread flavour [15]. Studies have shown that dry beer malt groats, divided into fractions, have a different chemical composition (Table 4).

***Table 4**. Chemical composition of beer groats, depending on the degree of grinding*

Size of particles, mm	Water	Lipids	Protein	Mineral substances	Carbohydrates
Less than 0.25	4.1	6.8	25.9	2.0	61.2
0.25	4.0	6.1	22.5	2.4	65.0
0.58	4.3	4.9	18.5	2.9	69.4
0.73	4.4	3.5	16.1	2.7	73.3
1.0	5.1	4.3	12.4	2.8	75.4

The composition fraction of beer groats with a particle size of less than 0.25 mm contains the largest amount of protein and lipids – 25.9% and 6.8%, respectively, but the amount of carbohydrates in it is 61.2%, as well as minerals (2.0%), which is the lowest value compared to other fractions.

According to the studies conducted, the composition of beer groats with a particle size of less than 0.73 mm is the best choice for adding as a structure-forming agent for fish cutlets. Thus, it is advisable to use a fraction with a particle size greater than 0.73 mm as breading. Recipes for fish cutlets are presented in Table 5.

***Table 5**. Recipes for fish cutlets per 100 kg*

Components	Consumption, kg		
	Control	Sample 1	Sample 2
Minced meat from common rudd	–	59.3	51.0
Minced pollock	62.5	–	–
Fresh onion	4.0	4.0	3.0
Carrot	5.0	–	–
Black pepper	0.2	0.2	0.2
Allspice	–	0.2	
Food grade salt	1.0	1.0	2.0

Table 3, Continued

Components	Consumption, kg		
	Control	Sample 1	Sample 2
Sugar	0.3	0.3	0.3
Breading from beer groats	-	5.0	5.0
Wheat flour	6.0	-	-
Beer groats additive	–	4.0	4.0
Water	6.0	8.0	6.0
Wheat bread	6.0	-	-
Egg powder	4.0	4.0	3.5
Sweet pepper	–	–	6.0
Champignons	–	4.0	–
Dry milk	2.0	2.0	3.0
Olive oil		6.0	4.0
Butter	3.0	2.0	2.0
Total	100	100	100

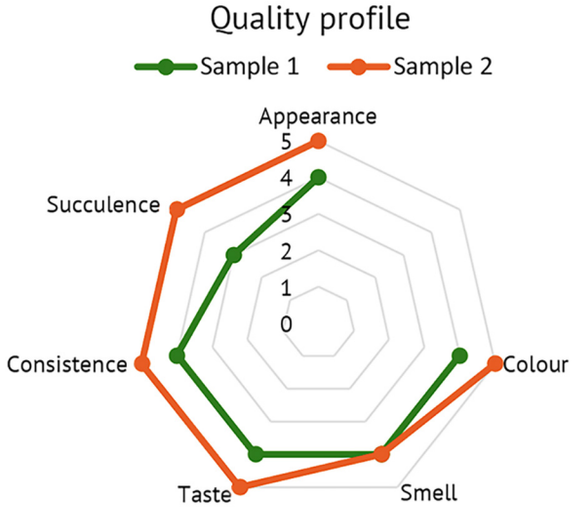

Figure 1. Quality profile

As a result, a comparative organoleptic assessment of the quality of finished fish products with different breading was performed (Fig. 1). Sample 1 – minced fish cutlets in flour breadcrumbs; sample 2 – minced fish cutlets in beer groats breadcrumbs.

According to the results of organoleptic evaluation, sample No. 1 received fewer points compared to sample No. 2. The crust was not tight, due to which the colour of the fried product was uneven, the fish cutlets were not juicy enough and dry. Sample No. 2 received the highest scores. In this sample, breading improves the organoleptic quality indicators of the finished product. The finished semifinished products have a golden colour, are evenly baked, and have a harmonious smell.

Thus, the use of beer groats as breading provides high taste qualities of finished products – carbohydrates contained in beer groats are somewhat destroyed under the influence of elevated temperature and a humid environment, starch is denatured, a ruddy crust forms on the surface of fish cutlets, which gives the cutlets an attractive appearance. The rational amount of beer groats introduced as breading is 5.0%.

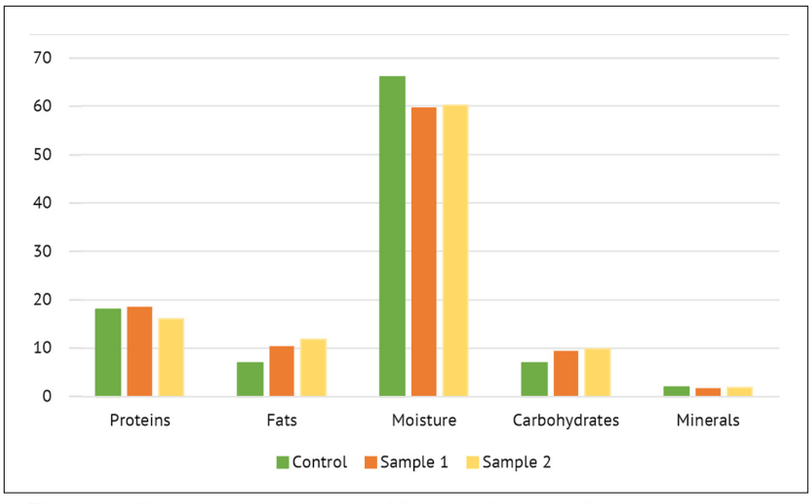

Figure 2. Chemical composition of finished fish semifinished products, %

Developed moulded fish semifinished products are characterised by high-protein values in all samples – 16.1-18.6%, lipids – 7-11.9%, carbohydrates – 7-9.9%, minerals – 1.8-2.0% as components that determine their nutritional value. The high content of lipids in cutlets is associated with heat treatment in heated oil (roasting), where partial absorption of vegetable oil occurs.

Previous studies of researchers have established the effectiveness of using fish as a structural component of minced meat systems. Studies show that one of the key criteria for the quality of minced meat systems is the indicators of higher education institutions. Myofibrillar proteins, which belong to salt-soluble proteins and are characterised by high biological value, are distinguished by high WRC. In the meat of fish (carp, silver carp), their share is from 75 to 80% of the total amount of protein. The high content (compared to meat of farm animals) of hygroscopic proteins explains the reason for the slight loss of moisture during heat treatment of fish, as well as causes high juiciness and yield of finished products. Accordingly, studies have confirmed the need to introduce structure-forming agents into minced meat systems [12].

In the studies by A. Marcus & G. Fox, N. Ishiwaki, et al. comparable results are highlighted, which confirm that the protein content in the beer groats fractions differs by almost 2 times, and primarily depends on the degree of grinding. The content of water, lipids, carbohydrates, and minerals is more stable and differs by 1.2-1.4 times [15; 16]. Scientists have found that breading strengthens the surface layer of fried fish cutlets, gives them a monolithic appearance, the skin is uniform and firmly held on the surface of the product, which provides the necessary juiciness of finished moulded products, a delicate consistency, preserving the fishy taste and smell [17-19].

Conclusions

As a result of the conducted studies, it was found that the physio-chemical parameters of minced meat from chilled red fish are higher than those of frozen fish. ES chilled – 88.4%, frozen – 82.9%, respectively; WRC chilled – 66.3%, frozen – 63.3%. However, the value of the LHT indicator, on the contrary, increases in frozen fish and amounts to 15.5%, in chilled fish –11.3%, which confirmed the feasibility of using structure-forming agents.

It was found that the best choice for adding as a structure-forming agent for fish moulded products is the composition of beer groats with a particle size of less than 0.73 mm, for breading more than 0.73 mm.

According to the results of the organoleptic assessment, it was proved that breading fish semifinished products in beer groats provides an improvement in organoleptic quality indicators of the finished product, compared to breading in wheat flour.

Based on the results obtained, the authors of this paper determined the areas of further research: to investigate the effect of introduced beer groats on the structural and mechanical properties of fish moulded semifinished products during storage.

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Ефективність використання пивної дробини у технології рибних формованих напівфабрикатів

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Анотація. Актуальність досліджень зумовлена практичною необхідністю застосування пивної дробини, в якості структуроутворювача, в технології рибних формованих напівфабрикатів. У зв'язку з цим дана стаття спрямована на виявлення ефективності використання пивної дробини у технології рибних формованих напівфабрикатів, а саме на органолептичні та функціонально-технологічні властивості готової продукції. Для вирішення поставлених завдань використовувались узагальнення, порівняння та наступні методи досліджень: вміст вологи – методом висушування зразка до постійної маси; зольність – загальноприйнятим ваговим методом; вміст жиру – методом Сокслета; визначення вмісту білка – методом Кьєльдаля згідно з ДСТУ 8030, ДСТУ 8718; втрати маси при тепловій обробці зразків визначали методом зважування до та після термічної обробки. У статті представлено результати досліджень фізико-хімічних показників фаршу з охолодженої та мороженої червонопірки, а саме: водоутримуюча здатність, стабільність емульсії та втрати маси при тепловій обробці, що підтвердили необхідність використання структуроутворювачів з метою поліпшення функціонально-технологічних властивостей фаршів. Результати досліджень в'язкості та липкості рибних фаршів свідчать, що адгезійні властивості м'язової тканини знижуються при заморожуванні. Це можна пояснити тим, що при заморожуванні відбуваються денатураційні зміни, які впливають на структуру білка. Наведено результати досліджень хімічного складу пивної дробини, залежно від ступеня подрібнення. Під час досліджень з'ясовано, що склад пивної дробини з розміром частинок менше 0,73 мм є найкращим варіантом для додавання в якості структуроутворювача, понад 0,73 мм доцільно використовувати в якості панірування. Проведена порівняльна органолептична оцінка якості готової рибної продукції з різним паніруванням показала, що панірування рибних котлет в пивній дробині є перспективним, оскільки забезпечує поліпшення органолептичних показників якості готового продукту: хрустка шкоринка надає готовій страві привабливий зовнішній вигляд і доповнює смак. Практична цінність наукової роботи полягає у можливості використання даних досліджень у пивоварній, рибній та інших галузях харчової промисловості з метою ефективного, безвідходного використання сировини для виробництва якісної продукції

Ключові слова: рибний фарш, структуроутворювачі, функціонально-технологічні властивості, панірування, рибні котлети

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Laying and Preservation of Hens of the Industrial Flock Depending on the Density of Their Placement in Cage Batteries

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Abstract. The relevance of this study is conditioned upon the lack of experimentally based data on optimising the density of laying hens of modern egg crosses in cage batteries of new multi-tiered structures. The purpose of this study was to determine the effect of the density of keeping chickens of an industrial herd in cages of 12-tier batteries on their egg production and safety. For this purpose, laying hens of 3 groups of the Hy-Line W-36 industrial flock of crossbreeds were kept in separate similar poultry houses, but at different densities. In particular, the hens of the 1st group were placed in cages at a density of 23 heads/m^2 according to the norms, and the 2nd and 3rd groups – at 26 and 28 heads/m^2, respectively, i.e., at a density of 13.0% and 21.7%. According to the characteristics of this cross, the laying capacity of hens of an industrial flock should be at least 262.2 eggs per initial laying hen for 62 weeks of life. However, in hens of Group 1, it was 231.4 pcs./head, i.e., it was 11.7% against the background of 5.1% lower preservation, which, if optimal paratypic conditions of existence were created, would correspond to the normative level (96.0%). When the density of housing was increased to 26 heads/m^2 (Group 2) and to 28 heads/m^2 (Group 3), the laying ability of hens was 220.8 pieces/head and 227.2 units/head with retention of 91.1% and 88.4%, respectively. An increase in the planting density of chickens of the 2nd and 3rd groups led to a decrease in egg production and safety but yielded more production per 1 m^2 of production areas. Additionally, 3.9-12.9 million eggs were obtained during the 43 weeks of the productive period, including 1.6-5.3 thousand per 1 m^2 of their area. Thus, the specified compaction can be applied as a technological method of rapidly increasing the production of edible eggs without the construction of new or reconstruction of existing farms in case of an added need for this product in the Ukrainian or foreign food markets

Keywords: production of edible eggs, productivity, cage equipment, laying curve, hens of egg crosses, live weight, housing conditions

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Introduction

Overcrowding of chickens in any type of housing (cage, floor, alternative, etc.) adversely affects their laying capacity and viability [1; 2]. Some researchers [3] consider this to be a consequence of chronic stress, which is formed and gradually increases (accumulates) during the uncomfortable keeping of laying hens during the period of productivity. In hens of industrial flocks of modern egg crosses, this period usually lasts up to 72 weeks, i.e., until they reach 90 weeks of age [4]. The density of their maintenance (or provision of an area) is regulated according to the standards of technological design in poultry farming – VNTP-APK-04.05 [5] and other regulatory requirements [6]. In particular [5], the stocking density of hens of an industrial flock of white-egg crosses in cage batteries should not exceed 22-25 heads per 1 m^2 of the floor area of the cage, which corresponds to providing them with an area of 400-450 cm^2/head. However, developers of foreign breeding crosses [4], which are used for the industrial production of edible eggs in Ukraine, recommend keeping laying hens in cages under more comfortable conditions, at a density of 13-20 heads/m^2 (or 490-750 cm^2/head) per the requirements established in their countries (USA, Canada, EU countries, etc.). Disregarding this recommendation due to an effort to obtain as much product as possible from 1 m^2 of available space, most Ukrainian food egg producers keep industrial flock hens in cages with a density of 22-25 heads/m^2 (400-450 cm^2/head) per current standards [5]. Furthermore, to substantially increase the available production areas, some of them also resort to replacing the cage equipment for keeping chickens, namely 3-4-tiered batteries with 6-12-tiered ones. However, the effectiveness of using these multi-tiered cage batteries to produce edible eggs while keeping laying hens of modern egg crosses, extremely productive and at the same time demanding in terms of maintenance conditions, has not yet been investigated.

Under best living conditions, laying hens of modern egg crosses can lay up to 365 eggs per year [4], which is possible with daily ovulation of a new egg cell. Their wild ancestors (*Gallus bankiva*) usually lay only 3-9 eggs per year [7]. Over the 3-5 thousand years of breeding of domesticated chickens, humankind has created many populations and breeds, including specialised egg-laying crosses, the hens of which can lay eggs almost every day under certain conditions. They usually ovulate once a day, namely 30 minutes after laying an egg. Theoretically, it could occur up to 4 times a day, but under the conditions of laying eggs without a shell, for the formation of which the laying hen's body spends up to 19 hours of time [8].

Many factors influence the rhythmicity of the specified ovulatory cycle, and therefore the laying hens. Until recently, the most influential factor was the nutrition factor related to their supply of water and feed, its balance in terms of basic nutrients [2]. In modern times, the factor of stress is also considered to be very influential, which can affect laying hens at any time during a long productive period. Usually, a stressful situation, which arises, e.g., due to the restriction of access to water or feed, soon leads to aggressive behaviour of separate individuals, which suppress other laying hens of the flock. It is believed that stress factors can be infections, invasions, overcrowding, too high or low air temperature, improper sanitary conditions of the environment and other irritants [2; 9]. New relationships between laying hens in stressful situations, which arise when they are kept in large groups (1-2 thousand heads) in sections of the poultry house, are more significant than small ones (3-30 heads) – when kept in cages [10]. These new relationships are mostly caused by the struggle for dominance in the flock or in a certain territory and can change from one behavioural form to another depending on the situational conditions of existence [11]. If there is an even supply of fodder on the holding area, the territorial form of the relationship between individuals of the flock prevails, and if there is an uneven supply of fodder or is a shortage, it is dominant. However, aggression and the establishment of new hierarchical relationships are inherent in both forms [12].

The body's reaction to the action of a stimulus (stressor) depends on the intensity and duration of its impact until the formation of characteristic signs, on the specificity of this action, biological features of the object of influence and other factors [13]. In any case, stressful situations require the body to spend more energy to adapt to new living conditions, changes in instinctive behaviour, which leads to a decrease in laying ability of hens by 19.3-28.8% due to disruption of the ovulatory cycle, their viability, and egg quality [14]. A wide range of behavioural, physiological, and immunological interdependent changes in the body of chickens are associated with a decrease in their egg-laying capacity due to the effects of stress factors [15]. Certain behavioural actions of hens in stressful situations are accompanied by a 34.7% decrease in feed consumption [16], disruption of the endocrine system, acid-base homeostasis, a decrease in antioxidant status, inhibition of the functions of individual organs and physiological mechanisms [2]. An increase in the level of corticosterone, norepinephrine, and adrenaline results in dysregulation of physiological processes related to steroidogenesis, i.e., growth, development of follicles, ovulation of eggs, and therefore egg deposition [17].

Stress is divided into 2 types, acute and chronic. They are similar in physiological mechanisms but differ in the duration of the stimulus and the intensity of the reaction to it. The acute type is characterised by an extremely elevated level of response, especially upon certain unexpected actions, such as catching laying hens during vaccination or transportation from one farm to another, upon changes in the housing method (from floor to cage or vice versa), upon unexpected turning off of the light in the poultry house, etc. Symptoms of chronic stress arise as a result of the action of a less powerful stimulus over a long period of time, i.e., gradually, not suddenly. The level of reaction under the periodic action of one or more irritants can be both insignificant and increase to an elevated level due to the deterioration of the conditions of keeping laying hens, the spread of a disease of a non-infectious nature in the flock, due to incorrect work of personnel or technological equipment [13]. Therefore, overcrowding, use of imperfect technological equipment or keeping under other unfavourable conditions leads to a decrease in laying and viability of hens, which is probably related to the occurrence of chronic stress in them.

The purpose of this study was to determine the compliance of the parameters of the stocking density, prescribed for chickens of the industrial flock by the norms of technological design in the poultry industry VNTP-APK-04.05 in force in Ukraine, to the needs of laying hens of the modern egg cross created in the USA for their maintenance in cage batteries of new 12-tier structures.

Materials and Methods

Research was conducted during 2021-2022 in the conditions of a modern complex to produce edible eggs of "YASENSVIT" LLC, located in the Kyiv Oblast. 3 groups of laying hens of the "Hy-Line W-36" industrial flock of cross-breeds (Table 1) were formed from repair hens grown up to 16 weeks of age, which were kept in separate poultry houses with an area of 2,463.3 m^2, equipped with 12-tier cage batteries "Salmet" (Germany), comprising 30,912 cages with an area of 0.392 m^2 (0.70x0.56 m). The laying hens of the research groups in separate poultry houses were kept as a forced step due to their equipment with stations for automated collection, accounting, and conveyor transportation of eggs to sorting machines of the egg storage, which made it impossible to determine their number for each cage battery.

Table 1. *Experiment scheme*

Indicator	Laying hen group		
	1 (control)	2	3
Total number of cells, pcs.	30,912	30,912	30,912
Hens per 1 cage, heads	9	10	11
Number of hens in a group, heads	278,208	309,120	340,032
Density, heads per 1 m^2 of cage floor area	23	26	28
Availability of cage area for hens, cm^2 of cage area per head	435.6	392.0	356.4
Feeding front, cm per 1 head	7.78	7.00	6.36

Likewise, the number of dead and culled laying hens, the consumption of compound feed, water, and electricity were recorded separately for each poultry house every day.

Thus, a batch of 16-week-old repair hens that met the requirements of DSTU 4661 [18] were delivered from the breeding area to the industrial flock farm and divided into 3 groups. Hens of each group were placed in cages of the corresponding poultry houses according to the density per the experiment scheme (Table 1). By gradually increasing (by 15 minutes per day) the total length of daylight from 8 to 14 hours per day, they stimulated the beginning of their pregnancy when they reached 19 weeks of age. The experiment lasted 43 weeks, namely from the beginning of laying (from the age of 19 weeks) until reaching the age of 62 weeks. Hens were generously provided with complete ration compound feed that met the requirements of DSTU 4120 [19], the consumption of which, depending on the age of the hens, gradually increased from 73 to 102 g per head per day, as well as drinking water according to DSTU 7525 [20]. The parameters of the light regime, microclimate, and air exchange in the poultry houses throughout the experiment met the requirements of VNTP-APK-04.05 [5].

The number of eggs laid and the intensity of laying hens, the number of dead and culled laying hens were determined daily by group to determine the preservation of the stock. Once a week, the weight of eggs and the live weight of laying hens were measured from certain marked cages in a sample of at least 100 (n⩾100). The efficiency coefficient of egg production depending on the density of laying hens was determined according to Equation 1 [21]:

$$E_{ec}=(1.4\times M)-(0.35\times K) \quad (1)$$

where E_{ec} is the efficiency coefficient, conditional units; 1.4 and 0.35 are constant values; M is the egg mass obtained per 1 laying hen, kg; K is the feed costs to produce 1 kg of egg mass, kg.

The significance of the difference between groups was assessed using one-way analysis of variance (ANOVA) and the Tukey-Kramer multiple comparisons test [22] as a post-hoc testing tool. The distribution of sample data for normality was verified according to the Kolmogorov-Smirnov criterion [23]. If the data distribution significantly differed from normal, the non-parametric Mann-Whitney U-test was used [24]. Differences between groups were considered significant at $p<0.05$.

Results and Discussion

The initial number of hens in Group 1, as presented in Table 2, was considerably smaller than in Groups 2 and 3 due to their density of 23 heads per 1 m^2 of the floor area of the cage per the requirements of VNTP-APK-04.05 [5]. The number of hens of Group 1 in each cage with an area of 0.392 m^2 at the beginning of the experiment was 9 heads. The planned densification of hens of Group 2 up to 26 heads/m^2 was achieved by placing 10 heads in similar cages. By placing 11 chickens in cages, their further density was achieved, up to 28 heads/m^2 (Group 3). As a result of the mentioned compaction, 30,912 more hens were planted in the Group 2, and in Group 3 even more – 61,824 heads. Notably, if the hens of Group 1 (control) were placed according to the density per the recommendations of the developer of the "Hy-Line W-36" cros [4], namely 13-20 heads/m^2, then their number in each cage would vary within 5-8 heads, i.e., there would be no more than 8 heads, and in a group (poultry house), respectively – no more than 247,296 heads, or 30,912 heads less.

***Table 2**. Productivity of hens depending on the density*

Feature	Laying hen group			Requirements
	1 (control)	2	3	
Placed chickens, heads	278,208	309,120	340,032	
Density, head/m^2	23	26	28	22-25[1] 13-20[2]
Died and culled, heads	24,202	27,512	39,444	
Hens at the end of the experiment, heads	254,004	281,608	300,588	
Livestock safety, %	91.3±0.05	91.1±0.05*	88.4±0.10*	96.9
Eggs obtained: – total in the group (poultry house), pcs. – per 1 m^2 of birdhouse area, pcs. – per initial laying hen, pcs./head	 64,377,331 26,135 231.4±0.23	 68,253,696 27,708 220.8±0.09*	 77,255,270 31,363 227.2±0.47*	263.9-271.9
Efficiency coefficient production of eggs, conditional units	19.7±0.07	19.1±0.07*	19.2±0.07*	
Live weight of laying hens, kg – at 52 weeks of age – at 62 weeks of age	 1,524±0.17 1,531±0.12	 1,523±0.28* 1,536±0.52*	 1,448±0.21* 1,496±0.67*	 1,550-1,610 1,550-1,610
Egg mass, g – at 52 weeks of age – at 62 weeks of age	 63.7±0.04 65.7±0.02	 64.2±0.01 66.6±0.01*	 65.0±0.03* 65.9±0.04*	 62.5 63.0

***Note:** [1] – density of hens per the requirements of Ukrainian standards [5]; [2] – per the recommendations of the developer of the chicken cross [4]; *p<0.05 – in comparison with Group 1 (control)*

The conservation of chickens in Group 1 at the end of the experiment was 91.3%, i.e., it was 5.6% less than the normative level for this cross (96.9%) under the conditions of their keeping at a density of no more than 13-20 heads/m^2 [4]. The factual losses of laying hens (killed and culled) in Group 1 amounted to 24,202 heads, and upon placing according to the requirements of the cross developer, there would have been no more than 7,666 heads. This difference of 16,536 heads is probably a concrete consequence of keeping them at a density per Ukrainian standards [5], which is slightly higher than recommended by the developer of the cross [4]. In Group 2, and especially in the Group 3, the losses of laying hens were even greater than in Group 1 due to their respective over-densification.

Cross-bred hens "Hy-Line W-36", according to the characteristics of the cross [4], can lay no less than 262.2 eggs per initial laying hen in 62 weeks of life, but in case of keeping according to the density recommended by its developer – 13-20 heads/m^2. As the experimental data shows (Table 2), keeping hens in Group 1 at a density of 23 heads/m^2 led to a decrease in egg production by 30.8 eggs (13.3%), namely to 231.4 eggs/head. Increasing the density of housing to 26 heads/m^2 (group 2) led to a decrease in egg production by another 10.6 eggs (to 220.8 eggs/head). Further densification of hens to 28 heads/m^2 (Group 3) did not lead to a corresponding decrease in their laying capacity. In the hens of this group, the laying rate was 227.2 eggs per head, i.e., it was 6.4 eggs higher than in Group 2. It was possible to find out the reason for this as a result of determining the factual density of keeping hens of Group 3, considering their current conservation. It was determined that due to the low level of conservation (88.4%), the initial number of hens from 11 heads in each cage decreased to 9.7 heads at the end of the experiment. The density of their keeping decreased, respectively, from 28 to 24.7 heads/m^2. In fact, it decreased to 24.7 heads/m^2 much earlier, during the first 10 weeks of the experiment. That is, most of the 39,444 laying hens lost died or were culled during the first 10 weeks of the 43-week study period. Therefore, laying hens that remained alive and healthy were kept for another 33 weeks of the experiment at a density of no more than 25 heads/m^2, which meets the requirements of the norms [5]. The density of chickens of Group 2 at this time, as shown by similar calculations, was 26.0 heads/m^2.

Notably, at the beginning of the experiment, 30,912 (11.1%) and 61,824 (22.2%) more laying hens were placed in the same area of birdhouses in Groups 2 and 3 than in Group 1 due to their certain compaction (to 26-28 heads/m^2). As a result, in Groups 2 and 3, more eggs were obtained in general and per 1 m^2 of the poultry house area, even despite a substantial ($p<0.001$) decrease in the level of laying ability of hens. In Group 2, an added 1,573 eggs were obtained from 1 m^2 of the poultry house area, in Group 3 – 5,228 eggs, but at a slightly lower level of the coefficient of efficiency of their production than in the control (Table 2). Furthermore, compared to control Group 1, 3,310 and 15,242 more laying hens were lost in these two experimental groups. Their live weight in case of prompt slaughter for meat would be 5,130 and 23,625 kg, respectively. Therefore, increasing the density of keeping Hy-Line W-36 cross hens in cages to 26-28 heads/m^2 ensures obtaining a slightly larger number of edible eggs from 1 m^2 of technological areas, but at the expense of reducing the efficiency of their production and added losses of laying hens.

Upon comparing the curve (Fig. 1) of the factual and normative intensity of laying hens, the current level of compliance with the norm regarding its growth, duration of retention at the peak and decline is usually judged to identify violations of the technological process of egg production and their prompt elimination. The laying intensity of Hy-Line W-36 cross-bred hens should be at least 50% on the 20th week of their life, 90% on the 22nd-23rd, and 95-96% on the 24th-25th. This peak level should last 10-12 weeks and only then gradually decline to 86% at 62 weeks of their life. According to the given curves (Fig. 1), the laying of hens of all 3 groups was started when they reached 19 weeks of age, i.e., with a delay of 1 week according to the technological map-graph of the farm. Its intensity in hens of Groups 1 and 3 increased faster than in Group 2. They reached 50% of its intensity level at 22 weeks of age, and hens of Group 2 – at 24 weeks of age.

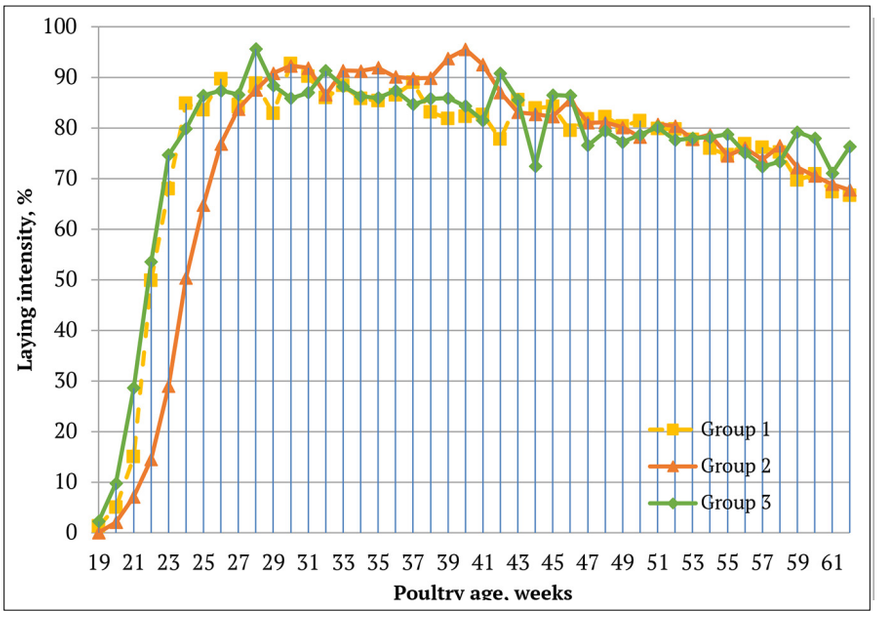

Figure 1. Curve of egg production intensity of hens

Hens of group 1 reached 90% of the laying rate at 24 weeks of age, the peak (92%) at 29-30 weeks of age (with some fluctuations), and at 62 weeks of age it decreased to 67%. Chickens of Group 2 reached 90% of the level at 29 weeks of age, reached the normative peak (96%), but only at the 40th week of life. Laying hens of Group 3 reached the normative peak level a little earlier, at 28 weeks of age, but it turned out to be short-lived. At 62 weeks of age, they exceeded their counterparts from other groups in terms of the intensity of pregnancy. Therefore, the configurations of the intensity curves of laying hens of all groups do not coincide with the normative ones from the beginning to the end of the experiment. This indicates a relatively uniform impact, i.e., without a cumulative effect, on this trait of a possible chronic stressor throughout the entire 43-week observation period.

The egg mass (Table 2) in hens of all groups met the regulatory requirements [4], and the live weight turned out to be somewhat lower. In laying hens of Group 3, this may be due to a lower provision of their feeding front during the first 10 weeks of the experiment.

The increase in the production of edible eggs is achieved by the majority of poultry complexes, as already mentioned above, not by the construction of new farms or poultry houses, but by the replacement of 1-3-tiered cage batteries of outdated structures in the existing premises with new 6-12-tiered ones. By replacing 3-tiered batteries with 12-tiered ones, the number of seats in the poultry house with an area of 2463.3 m^2 increases from 69.6 thousand to 278.2 thousand, i.e., 4 times. Accordingly, the number of eggs obtained per year in the poultry house as a whole and per 1 m^2 of its area also increases by 4 times (from 9.6 to 38.4 thousand eggs). This is of particular importance for enterprises that lack free land for the construction of new poultry houses. But already modernised enterprises strive for further increase in the production of eggs due to high consumer demand for them in the Ukrainian and foreign markets. For this purpose, such enterprises resort to increasing the population of laying hens due to certain compaction of them [25]. Usually, if the poultry house is filled with the next batch of young chicks on the eve of the expected increase in demand for eggs, then they are planted in each cage by one or more heads exceeding the standard number. This leads to their compaction, the level of which depends on the number of additional laying hens planted. As evidenced by the results of the experiment, this fully applies to hens of the egg cross under study. Their over-compaction led to a certain decrease in carrying capacity and conservation inherent in chronic stress, which is consistent with the results obtained by other authors [13; 14; 26].

The effect of overcrowding of hens on their laying ability, conservation, and parameters of other characteristics (Table 2) was noticeable during the entire 43-week period of the experiment, i.e., until they reached 62 weeks of age. In particular, with an increase in the

housing density from 13-20 heads/m^2 (which is recommended for the Hy-Line W-36 cross) to 23 heads/m^2 (Group 1), the hens did not reach their typical laying capacity – 262.2 pcs./head in 62 weeks of life. It amounted to only 231.4 units/head, i.e., it was smaller by 11.7%. The data obtained are consistent with the results of many studies, which describe a decrease in egg production as a reaction of the bird's body to acute [27] and chronic stress [28], and the experimental administration of ACTH in hens confirmed atresia of follicles and a decrease in the weight of the oviduct [29]. Despite this, the specified increase in the density of keeping chickens allowed obtaining 1.6-5.2 thousand more eggs from 1 m^2 of the poultry house, but at the expense of a decrease in the efficiency of their production and added losses of laying hens. Other researchers obtained comparable results [30], who also noted a decrease in egg production per initial laying hen, as a reaction of the hens' body to the increased density of their housing. Furthermore, there are reports that the decrease in egg mass output is the result of the effect on the bird's body and other technological stressors, such as transportation, immobilisation, social isolation, etc. [31].

No influence of the researched housing density on egg weight was found. Its deviations from the normative level, which occasionally happen on farms, are probably the result of the action of food or other factors not investigated in this study.

Conclusions

1. The stocking density of laying hens of an industrial flock of white-egg crosses, which according to the requirements of VNTP-APK-04.05 should be an average of 23 heads/m^2, is not optimal for "Hy-Line W-36" cross hens if they are kept until they reach 62 weeks age in cages of 12-tier batteries.

2. Further densification of hens to 26-28 heads/m^2 leads to a decrease in egg-laying, conservation, and efficiency of production of edible eggs, but ensures obtaining a larger volume of them from the poultry house as a whole and from 1 m^2 of its area.

3. Densification of hens to 26-28 heads/m^2 by keeping them in cages of 12-tier batteries installed in poultry houses with an area of 2,463.3 m^2 made provision an added 3.9-12.9 million eggs for 43 weeks of laying, including 1.6-5.3 thousand per 1 m^2 of their total area, but with a certain decrease (from 19.7 units to 19.1-19.2 conditional units) of the efficiency factor of their production.

4. In the future, at the first stage, it is necessary to determine the level of profitability of the production of edible eggs and the economic feasibility of increasing their volume with the investigated compaction of laying hens.

5. At the second stage of research, it is worth comparing the efficiency of egg production for keeping laying hens in 12-tier cage batteries according to the density per the requirements of VNTP-APK-04.05 (20-25 eggs/m^2) and under more comfortable conditions (13-20 eggs/m^2) per the recommendations of the developer of the "Hy-Line W-36" cross. The results of these studies can be considered upon changing and amending the current norms of technological design in poultry farming regarding the density of hens of an industrial flock in cage batteries of 12-tier structures.

It is important to direct further research to the determination of the limit level of the density of laying hens in an industrial herd, exceeding which leads to the occurrence of obvious chronic or acute stress. Such a task is important from both theoretical and practical standpoint and can be performed in the future by keeping a limited number of laying hens in the vivarium.

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Несучість та збереженість курей промислового стада залежно від щільності їх посадки в кліткові батареї

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Анотація. Актуальність досліджень зумовлена браком експериментально обґрунтованих даних з оптимізації щільності утримання курей-несучок сучасних яєчних кросів в кліткових батареях нових багатоярусних конструкцій. Мета роботи полягала у визначенні впливу щільності утримання курей промислового стада в клітках 12-ярусних батарей на їх несучість та збереженість. Для цього несучок 3-х груп промислового стада кросу «Ну-Line W-36», утримували в окремих пташниках-аналогах, але за різної щільності. Зокрема, курей 1-ї групи посадили в клітки за щільністю 23 гол./м^2 згідно з нормами, а 2-ї та 3-ї груп – за 26 та 28 гол./м^2, відповідно, тобто за ущільнення на 13,0 % і 21,7 %. Згідно з характеристикою цього кросу несучість курей промислового стада має становити не менше ніж 262,2 яєць на початкову несучку за 62 тижні життя. Однак, у курей 1 групи вона становила 231,4 шт./гол., тобто була на 11,7 % на тлі нижчої на 5,1 % збереженості, яка за створення оптимальних паратипових умов існування відповідала б нормативному рівню (96,0 %). За підвищення щільності утримання до 26 гол./м^2 (2 група) та до 28 гол./м^2 (3 група) несучість курей становила 220,8 шт./гол. та 227,2 шт./гол. при збереженості 91,1 % та 88,4 %, відповідно. Підвищення щільності посадки курей 2-ї та 3-ї груп призвело до зниження несучості та збереженості, але забезпечило отримання більше продукції з 1 м^2 виробничих площ. Додатково отримано за 43 тижні продуктивного періоду 3,9–12,9 млн. яєць, у тому числі 1,6–5,3 тисяч у перерахунку на 1 м^2 їх площі. Таким чином, зазначене ущільнення може бути застосовано як технологічний прийом швидкого збільшення обсягів виробництва харчових яєць без будівництва нових чи реконструкції наявних ферм у разі виникнення додаткової потрібності у даному продукті на внутрішньому чи зовнішньому ринках продовольства

Ключові слова: виробництво харчових яєць, продуктивність, кліткове устаткування, крива несучості, кури яєчних кросів, жива маса, умови утримання

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The Effect of Artificial Lighting of Cowsheds on the Milk Productivity of Cows Under the Conditions of Tethered Housing

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Abstract. The relevance of this study is conditioned upon the need to establish the possibility of using artificial lighting to increase the productivity of cows with tethered maintenance. This paper is aimed at identifying the effect of adjustable lighting of the feed table with LED lamps on the dairy productivity of cows. The cowshed lighting was provided by the SmartAC (LRC) automatic control system. The research method was to analyse the dynamics of cow milk yield under controlled photoperiod conditions and the level of illumination of the room. Two groups of cows were formed: experimental cows were kept in an experimental cowshed with natural illumination of the feed table of 101±20.2 lx and artificial illumination of 202±19.9 lx, the control group was kept in a typical 2-row room for 100 heads, in which natural illumination feed table was 139±22.8 lx, artificial – 26±3.2 lx. The duration of the photoperiod was 16 hours, and the ratio between natural and artificial lighting depended on the astronomical length of the day. Milk productivity of cows was assessed according to the method of control milking. Milk yields were recorded one month before the installation of the experimental lighting system (in February) and for the next four months (from March to June). Before the installation of the experimental lighting system, the difference in milk yield of cows was not statistically significant. In the future, despite fluctuations in the amount of milk yield caused by feeding, the experimental group of cows exceeded the control group in terms of milk productivity. The advantage of the cows of the experimental group in terms of daily milk yield was from 2.3 kg in March to 5.8 kg ($p<0.01$) in May. During the period of maximum daylight hours (June), the effect of artificial lighting on the dairy productivity of cows was insignificant. It was noted that the increase in the preference of experimental cows for milk yield occurs over several months, and the positive impact of improved lighting of the feed bunk increases along with an increase in milk productivity on the farm. That is, the higher the feeding level, the greater the effect of lighting control. The obtained results were confirmed after the analysis of the productivity of analogue cows by age and lactation phase, selected from the experimental and control groups. The results of the study are of practical value for the improvement of lighting in cowsheds with tethered housing

Keywords: dairy cattle, milk yield, illumination, photoperiod, feed bunk

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Introduction

Modern technological solutions for keeping cows usually provide that the animals are indoors most of the day, or 24 hours a day. The natural illumination of cowsheds is substantially less than the external one and is associated with the duration of daylight hours. To increase the productivity of cows on farms, various levels and duration of artificial lighting of cowsheds are used. These techniques are of great interest because, due to the influence on physiological processes and active behaviour of cows, they can improve their productivity. On average, about 17% of the total electricity consumption on dairy farms is used for lighting [1], and its optimisation allows influencing the productivity of cows and reducing the consumption of energy resources. There are several factors related to lighting, namely the types of lamps and their power, their location in the room, ceiling height, duration of the lighting period, etc. The study of variable parameters of dairy farm lighting systems and their impact on animal productivity allow developing optimal modes for practical application and justifying their feasibility.

Lighting of the farm premises is provided both by natural light and using various models of lamps. Depending on the choice of arranging natural lighting, there are substantial changes in the illumination of premises during the day and depending on the season. Thus, in milking parlours with a transparent roof, the illumination varied from 80 lx at night in winter to 1,030 lx at midday in summer [2]. The influence of lighting on the productivity of cows has many physiological prerequisites associated with humoral factors and the extension of the animal's activity period. An increase in milk production and a more stable lactation were observed in cows that calved before spring [3], when the natural lengthening of the photoperiod and the increase in illumination occur. Extending the duration of lighting up to 17 hours, compared to the natural 10...13 hours, and added lighting with 350 lx fluorescent lamps at eye level contributed to obtaining an added amount of milk [4]. There are several explanations for such phenomena. It was found [5] that light inhibits the production of N-acetyl transferase, which is the main enzyme during melatonin synthesis. Melatonin slows down the metabolism, activates the deposition of fat in the body and reduces the productivity of animals. The activity of melatonin production increases during the dark hours of the day and during sleep. Mammalian photoreceptors, which regulate melatonin synthesis, are thought to respond most to the blue spectrum of light. It was proved the possibility of added stimulation of dry cows with blue light through one eye on suppressing the level of melatonin in the blood and further increasing milk productivity in the first 12 weeks of lactation [6]. Suppression of the melatonin level due to the short-term use of the blue spectrum in LED lamps was also confirmed in calves [7], although it did not contribute to an increase in the level of hay consumption and the duration of chewing.

Light also affects changes in the concentration of glucocorticoids in the blood [8]. Cows that were kept under artificially extended lighting conditions (16 hours of light and 8 hours of dark period) were found to have 1.5...1.8 times higher prolactin levels than cows that were kept in natural light conditions lasting 9...12 hours [9]. The extension of the duration of the light period during the day was associated with the increased secretion of insulin-like growth factor by dairy cows [10], which in turn leads to an increase in milk productivity [11]. It was also established that the levels of prolactin and insulin-like growth factor were the highest in Holstein cows in rooms with 200 lx illumination, compared to other groups [12].

In studies on determining the optimal lighting and duration of lighting in rooms with automatic milking systems [13], it was found that the highest milk productivity (40.8 kg and 39.9 kg) is observed under lighting conditions of 16 hours per day at the level of 50 lx and 100 lx. Increasing the illumination to 200 lx and using only natural light for 14.2 hours a day led to a decrease in milk yield. In this experiment, it was established that the content of dry milk residue was higher in the milk of cows that were kept in rooms with natural lighting. According to the literature review [14], increased light brightness has a positive effect on reducing the service period of cows, but not all researchers obtained unequivocal results. They note that increasing the illumination to 200 lx can be a stress factor.

An understudied factor in animal husbandry is the spectrum of light that will be optimal for application. It is known that the leaves of plants absorb visible radiation in the red, blue, and infrared spectra. It is believed that cows can partially perceive short-wave infrared radiation when choosing feed. Studies [15] show that the eye of cattle responds to a spectrum of light close to infrared radiation, and combined illumination of different spectra contributes to more active behaviour of animals. Studies confirm the effect of light spectra on physiological responses in cows [16]. But the absence of a substantial difference in milk productivity indicates that the spectral composition of LED lighting in the cowshed is secondary to photoperiod duration and lighting intensity.

In farm settings, it is important to understand whether the lighting period needs to be synchronised with the time of day. It was found [17] that the lighting time using LED lamps has only a certain effect on the parameters of cow blood and its immune response, but the difference in prolactin, IgA and IgG content was not significant, and there were no changes in milk production.

Automation of the lighting mode of cowsheds with the help of programmable logic controllers is a modern trend. A study was conducted on the effect of the developed LED lamp on the health and productivity of black-and-white cows [18]. It was established that the use of systems with an adjustable amount of light does not adversely affect the body of cows, but on the contrary, stimulates their activity and promotes more active feed consumption and increased milk production.

In general, studies confirm the positive influence of certain ranges of illumination and optimising the duration of the photoperiod on the productivity of cows, but many issues are still understudied. It is relevant for Ukraine to investigate the possibilities of adjustable lighting systems in cowsheds with both tethered and untethered housing since such premises still are widespread and the technological conditions for the use of cows in them require improvement.

The purpose of this study was to analyse the influence of the light level of the insulin-like growth factor on the productivity of dairy cows under tethered conditions.

Materials and Methods

Research was carried out during February-June 2021 in the conditions of a separate unit of the National University of Life and Environmental Sciences of Ukraine "Agronomic Research Station" in two-row cowsheds with tethered housing. For studies of the efficiency of the experimental lighting system, a two-row cow shed with tethered housing was allocated (Fig. 1). The width of the room was 10.3 m, the length of a solid row of stalls was 30 m. Feed table with a width of 3.5 m. The windows were located in a longitudinal wall on one side, the opposite wall was solid. The initial lighting system provided for the use of 16 LED lamps with 10 W lamps. The lamps were arranged 8 in one row above the stalls at a height of 2.55 m with an interval of 3 m. At the beginning of March 2021, LED lamps with the SmartAC automatic control system (LRC) were installed in the experimental barn. Lamps of the experimental lighting system with a power of 60 W with LEDs of different spectra were placed above the side of the feed table on the side of the experimental group of cows. Total number of luminaires – 6 pcs. Lighting control was automatic with maintenance of a duration of 16 hours a day and considering the length of daylight and with the possibility of manual control.

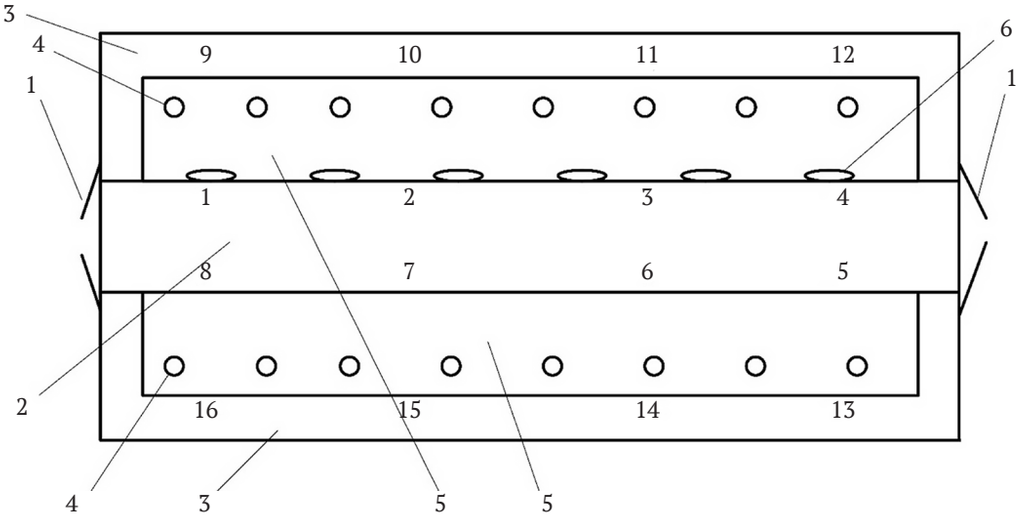

Figure 1. Scheme of an experimental cowshed 1 – gate; 2 – feed bunk; 3 – technological passage; 4 – LED lamps with 10 W lamps; 5 – stall location area; 6 – LED lamps of the experimental lighting system with a power of 60 W. 1…16 – places of measurement of illumination in the cowshed

The experimental group of cows (24 cows) was kept in a continuous row on one side of the experimental cowshed.

For control, another group of cows (52 heads) was taken, which were kept in a typical 2-row cowshed for 100 heads with tethered confinement. The artificial lighting system was the same as in the experimental cowshed before the installation of the experimental installation.

The effect of changing the lighting system on the productivity of cows was determined by comparing the average productivity per milking cow in the experimental and control groups. To clarify the obtained results, analogue cows were selected from the experimental and control groups, whose performance was compared during the experimental period. The first calving cows (6 heads in the experimental group and 8 heads in the control group) were selected for the analogue groups, which were at the end of the second–beginning of the third phase of lactation at the time of installation of the experimental lighting system. This period was chosen to exclude the possibility of a physiologically determined increase in milk yield at the beginning of lactation, so all changes in milk productivity in cows are mainly due to the influence of the feeding factor and technological conditions of keeping.

The duration of the photoperiod in the cowsheds was 16 hours per day, during which the level of illumination depended on the length of the daylight hours and the artificial lighting system. Illumination in the premises was determined by a WALCOM lx-1330B lux meter, by the method of point measurements (16 points) along the feed bunk and the technological passage behind the stalls at floor level and at a height of 1 m.

Cows were fed with a general mixed diet using silage, hay and a mixture of concentrated fodder. The composition of the ration during the study period partially changed, but the level of feeding of the cows of the experimental and control groups did not differ among themselves. In the summer, part of the silage was replaced with freshly mown alfalfa. Cows of the experimental and control groups were milked in the milk duct. Individual milk productivity was determined by the method of monthly control milkings. The materials were processed using the methods of variational statistics. Means M, statistical error ±m, probability of difference of means $p \leq 0.05$; 0.01; 0.001 were determined.

Results and Discussion

Before the installation of the experimental lighting system in the experimental barn, the artificial lighting above the feed bunk was extremely weak (Table 1). The main reasons for this are the low power of the lamps and their location. The arrangement of lamps above the stalls allowed illuminating the working area of machine milking operators, but the feeding area was almost unlit. During the day, the natural illumination of the experimental barn was about

101 lux, which is considered a sufficient level [14] to ensure high productivity. In the stable period, the time of such illumination of the feeding zone is limited by the length of the day (at the beginning of the experiment it was 11 hours and 5 minutes), which should have an effect on the activity of forage eating and the physiological functions of the cows' body.

Table 1. *Illumination of cowsheds at the floor level of the feed bunk*

Indicator	Illumination, lx
Experimental cowshed	
Basic artificial lighting before installing the experimental system	5±0.8
Artificial lighting after installation of the experimental system	202±19.9
Natural lighting*	101±20.2
Control cowshed	
Artificial lighting	26±3.2
Natural lighting*	139±22.8

Note: * *Natural lighting was determined 1 hour after sunrise*

In the control barn, the artificial lighting of the feed table was 21 lx higher than in the experimental one, but it was substantially inferior to the parameters recommended in the literature and current standards [19]. The average level of natural light in it was also higher by 38 lx, but the difference between the rooms was within the statistical margin of error.

Arrangement of an experimental system with higher-power lamps above the feed table in the experimental cowshed allowed increasing its illumination by 40 times and bring it to the level of 200 lx, which is described in modern scientific experiments [13; 17]. Thus, the experimental group of cows was kept under conditions when the illumination of the feed table was at least 100 lx for 16 hours. In the experimental group, the duration of daylight hours with this level of illumination depended on astronomical factors and varied from 11 to 16 hours.

The average number of cows in the experimental and control groups changed during the experiment (Fig. 2). In February, a month before the installation of the experimental lighting system, the difference in milk yield in the groups was not statistically significant and amounted to 0.9 kg.

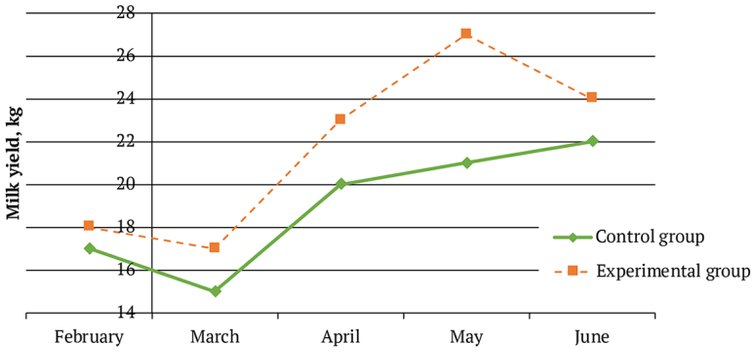

Figure 3. Average daily yield per dairy cow in experimental and control barns

During March, the weight in both groups decreased by an average of 2.2 kg, which is conditioned upon a change in the composition of the rations (the amount of protein feed additives was reduced, and silage feed was changed). But in the experimental cowshed, where the experimental lighting system was already working, the milk productivity of the cows was 2.3 kg higher. From April, there was a gradual increase in milk yield in both groups of cows, but the difference between them in terms of milk productivity also increased. Thus, in April, the weight of the cows of the experimental group was greater by 3.1 kg ($p<0.05$), in May by 5.8 ($p<0.01$). In June, when the duration of the astronomical daylight reached a maximum (16 h 27 min), and the cows were kept mainly in the walking areas, the difference in milk yield in the groups decreased to 1.8 kg and became statistically insignificant. In relative values, the advantage of the cows of the experimental group over the control group in terms of milk productivity ranged from 16% in March and April to 27% in May. Thus, it can be argued that increasing the artificial lighting of the feed table to 100...200 lx for 16 hours per day allows increasing the efficiency of the cows' use of the distributed fodder and improving their milk productivity. At the same time, the control and experimental groups were formed from cows of different ages and at various stages of lactation, and therefore the conclusion made required verification.

For verification, data on the performance of first calving cows were selected from both groups, which at the beginning of March were at the end of the second – the beginning of the third phase of lactation (Table 2).

***Table 2**. Illumination of cowsheds at the floor level of the feed bunk*

Month	Experimental cowshed (n=6)	Control cowshed (n=8)
February	18.1±1.1	18.4±1.0
March	16.4±1.0	15.0±1.0
April	23.3±1.5*	18.3±1.6
May	28.6±4.3	22.4±2.0
June	23.4±1.2	20.2±3.1

***Note:** * p<0.05*

The overall performance dynamics of the selected analogue cows was similar to the changes found in the full groups. In February, before the start of the experiment, the cows had almost the same productivity, in March the milk yield decreased, but there was a statistically insignificant advantage of the experimental cows of 1.4 kg. In the future, until May inclusive, milk yields began to grow, which reflects positive changes in feeding. In the experimental animals, the increase in milk yield was more substantial. In April, their advantage over the control group was 5.0 kg ($p<0.05$), and in May – 6.2 kg. In June, milk yield in both groups decreased, which is a combined result of feeding and elevated temperatures that are not favourable for cows, and the difference between them decreased by almost 2 times, due to the disappearance of the influence of the artificial lighting factor in the conditions of the maximum duration of the daylight hours, which exceeded 16 hours.

Therefore, during tethered keeping, the illumination of the feed table at the level of 100…200 lx with a duration close to the maximum duration of daylight (16 hours) allows increasing the milk productivity of cows, and the effectiveness of this method will increase against the background of a higher level of milk productivity of cows.

Analysing the obtained results, three main patterns can be identified. The first is to increase the milk productivity of cows in conditions of increasing the level of light in the cowshed. In similar studies [13], this result is confirmed. The authors indicate that under the conditions of only natural lighting per day, at the level of 10 lx, the milk yield of cows substantially decreases, but the amount of dry milk residue in it increases. And comparing the effectiveness of various levels of illumination with the use of artificial lighting (50, 100, and 200 lx), 100 lx was determined to be optimal. In this group of cows, the yield of milk was obtained, which was not significantly different from the highest in the experimental groups, but they exceeded the others in terms of the total yield of dry milk residue. The milk of these cows also had the lowest levels of cortisol, indicating a reduction in the stress load on the animals. Other authors make similar conclusions regarding the optimal levels of lighting in the cowshed and the increase in the stress load on cows at lighting levels of more than 200 lx [14]. In the conducted study, the level of natural lighting in cowsheds was close to the recommended level [13]. But the duration of time with this level of illumination depended on the daylight hours, and during the study increased approximately from 11 to 16 hours per day. At the end of the study, the control cows were kept for 16 hours with a light level that is close to best, which explains the disappearance of the probable difference in daily milk yield with the experimental group. Notably, the natural lighting outside the premises during the day considerably exceeds 1,000 lux, and therefore it is advisable to further check the possibility of an adverse effect of a long stay of dairy cows under bright sunlight.

The second regularity, which was established in the study, is the postponement of the positive effect of improved cowshed lighting on the dairy productivity of cows. The highest effect was noticed three months after the beginning of the experiment, in May, although during this period the illumination of the cowshed with the control group over 100 lx lasted from 15 to 16 hours, which is an indicator close to the experimental group. A similar result with a delay in productivity growth was obtained in Great Britain [20]. The authors note that illumination of 150 lx for 16-18 hours per day at cow eye level increased milk yield by approximately 2 litres per day, with a delay of 2-3 weeks. In this study, it was noted that feed intake also increased, but with a delay of 7-9 weeks. Therefore, it can be assumed that milk yield increases in the short term due to humoral effects caused by the influence of lighting on the concentration of melatonin, prolactin, and insulin-like growth factor [5; 10; 12]. Overall, the productivity of cows increases due to higher feed consumption. In June, when the duration of the photoperiod with natural lighting reaches its maximum and the conditions in the experimental and control cowsheds are equalised, the preservation of the advantage in terms of milk yield from cows that were kept until this time in improved lighting conditions is also explained by the delay in the reaction of the animals.

The third pattern observed in the study is that the positive effect of light exposure on milk production of cows increases in conditions of increased productivity. During the study, there were changes in many factors that have a direct impact on the productivity of cows, namely the composition of the diet and temperature regimes caused by changes in the seasons. It was found that with the increase in average productivity, the difference between the control and experimental groups also increases. Similar features are not covered in the scientific literature, so this problem can be further studied in more detail.

Conclusions

The lighting of the feed bunk affects the productivity of cows in tethered housing. Extending the duration of the photoperiod to 16 hours per day with illumination of 100…200 lx allowed the experimental group to increase milk yield by 16…27% compared to the control group,

which was confirmed by the analysis of the productivity of analogue cows.

In periods with the maximum duration of the daylight hours and a sufficient level of natural lighting, the influence of artificial lighting on the productivity of cows is minimal. An increase in the milk productivity of cows due to the improvement of lighting of the feed bunk occurs gradually over the following months. The degree of influence of lighting on the productivity of cows depends on feeding, the higher the level of nutrition, the greater the effect of optimising the lighting of premises.

Since a change in the degree of influence of artificial lighting on the productivity of cows was observed throughout the year, in further studies it is advisable to investigate the effectiveness of calendar schedules of switching on and off lamps and to determine the level of compensation of illumination during the periods of sunrise and sunset.

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Вплив штучного освітлення корівників на молочну продуктивність корів за умов прив'язного утримання

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Анотація. Актуальність дослідження зумовлена потребою встановити можливість використання штучного освітлення для підвищення продуктивності корів за прив'язного утримання. Дана стаття спрямована на виявлення впливу регульованого освітлення кормового столу світлодіодними світильниками на молочну продуктивність корів. Освітлення корівника забезпечувалась автоматичною системою керування SmartAC (LRC). Методом дослідження був аналіз динаміки надоїв корів у умовах контрольованого фотоперіоду і рівня освітленості приміщення. Було сформовано дві групи корів: дослідних утримували в експериментальному корівнику з природною освітленістю кормового столу 101±20,2 Лк і штучною – 202±19,9 Лк, контрольну групу – утримували в типовому 2-рядному приміщенні на 100 головомісць, в якому природна освітленість кормового столу становила 139±22,8 Лк, штучна – 26±3,2 Лк. Тривалість фотоперіоду становила 16 годин, а співвідношення між природним і штучним освітленням залежало від астрономічної тривалості дня. Молочну продуктивність корів оцінювали методом контрольних доїнь. Надої фіксували за місяць до встановлення експериментальної системи освітлення (у лютому) та впродовж чотирьох наступних місяців (з березня по червень). До встановлення експериментальної системи освітлення відмінність за надоєм корів була статистично не значуща. У подальшому, попри коливання величини надоїв, які зумовлені годівлею, дослідна група корів переважала контрольну за рівнем молочної продуктивності. Перевага корів дослідної групи за добовим надоєм становила від 2,3 кг у березні до 5,8 кг ($p<0,01$) у травні. У період максимальної тривалості світлового дня (червень) вплив штучного освітлення на молочну продуктивність корів був незначний. Помічено, що нарощування переваги дослідних корів за надоєм відбувається впродовж кількох місяців, а позитивний вплив покращеного освітлення кормового столу збільшується разом із зростанням молочної продуктивності у господарстві. Тобто чим вищий рівень годівлі, тим більший ефект від управління освітленням. Отримані результати були підтверджені після аналізу продуктивності корів-аналогів за віком і фазою лактації, виділених із дослідної і контрольної груп. Результати дослідження становлять практичну цінність для удосконалення освітлення в корівниках з прив'язним утриманням

Ключові слова: молочна худоба, надій, освітленість, фотоперіод, кормовий стіл

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Justification of Power Parameters of the Process of Semi-Fluidisation Freezing of Fruit and Berry Products

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Abstract. The existing semi-fluidisation devices are described by high-energy consumption during operation, heavy metal structure, and complexity of the drive mechanism. Therefore, the search for effective heat exchange schemes in low-temperature processing of fruit and vegetable products, provided that its damage and energy consumption for the process are minimised, constitutes the relevance of this study. The purpose of this study was to determine and substantiate the amplitude-frequency and power mode parameters of the vibration wave driving organ of the semi-fluidisation machine for freezing fruit and berry products, the regularities of changes in the main characteristics of low-frequency vibrations in the process under study. To perform these tasks, an experimental model of a semi-fluidisation machine with a vibration wave driving organ was developed and a set of special devices was manufactured in the form of a microcontroller system that provides measurement and automatic adjustment of the main parameters of the process under study. Intensification of heat exchange in the process of fluidisation freezing in the conditions of a pseudo-suspended state of products is described by a high heat transfer coefficient, which can exceed typical convective processes by several orders of magnitude; an increase in the active heat exchange surface up to 100% is observed; the contact surface with the energy carrier increases proportionally, which leads to a decrease in the active temperature difference; there is a 2-3 times decrease in internal friction in the mass of products and, accordingly, the technological resistance in the mass of loading is reduced, which is a potential for increasing the technical and economic characteristics of the low-temperature processing under study. The practical value of this study can be attributed to the application of vibro-slush freezing of the proposed structure with a vibration-wave product driver and a spatial elastic system for levelling out parasitic vibrations, which allows simplifying the structure, reducing power loads and, accordingly, energy costs

Keywords: wave conveyor, vibration-wave driving body, travelling wave, driving force, low-frequency oscillations, unbalanced vibration exciter

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Introduction

The semi-fluidisation devices presented today have as a load-carrying body a belt conveyor with a perforated surface and standard drive equipment, the operation of which is described by high-energy consumption, metal consumption of the structure, and the complexity of the drive mechanism [1]. Therefore, the development of effective schemes for creating a travelling wave on the surface of the tape upon using local mechanical vibration exciters allow implementing heat exchange in subcooling or freezing of products under the condition of minimising the force contact interaction and, accordingly, energy consumption for the process, which constitutes the relevance of this study.

As a physical phenomenon, fluidisation is interpreted as the transformation of a solid body into a powder-like state to improve its transportation or subsequent technological processing, namely low-temperature heat exchange. Semi-fluidisation can be called the process of supercooling or freezing, wherein the product layer moves on a moving belt and is simultaneously ventilated by a jet of cold air at a speed not exceeding a critical value, which is limited by the technological and design requirements of the process under study [2].

These processes combine the effect on the working organs of the machine, the mass of products or the technological environment of centrifugal forces, the period, and direction of which change with a frequency of the order of 100...200 rad/s with amplitudes of 2.0...5.0 mm [3]. The action of sign-changing centripetal and Coriolis accelerations of individual particles of the bulk product mass leads to the intensification of both the circulation and relative movement of product particles in the working chamber along the most diverse and arbitrarily complex trajectories, the creation of a pseudo-fluidised layer of products and coolant that provide optimal conditions for effective heat and mass exchange between these technological components of the process; a significant increase and intensive renewal of the interaction surfaces of technological environments, an increase in the speed of convective diffusion, a decrease in the effective density of the material, and a change in the rheological and structural-mechanical properties of raw materials during the implementation of the food production under study.

Based on the analysis of Ya. Postolsky and F. Deng [4], Reynolds in 1954 described the concept of fluidisation as a process of rapid movement of gas through a layer of melt to remove certain of its constituent elements and create an oriented arrangement of them, while the outstanding chemist O. Trishyn noted in 2013 that pseudo-fluidisation and fluidisation are synonymous [5].

In the studies of S.M. Ashtiani, A.N. Chernenkova et al., unique physical and mechanical characteristics are presented, namely due to an increase in the heat transfer coefficient α, an increase in the active heat exchange surface up to 100% is observed [5; 6]. In case of an increase in the heat transfer coefficient (in comparison with convective heat exchange, an increase of up to 20 times is possible), the contact surface with the energy carrier increases proportionally, which leads to a decrease in the active temperature difference and, accordingly, creates a potential for increasing the technical and economic characteristics of the low-temperature processing under study. Furthermore, according to the researches of O. Danyliuk, V.M. Atamaniuk et al. in the conditions of a pseudo-suspended layer, there is a 2-3 times decrease in internal friction in the product mass [7; 8], which proportionally reduces the technological resistance of such an environment and, accordingly, the energy costs for its processing, namely upon sparging through the bulk mass of the gaseous coolant flow.

The process of fluidisation freezing is often equated with drying in the conditions of a suspended state of products, which is described by a very intensive heat exchange, which in terms of heat transfer coefficient can exceed typical convective processes by several orders of magnitude. In comparison with the methods of tunnel freezing with forced circulation of the coolant according to the studies of G.A. Nakov and N.I. Ivanova, fluidisation under low-temperature treatment gives a 30-40-fold increase in the intensity of heat exchange [8]. According to the study of V.I. Osypenko, the average values of heat transfer coefficients under the conditions of the fluidisation layer exceeded by 4-5 times the indicators obtained during freezing of products in tunnel apparatuses with forced air circulation at the same airflow rates [9].

Problematic aspects in these studies were that the presented processes and equipment for low-temperature processing of fruit and berry and vegetable products in modern food technologies were realised at a sufficiently high metal consumption and energy consumption, in a fluidisation chute with a perforated bottom, under the action of a variable flow of coolant, in the process of transporting products with a mesh tape, in the working area of a vibrating container. The pseudo-weighted or fluidisation layer of products in such processes is realised by sparging the mass of products with a flow of coolant from bottom to top through holes in the bottom of the chute, the walls of the oscillating container, and the mesh surfaces of the conveyor belt.

When implementing the semi-fluidisation process according to Striling's scheme [2], products are transported by a belt mesh conveyor, under which the evaporator of the refrigerating unit is located. The air supplied through the evaporator moves through the layers of products located on the mesh surface of the tape, from bottom to top. This movement ensures the transition of products to a pseudo-weighted state at a small distance from the grid. This processing is especially suitable for processing soft and fragile products, such as strawberries, raspberries, cauliflower segments, asparagus, and Brussels sprouts. To reduce the possible damage to products with full fluidisation in the process, lower values of the Froude criterion are used, for example, in the work of Savenkova for strawberries, Fg = 50...60 [10; 11].

To exclude freezing of moistened particles to the belt in some designs of freezers, a powerful jet of air is used in the entrance zone of the tunnel at 4-6 m/s, increasing the value of the Froude criterion, in particular, for strawberries to the value of Fg=100...140. Under such conditions, there is a local "boiling" of the fluidisation layer, which is close in parameters to the process of complete fluidisation. If the duration of the process is within 10-20 s, the danger of the product freezing to the grid is eliminated, and at the same time, the probability of fruit damage is considerably reduced, which is shown in the article by A.V. Shyshkin [12; 13].

Therefore, the process of fluidisation refrigerating action showed high indicators of treatment efficiency against conventional freezing in tunnels with forced air circulation [13; 14] due to a considerable increase in the intensity of heat exchange, an increase in the heat transfer coefficient and the active surface of heat exchange, which reduce the active temperature difference and increase the economic indicators of the operation of low-temperature equipment. The scientific originality of this study lies in the transformation of mechanical forced vibrations into a travelling and standing wave of a flexible load-bearing body, which creates a technological movement of products.

High results were also obtained for the use of fluidisation in low-temperature processes occurring during refrigeration, long-term storage of fruit, berry and vegetable products, the development of which is the object of research in this scientific article.

The purpose of this study was to determine and substantiate the amplitude-frequency and power mode parameters of the vibration wave driving organ of the semi-fluidisation machine for freezing fruit and berry products, the regularities of changes in the main characteristics of low-frequency vibrations in the process under study.

To achieve the purpose, the main tasks of scientific study were set as follows: to analyse the current state, innovative developments of Ukrainian and foreign scientists, to identify promising areas or the use of fluidisation action, to substantiate the structural and technological scheme of the semi-fluidisation plant; to determine the patterns of changes in the main parameters of the oscillatory process and substantiate its amplitude-frequency and power parameters.

Materials and Methods

Among the main stages of the performed study, it is possible to note the development and production of a research installation for the implementation of the semi-fluidisation process, which was carried out during 2020-2021; compilation of the necessary measurement base for evaluating electromechanical and heat exchange process parameters, in particular, ROBOTRON equipment for evaluating amplitude-frequency and kinematic characteristics directly using oscillographs and indirectly based on graphically obtained trajectories of movement of system points, wattmeter, voltmeter, and ammeter, necessary power sensors, microcontroller system; analytical determination of the main geometric, kinematic, and force parameters using methods of higher mathematics, physics, theory of fluid media in the conditions of a pseudo-liquefied layer, geometric analysis of an oscillating system, using the characteristics of the experimental model; processing and graphical interpretation of the obtained results using the MathCad mathematical environment. This technique effectively combines experimental and theoretical studies, the results of which are processed by modern information technologies.

To perform these tasks, a pilot model of a semi-fluidisation machine was developed (Fig. 1) with a vibration wave driving organ [1], which described the developed scheme of using an unbalanced vibration exciter for the development of a working wave on the surface of the tape, manufactured a complex of the above-mentioned equipment and devices in the structure of a microcontroller system, providing measurement and automatic regulation of the main parameters of the process of low-temperature processing of fruit and vegetable products in a fluidised state [15]. The presented developments allow realising the effects of increasing the surface of heat and mass transfer, soft power action on products, and reducing dynamic loads on the support units of the drive mechanism.

Tensioning device 7 (Fig. 1), equipped with a spring 11 and an adjustment nut 12 of the tensioning device, stabilises the movement of the load-bearing belt 1. Freezing of the product 13 occurs due to the mass of snow coat or finely crushed ice 14 in a fluidised layer, formed due to the horizontal and vertical movement of the load-carrying belt 1, which gently throws it up, preventing injury or damage, as in known designs of semi-fluidisation devices [16]. The mass of the snow coat or finely crushed ice 14 is removed through the tray 15 as a result of its separation in the vibrating sifter 16 from the products 13 being processed. Product 13, which has been frozen and cleared of snow, goes to the next operation. The processing cycle is then repeated to achieve the required performance, depending on the technological requirements.

Studies of the effect of low-frequency oscillations to create wave motion of the product mass, the snow coat of the coolant on the surface of the tape were implemented during the application of the accelerometer in the mode of an autonomous probe placed in the process mass.

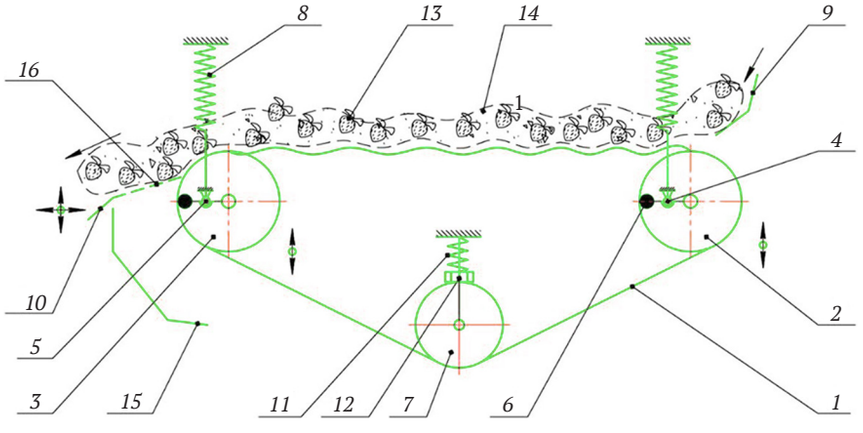


Figure 1. Diagram of the developed fluidisation device for vibro-slush freezing

The real-time microcontroller system allowed obtaining the information on the main parameters of the process on the display of a personal computer, which enabled the optimisation of the modes of heat exchange processing, observed in the dynamics of product cooling to the values specified by the technology. The set temperature of the refrigerant was maintained automatically if it could be quickly adjusted using the power regulator. The specified frequency and amplitude of vibrations were set independently by an electronic device and by changing the angle of the imbalance setting of the vibrator located inside the support rollers of the tape.

Results and Discussion

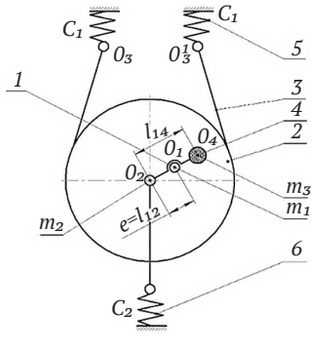
In the developed semi-fluidisation technological machine, the process of heat removal is realised in the case of contact of fruits and berries, which are prone to damage during transportation in the working area, and the mass of the snow coat in the conditions of their fluidised layer. As a result of this movement, gravitational and centrifugal forces, and the influence of aerodynamic drag of the elements of this technological environment are counteracted. Modern schemes of these devices make provision for the creation of a fluidised bed exclusively due to aeration through a perforated transport belt [17], which creates sufficiently large technological supports and, accordingly, high-energy consumption. The load-carrying body of the fluidisation-tunnel apparatus performs a longitu-dinal movement together with the products, which makes it difficult to supply the fluidised bed with a coolant flow [18]. The mechanisms for tensioning the tape and motoring the drive drum are complex enough for the considerable length of the working chamber [5]. Under such conditions, heat transfer is carried out only by convection, which helps press the products to the conveyor belt and leads to a decrease in the free contact surface in the process mass [19]. Furthermore, a common disadvantage of existing semi-fluidisation machines is their high metal and energy consumption [5].

The application of the device for vibro-slush freezing of the proposed design (Fig. 1), thanks to the installation of an unbalanced vibration exciter, moving shafts, a tensioning device, spring sup-ports, an elastic element of a tensioning device, an adjusting nut of a tensioning device, a mass of snow coat or finely crushed ice, a tray for removing snow fur particles or of finely crushed ice, a vi-brating sifter for separating particles of a snow coat or finely crushed ice from products, allows sim-plifying the design, reducing energy consumption by 2.5-3.0 times, improving the vertical movement of the product for the possibility of its longitudinal movement to ensure sufficient freezing in one pass, increasing the intensity of heat exchange in the fluidised bed with the possibility of bringing the area of contact interaction up to 100%, which determines the potential for increasing the produc-tivity of the freezing process in general. The developed scheme also makes provision for heat ex-change by conduction, which is known to substantially improve the contact interaction conditions of the coolant and products [2].

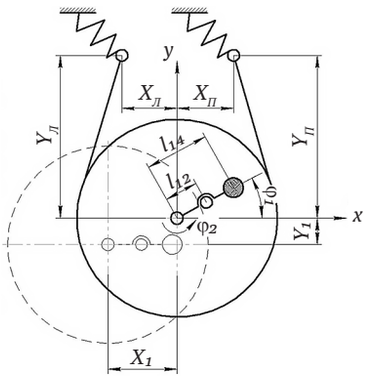
The power parameters of vibration determine the regularities of the mechanical impact on the machine elements and the object of processing, among which it is possible to note the magnitude of the driving force, which directly creates the working movement of the executive bodies of the ma-chine in the event of their removal from the equilibrium position; forces that arise in the event of de-formation of the elements of the elastic system, returning the executive bodies to the equilibrium po-sition; tension forces of elastic band branches; unbalanced forces that arise in the system in the event of parasitic and working forces and reduce the reliability of the support unit and the vibration exciter in general.

To generate vibrations during interoperational transportation of fruit and berry products, name-ly strawberries, cherries, and snow coat, the machine under study made provision for the use of two mechanical vibration exciters mounted in the support rollers of the belt mechanism. The speed of ro-tation was registered from the drive shaft with an accelerometer, and the power – with a wattmeter. The presented mechanism allows reducing the energy consumption by 2.5-3.0 times while maintain-ing an intensive vibration-impulse mode of movement of technological masses and ensuring suffi-ciently comfortable operating conditions of the bearing supports of the drive shaft from the stand-point of levelling dynamic loads under the spatial elastic system, since the proposed elastic system of the vibration exciter allowed levelling the transfer of parasitic vibrations to the supporting structure. The dynamic load on the latter is reduced by 4.5 times also due to the presence of a spring-loaded suspension of the guide belt of the developed semi-fluidisation machine, which was estimated by the corresponding decrease in the amplitude of oscillations of the drive shaft up to 5 times for the reso-nant mode [20].

To identify the desired amplitude-frequency and force parameters when using analytical geometry methods, a calculation scheme was developed that illustrates the initial (Fig. 2, a) and current (Fig. 2, b) position of the drive mechanism, its main geometric parameters.



a



b

Figure 2. Design scheme of the vibrational system of vibration wave transport in case of deviation from the equilibrium position: 1 – roller; 2 – tape; 3 – drive shaft of the vibrator; 4 – counterweight; 5 – elastic suspension; 6 – vibration resistance; m_1 – the mass of the drive shaft with the support assembly; m_2 – mass of roll, tape, and products; m_3 – counterweight mass; C_1 – stiffness of the elastic suspension; C_2 – stiffness of vibration support; X_1 – linear horizontal deviation of the centre of mass of the cylinder; Y_1 – linear vertical deviation of the centre of mass of the roller; φ_1 – angular deviation of the roller; φ_2 – angular deviation of the centre of mass of the drive shaft of the vibration exciter

The developed oscillating system is characterised by 4 degrees of freedom, namely, the angle of rotation of the drive shaft φ_1, the angle of rotation of rollers or working and at the same time support rollers φ_2, linear displacements of the centre of mass of the drive shaft relative to the coordinate axes: *X1* and *Y1*. The system is three-mass, for which $m_0=m_1+m_2+m_3$ is the total mass of moving parts of the system, kg; m_1 – mass of the drive shaft; m_2 – mass of the working container; m_3 – mass of the counterweight.

The driving or exciting force arising from the rotation of the drive shaft of the vibration exciter can be represented as the product of its two projections on the coordinate axis:

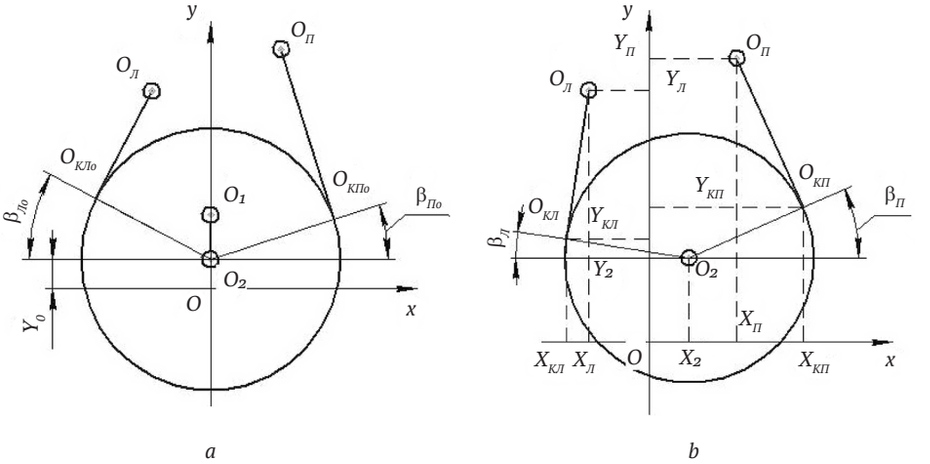
$$F_x = m_1 l_{12} \omega_1^2 \sin \omega_1 t, F_x = m_1 l_{12} \omega_1^2 \cos \omega_1 t, F_B = \sqrt{F_x^2 \quad F_y^2} \tag{1}$$

Restorative or internal elastic resistance forces of the system reveal elastic elements and vibration supports, which characterise the occurrence of a double elastic connection between the flexible load-bearing body and the body of the installation, as well as between the elastic rollers of the guide part of the machine and its base.

The first elastic connection determines the tension force of the guide tape *T*, which depends on the total deformation of the flexible connection Δl and its stiffness C_{pr}:

$$T = \Delta l \cdot C_{pr} \tag{2}$$

These characteristics are found based on geometric analysis of the oscillatory system under study. The points of suspension of the O_3 tape and its contact with the support rollers on the left and right sides are respectively denoted by $O_л$, $O_{кло}$, $O_п$, $O_{кпо}$ (Fig. 3).



a *b*

Figure 3. Geometric parameters of the roller coupling with the tape: *a*) the system in the initial position; *b*) the system in the current state

Then the distance between them is as follows:

$$O_{П}\ O_{КПО} = \sqrt{X_{П}^2 + Y_{G}^2 + R^2} \tag{3}$$

Similarly, at the current moment of time, these distances will be equal:

$$\begin{aligned} O_{Л}\ O_{КЛ} &= \sqrt{(X_1 + X_{Л} + l_{12}\ sin\ \varphi_1)^2 + (Y_{Л} - X_1 + l_{12}\ cos\ \varphi_1)^2 + R^2} \\ O_{П}\ O_{КП} &= \sqrt{(X_{П} - X_1 + l_{12}\ sin\ \varphi_1)^2 + (Y_{П} - X_1 - l_{12}\ cos\ \varphi_1)^2 + R^2} \end{aligned} \tag{4}$$

For the vibration drive under study, the total deformation of the tape and the elastic element of the spring-loaded suspension at the current moment of time for the left and right branches will be as follows:

$$\begin{aligned} \Delta l_{Л} &= \sqrt{(X_1 - X_{Л} - l_{12}\ sin\ \varphi_1)^2 + (Y_{Л} - Y_1 + l_{12}\ cos\ \varphi_1)^2 - R^2} - \sqrt{X_{Л}^2 + Y_{Л}^2 - R^2 + R\varphi_1} \\ \Delta l_{П} &= |O_{П}\ O_{КП}| - |O_{П}\ O_{КПО}| - R\varphi_2 = \\ &= \sqrt{(X_{П} - X_1 + l_{12}\ sin\ \varphi_1)^2 + (Y_{П} - Y_1 - l_{12}\ cos\ \varphi_1)^2 + R^2} - \sqrt{X_{П}^2 + Y_{П}^2 - R^2 - R\varphi_2} \end{aligned} \tag{5}$$

Component $R\varphi_2$ considers the rotation of the support roller of the belt with the mounted vibration exciter by an angle φ_2. Then the tension forces of the tape for the left and right branches are expressed as dependencies:

$$T_{Л} = C_{np}\left(\sqrt{(X_1 - X_{Л} - l_{12}\ sin\ \varphi_1)^2 + (Y_{Л} - Y_1 - l_{12}\ cos\ \varphi_1)^2 - R^2} - \sqrt{X_{Л}^2 + Y_{Л}^2 - R^2 + R\varphi_2}\right) \tag{6}$$

$$T_{П} = C_{np} = \left(\sqrt{(X_n - X_1 + l_{12}\ sin\ \varphi_1)^2 + (Y_n - Y_1 - l_{12}\ cos\ \varphi_1)^2 - R^2} - \sqrt{X_n^2 + Y_n^2 - R^2 + R\varphi_2}\right) \tag{7}$$

The presented dependencies are built using the MathCad mathematical environment (Figs. 4; 5).

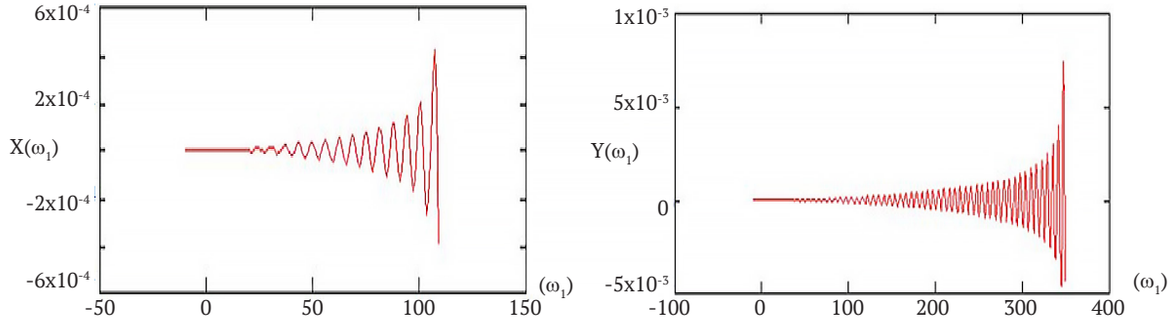


Figure 4. Trajectories of the centre of mass of the working roller along the axes of the plane coordinate system X_r and Y_r (m) from the angular velocity of the drive shaft of the vibration exciter ω1 (rad/s)

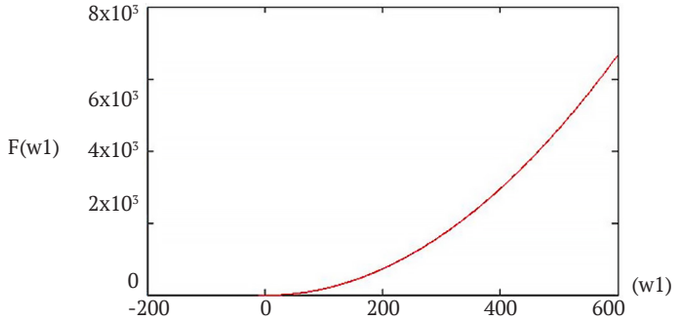


Figure 5. The absolute value of the driving force F_r (H) from the angular velocityof the drive shaft of the vibration exciter ω1 (rad/s)

Graphical dependencies of the trajectory of the centre of mass of the working roller along the axes of the plane coordinate system X_r and Y_r (Fig. 4) indicate a stable wave mode of motion within the angular velocity of the drive shaft of the vibrator ω_1*=50-80 rad/s*, which corresponds to the value of the vibration speed υ_r*= 0.10-0.18 cm/s* (Fig. 5). The absolute value of the driving force begins to increase substantially at F_r*=1-1.5 kN* at values of ω_1*=100-120 rad/s* (Fig. 5).

Conclusions

Considering the above directions for improving the process of fluidisation freezing of fruit and berry products, a semi-fluidisation machine with a vibration-wave driving body for the movement of the belt mechanism was developed; a set of measuring devices for evaluating and determining the amplitude-frequency and power parameters of the researched cooling process.

The developed method allows increasing the intensification of heat and mass transfer due to the use of a fluidised bed of products, the use of vibration and wave effects and the current scheme of the developed conveyor installation, which not only reduces the forces of internal friction during transportation, but also forms a dynamic wave to ensure the forced movement of products along a flexible load-carrying body in conditions of continuous renewal of product layers in case of their mixing.

A stable wave mode of movement of the developed installation is observed up to the value of the angular velocity of the drive shaft of the vibration exciter ω_1*=100–120 rad/s*. Graphical presentation of amplitude-force dependences allowed justifying the theoretical range of angular velocity of the drive shaft of the vibration exciter in the range of *50-80 rad/s* and the magnitude of the driving force to create a given oscillatory mode in the interval of *0.5-1.0 kN* for the specified frequency interval.

This paper established that it is promising to use vibration wave schemes for an organic combination of transportation processes and low-temperature processing of granular products, improvement of heat exchange conditions through the combined use of convective and conductive heat transfer, substantial reduction of product damage, namely of fruits and vegetables.

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Обґрунтування силових параметрів процесу семіфлюїдизаційного підморожування плодово-ягідної продукції

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Анотація. Існуючі семіфлюїдизаційні апарати характеризуються порівняно високими енерговитратами при експлуатації, металоємкістю конструкції, складністю приводного механізму. Тому пошук ефективних схем теплообміну у процесах низько-температурної обробки плодоовочевої продукції за умови мінімізації її пошкоджуваності та енерговитрат на процес становить актуальність проведених досліджень. Метою роботи є визначення та обґрунтування амплітудно-частотних та силових режимних параметрів віброхвильового рушійного органу семіфлюїдизаційної машини для підморожування плодово-ягідної продукції, закономірностей зміни основних характеристик низькочастотних коливань у досліджуваному процесі. Для виконання приведених завдань була розроблена дослідна модель семіфлюїдизаційної машини з віброхвильовим рушійним органом та виготовлений комплекс спеціальних приладів у вигляді мікроконтролерної системи, що забезпечують вимірювання та автоматичне регулювання основних параметрів досліджуваного процесу. Інтенсифікація теплообміну в процесі флюїдизаційного заморожування в умовах псевдозваженого стану продукції характеризується високим коефіцієнтом теплопередачі, який може перевищувати типові конвективні процеси на декілька порядків; спостерігається підвищення активної поверхні теплообміну до 100 %; пропорційно зростає контактна поверхня з енергоносієм, що призводить до зниження активної різниці температур; відбувається зменшення у 2–3 рази внутрішнього тертя в масі продукції та відповідно знижується технологічний опір у масі завантаження, що становить потенціал для підвищення техніко-економічних характеристик досліджуваного процесу низькотемпературної обробки. До практичної цінності проведеної роботи можна віднести застосування віброшугового підморожування запропонованої конструкції із віброхвильовим рушієм продукції та просторової пружної системи для нівелювання паразитних коливань, що дає можливість спростити конструкцію, зменшити силові навантаження та відповідно енерговитрати

Ключові слова: хвильовий конвеєр, віброхвильовий рушійний орган, біжуча хвиля, змушуюча сила, низькочастотні коливання, дебалансний віброзбуджувач

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The Effect of Freezing on the Characteristics of Semifinished Products in a Dough Covering Using Non-Conventional Protein-Containing Raw Materials

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Abstract. The relevance of this study is conditioned upon the increasing interest in alternative sources of protein, to solve the problem of providing the population with biologically complete food products of a combined composition. The purpose of this study was to investigate the effect of freezing on the stability of the moisture content of semifinished products in the dough covering using several types of meat raw materials, protein, and flour from hemp seed processing products. For the study, eight recipes of minced meat were prepared using beef, pork, red and white meat of broiler chickens with flour and protein from hemp seeds in the amount of 20% to the total mass of minced meat. In the samples, indicators of moisture content, moisture binding, emulsifying ability of products before freezing and after defrosting, and activity of water in defrosted products were determined. In the experimental samples, a substantial difference was found in the stability of the moisture content of semifinished products, depending on the combination of flour and hemp seed protein in the recipes of semifinished products and conventional types of meat raw materials under the influence of freezing. It was found that the best combination of hemp seed flour with beef and pork meat, while protein with broiler chicken meat is the best combination in terms of emulsifying ability. All model samples of minced meat had values above 40%, and all samples, except the combination of hemp protein with pork, were higher than the control. Studies of water activity values in defrosted dumplings were within the normal range of up to 0.970 A_w, and the sample using hemp seed protein and pork had the lowest – at 0.951 A_w. The conducted studies indicate the expediency of selective combination of hemp seed processing products with various types of meat raw materials in the composition of semifinished products in a dough covering. The combination of several types of non-conventional protein-containing raw materials in the composition of frozen semifinished products in the dough covering requires considering their technological compatibility to ensure the possibility of implementing the developed recipes in the production of dumplings in industrial production conditions

Keywords: vegetable proteins, protein, hemp seed flour, frozen semifinished products, moisture content, water activity

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Introduction

One of the common nutritional issues is the lack of nutrients in the human diet due to the low balance of the composition and the dominance of starchy products [1]. The lack of essential nutrients necessary for the healthy functioning of the human body causes excessive food consumption, which can lead to the occurrence of diseases of the cardiovascular system. Among the nutrients important for the functioning of the body, protein plays a significant role, the norm of which for people with a sedentary lifestyle is 0.6 g/kg of body weight, and 1.2-1.7 g/kg of body weight for athletes [2; 3].

It is possible to improve the balance of meat-based products through the combination of animal and vegetable raw materials. Vegetable proteins allow balancing meat-based products in terms of the content of deficient nutrients and increase the biological value of the diet. Partial replacement of the meat-fat fraction with the vegetable fraction leads to a decrease in the amount of cholesterol and saturated fatty acids in the composition of products. Combined meat products in terms of amino acid content are closer to the ideal protein values according to FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization) [4], and their fatty acid composition is enriched with polyunsaturated fatty acids, which allows designing functional products [5].

In the same way, the modern rhythm of life forces to increase the share of consumption of fast food. Growth in sales of such products in high-income countries is 1% per year, and in middle-income countries is 10% per year. People would rather not spend time preparing food, and this leads to an increase in the demand for semi-finished products [6]. Insufficient quality composition of such products can cause the problem of deficiency of useful substances. Among meat semifinished products, considerable attention is paid to semifinished products in a dough covering (dumplings, ravioli, khinkali), which are easy to prepare and do not require considerable time to bring to culinary readiness. The combination of meat and protein-containing vegetable raw materials in the recipe composition of dumplings can both satisfy the consumer's need for a high-quality product and improve several functional and technological characteristics of frozen products.

The purpose of this study was to identify the influence of hemp seed processing products on the functional and technological characteristics of frozen semifinished products in a dough covering with different types of meat raw materials using shock freezing.

To achieve the stated objective, the following tasks were set:

– to determine the influence of hemp seed processing products on the moisture content before and after freezing of culinary semifinished products;

– to determine the influence of hemp seed processing products on the change in the moisture-binding capacity of frozen semifinished products;

– to identify the effect of freezing on the emulsifying ability of minced meat for culinary semifinished products using hemp seed processing products;

– to evaluate the activity of water in culinary semifinished products using hemp seed processing products after defrosting.

Literature Review

Trends in modern nutrition and the shortage of high-quality protein in terms of biological value require the search for alternative protein sources. Such sources for meat products are milk proteins, fish, hydrobionts, insect proteins, cultured meat, protein-containing vegetable raw materials. Milk proteins are widely used in meat products. Whey protein isolate performs well in low-fat products and increases the gel-forming ability [7]. Likewise, fish, as a protein-containing raw material, is used in the technology in the form of fillets, mechanically obtained minced meat. Fish raw materials are rich in polyunsaturated fatty acids and complete proteins, which contributes to the creation of functional products. Waterfowl meat is also rich in useful substances, and the combination of these ingredients in a meat-containing product allows obtaining higher functional and technological indicators [8].

Edible insects are regularly consumed as a staple food or dietary supplement by members of various rural communities in Southeast Asia, the Pacific, Africa, and elsewhere. Insects are rich in protein, and their chemical composition varies depending on the species and place of their cultivation [9; 10].

Cultured meat is a promising area in food technology. This type of product is obtained thanks to the cultivation of meat fibres on a nutrient substrate. The production of this type of product is environmentally safe, and the substrate for its creation can be vegetable raw materials, e.g., algae [11]. However, at this stage of development, cultured meat still differs from natural meat in terms of quality [12].

Modern research proves the rationality of introducing a considerable proportion of vegetable proteins into the human diet, which improve the overall quality of the protein composition of the diet and reduce the consumption of certain nutrients [13]. The results of studies [14] showed that, compared to animal protein, the consumption of vegetable protein can improve the lipid profile in patients with hypercholesterolemia. The creation of products using plant components necessitates the investigation not only of their biological value, but also functional and technological characteristics. The functional and technological characteristics change depending on the type of product and the method of their production [15].

The latest methods of production of healthy products are the creation of analogues of meat fibres based on vegetable raw materials. The main building materials for future products are soy and pea proteins, gluten, polysaccharides, and fibre. Through physicochemical interactions, plant proteins can aggregate particles and anisotropic fibrils to give a meat-like texture and taste in the mouth. Mixtures of vegetable oils and spices are used to change the texture and taste; pigments are added to reproduce the traditional pink colour for meat products; vitamins, minerals, antioxidants, and antimicrobials are included to improve nutrition and increase shelf life. There are opportunities to overcome technological barriers, nutritional, and safety issues to further develop the alternatives market [16].

However, the creation of vegan products based on vegetable proteins causes some discussions. Such raw materials have many advantages in terms of technological characteristics; however, plant proteins are common allergens, and to obtain higher quality products, raw materials require added

processing [17-19]. It was determined that such types of products do not fully satisfy buyers in terms of sensory qualities, and to obtain better quality, raw materials require added processing [20-22]. Such shortcomings can be eliminated by combining non-conventional raw materials with animal protein. A good example of the interaction of plant and animal proteins is the combination of whey proteins of milk and pea or soy proteins, which allow obtaining better emulsion stability and rheological characteristics of products [23; 24].

Meat-vegetable combined products have substantial prospects in the consumer market, thanks to the possibility of effective modelling of their taste-aromatic and functional-technological characteristics and positive impact on the body [25; 26]. Such products are more useful for the body, their use does not force a drastic change in the diet, and according to global surveys, society positively perceives the transition to combining meat and vegetable raw materials [27-29].

A study of the use of plant ingredients in the composition of meat products demonstrates a positive effect on the functional and technological indicators of meat and vegetable products [30]. The rich chemical composition of such raw materials increases the nutritional and biological value of the obtained products and makes them functional [31]. The use of plant ingredients, due to their content of calcium and magnesium, allows solving the issue associated with the use of phosphates in the composition of products and improving their technological properties [32].

The development of recipes using the products of the processing of oil-containing vegetable raw materials considerably affects the quality of sausage products. Thus, the use of mustard powder in several types of sausage products increases product yield and improves the amino acid composition of the product [33]. In the conditions of the development of industrial regional clusters, modern meat technologies are increasingly oriented towards the use of ingredients typical for a certain region for the development of the latest products. Plant extracts that increase the sensory characteristics of products are widely used [34].

Among vegetable protein-containing raw materials, hemp seed processing products are promising for Ukraine. Hemp food products such as flour, fibre, and protein concentrate are produced by grinding the hemp cake and fractionating the resulting mass. The resulting fractions vary in size, with the smallest usually classified by protein content as “hemp protein”. According to research [35], the biological value of hemp seeds and its processing products varies depending on the method of cultivation and processing. However, the amino acid composition of hemp flour and protein contains all essential amino acids at a sufficiently high level.

Studies of the use of hemp seed processing products show high technological efficiency in the composition of meat products. It has been proven that the joint use of turkey meat and hemp flour in meat-rich breads allows producing foods with high nutritional characteristics. Thus, the use of hemp seed flour in the amount of 8-12% allows increasing the protein content by 3.21-11.80% and considerably increases the functional and technological properties of combined meat products [36]. Studies of the rheological properties of minced meat using hemp seed flour show a significant increase in the stability of the meat emulsion and the ultimate shear stress values [37].

The impact of hemp seed processing products on the minced meat system has been understudied. Therefore, the search for ways to expand the use of such protein-containing raw materials in meat products, namely frozen meat semifinished products in a dough covering, needs to be investigated to expand the consumption. The design of recipes for frozen semifinished products faces the problem of functional and technological indicators of minced meat, which can change after defrosting.

It is known that the water content in fresh meat can reach 75% and varies depending on the species, condition, and type of heat treatment. Water in fresh meat is mainly divided into 3 parts: bound water, immobilised water, and free water, in which the ratio of immobilised water and free water directly affects the moisture-binding capacity of meat. Depending on the type of processing, moisture can change from a bound state to a free state, which influences both the organoleptic indicators of the product and its rheological and functional-technological characteristics [38].

Freezing causes the crystallisation of water molecules and the loss of meat mass, depending on the category of fattening for beef, on average, by 1.58-2.10%, pork – by 1.31-1.60%, lamb – by 1.74-2.20%. The quality of the product is also affected by the speed and temperature of freezing. A low freezing rate can lead to the destruction of the myofibrillar structure and a decrease in the moisture retention capacity [39]. Water activity is a parameter that directly describes the state of hydration of a certain substance and the degree of binding of water in it. Many aspects of food system technology are related to food system hydration, so water activity (A_w) measurements can become widely used in process applications. Water activity monitoring is most widely used for products with a long shelf life to avoid microbiological spoilage [40].

The introduction of plant ingredients into the composition of meat products can considerably affect their functional and technological characteristics and the equilibrium state of moisture in the product, which affects its rheological and technological characteristics, as well as sensory indicators of quality under various conditions of technological influence.

Materials and Methods

Research was conducted in laboratory conditions at the Department of Meat and Meat Products Technology and in the Problem Research Laboratory of the National University of Food Technologies in 2021-2022.

During research, the recipes of minced meat fillings for semifinished products in a dough covering with various meat raw materials and products of hemp seed processing (*Cannabis Sativa* L.) produced by LLC “Desnaland” of the Sumy Oblast were simulated. The “Siberian dumplings” recipe was chosen as the control sample. The recipe composition of experimental samples of dumplings is presented in Table 1.

***Table 1**. Recipe composition of experimental samples of dumplings using protein and flour from hemp seeds*

Raw material	Control	Sample 1 / Sample 5	Sample 2 / Sample 6	Sample 3 / Sample 7	Sample 4 / Sample 8
1	2	3	4	5	6
The composition of the minced meat filling					
Beef of the 1st grade, %	44	37	–	–	–
Fat pork, %	17	–	–	–	–
Semi-fat pork, %	33	37	74	-	-
Red meat of broiler chickens, %	–	–	–	74	-
White meat of broiler chickens, %	–	–	–	–	74
*Hemp seed protein/flour, hydrated 1:2 with water, %	-	20	20	20	20
Onions, %	6	6	6	6	6
Composition of the dough					
Wheat flour, %	58	58	58	58	58
Chicken eggs, %	8	8	8	8	8
Drinking water, %	34	34	34	34	34
Spices for 100 g of minced meat					
Table salt, %	1.7	1.7	1.7	1.7	1.7
Black pepper, %	0.6	0.6	0.6	0.6	0.6

Meat raw materials were ground using a meat grinder (HKN-22SS), minced meat was kneaded on a minced meat mixer (KVL 8470 S. KENWOOD). The dough was mixed using a food processor (KVL 8470 S. KENWOOD). Dumplings were formed manually using a mould.

The semifinished products were frozen using a shock freezing chamber (ASH05K) at -34-35°C until reaching -18°C inside the dumplings.

The moisture content was determined by drying a 5 g sample in a drying cabinet to a constant mass at 105°C. The water-binding capacity to the moisture content (WBCm) and to the weight of the sample (WBCw) was performed by pressing 0.30 g of the minced meat and calculating the ratio of the area of the wet spot to the weight of the minced meat or moisture in the sample [41]. The emulsifying capacity was determined by centrifuging a sample of combined minced meat homogenised with vegetable oil and calculating the ratio of the volume of emulsified oil to the total volume of the sample [41].

Determination of water activity was carried out using the HygroLab 2 device – a water activity analyser for analytical laboratories, with an accuracy of ±0.01 A_w.

Results and Discussion

The content and state of moisture is a factor that directly affects the quality and safety of finished products. The moisture content of products influences their rheological, organoleptic, and technological indicators.

The specific features of the technology of preparing semifinished products in a dough covering, namely the freezing process and the presence of a dough part in the recipe, make it rational to investigate the change in moisture content indicators before and after refrigerating, as well as separately minced meat fillings. Figure 1 shows the change in moisture content in minced meat fillings and dough before and after their shock freezing.

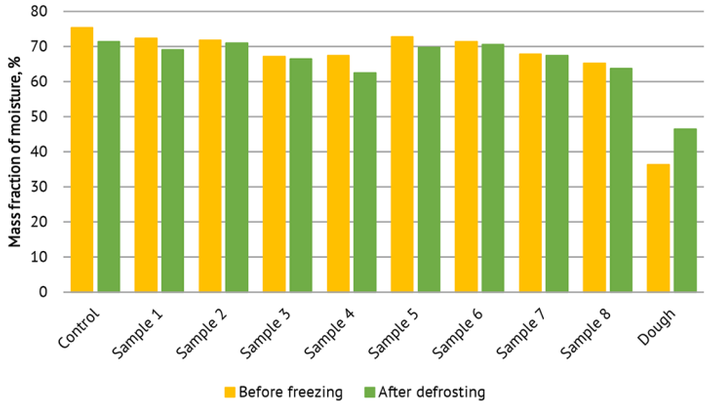

Figure 1. The value of the mass fraction of moisture in the samples of dumplings and dough under study before freezing and after defrosting

As Figure 1 demonstrates, all minced meat samples had sufficiently high moisture content values, ranging from 75.36 to 65.19% before freezing. Samples using protein and hemp seed flour had comparable results with no significant deviations. The comparison of the indicators of minced meat with diverse types of meat shows that the highest value in terms of moisture content was observed in samples based on beef and pork compared to samples based on broiler chicken meat.

After defrosting, the moisture content in the fillings of semifinished products in the dough shell decreased by 4.92-0.26%. The largest weight loss was observed in the sample using white meat of broiler chickens, namely 7.30%, which is 1.88% more than the loss in the control sample.

Research on the moisture content of the dough showed an increase in its moisture content before freezing from 36.36% to 46.49% after defrosting the dumplings, which indicates the redistribution of moisture from the minced meat to the dough covering during the freezing of the dumplings.

Figure 2 shows the averaged values of the moisture content of dumpling samples.

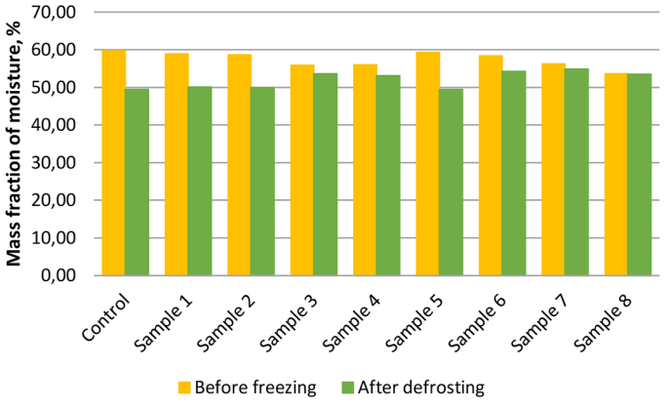

Figure 2. Value of the relative mass of moisture in the samples of dumplings under study before freezing and after defrosting

Studies of the average moisture content of dumpling samples (minced meat in a dough covering) showed that the moisture content of the samples before freezing ranges from 59.76% to 53.66% depending on the type of meat raw material (Fig. 2). The highest values of moisture loss after cryogenic exposure were observed in the control and the first and second samples of semifinished products using beef, fat pork, and semi-fat pork (control and samples No. 1 and No. 2, No. 5, No. 6). For samples with both white and red meat of broiler chickens using protein or hemp seed flour, the change in the moisture content of dumplings during cryogenic exposure changed insignificantly. The samples using white meat from broiler chickens differed the most, where the sample using flour had a 1.34% lower moisture value than the sample with hemp protein.

The moisture content in experimental dumplings after defrosting decreased for all samples and had a value of 54.86-49.52%. At the same time, moisture loss was the largest in the control, and the smallest in dumplings with broiler chicken meat using flour and protein from hemp seeds.

The moisture-binding capacity has a direct impact on the organoleptic and functional-technological properties of the product and is one of the key indicators of the quality of the minced meat emulsion and the product in general.

To investigate the moisture-binding capacity, samples of minced meat were taken before freezing and after defrosting. The obtained experimental data of WBCw are presented in Figure 3.

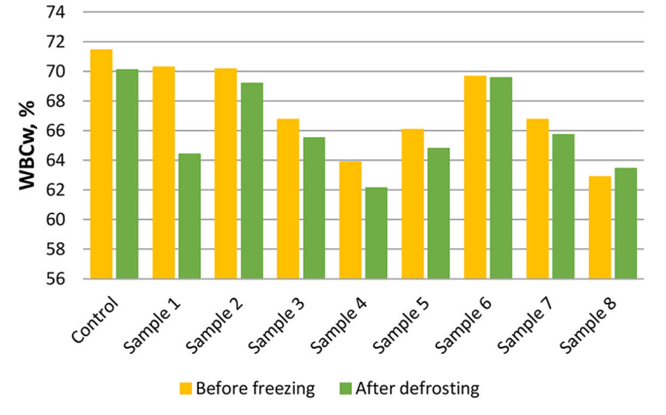

Figure 3. WBCw values in dumplings before freezing and after defrosting

The obtained experimental data of WBCw (Fig. 3) indicate that all samples had indicators at a sufficiently high level, which were corrected with the total moisture content of dumplings. Pork and beef dumpling samples had higher WBCw values compared to broiler chicken meat. At the same time, higher WBCw values were observed in samples with added protein compared to samples with hemp seed flour before freezing.

After defrosting, all minced meat samples decreased in WBCw, except sample No. 8 with hemp seed flour and broiler chicken white meat. Sample No. 1, which combined hemp seed protein with beef and pork, had the largest difference between WBCw values. In this sample, WBCw after defrosting decreased by 8.36% compared to the pre-freezing value. The best indicators were sample No. 6 using pork and hemp seed flour, where both indicators were at the same level – 69.64% and 69.54%.

The results of the WBCm study are presented in Figure 4.

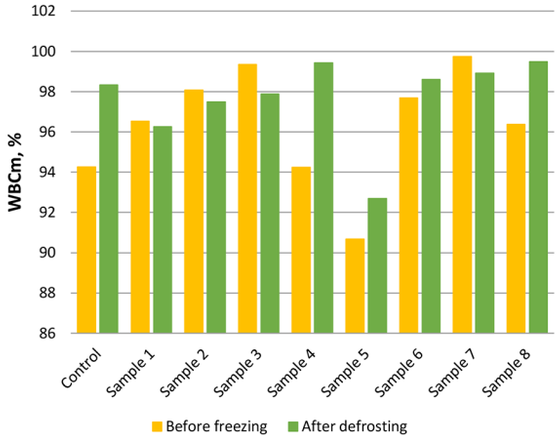

Figure 4. Value of WBCm in dumplings before freezing and after defrosting

The WBCm indicator (Fig. 4) characterises the moisture-binding capacity of minced meat to moisture content. The obtained data indicate sufficiently high values of this indicator for model mincemeats, which for all samples were higher than 90.00%.

This indicator was the lowest in the sample using pork and beef meat and hemp seed flour. The change of this indicator after defrosting occurred unevenly: in samples using protein, WBCm values decreased, except for the recipe with white meat of broiler chickens, and for samples using flour, after defrosting, WBCm values increased, except for sample No. 7.

Therewith, the highest WBCm values were observed in samples using broiler chicken meat.

Emulsifying ability is an indicator that directly characterises the functional and technological combined minced meat. The qualitative composition of proteins and the quantitative ratio of protein moisture and fat in the composition of minced meat contribute to the formation of a stable emulsion structure. The emulsifying ability of minced meat for semifinished products in the dough covering was investigated after defrosting (Fig. 5).

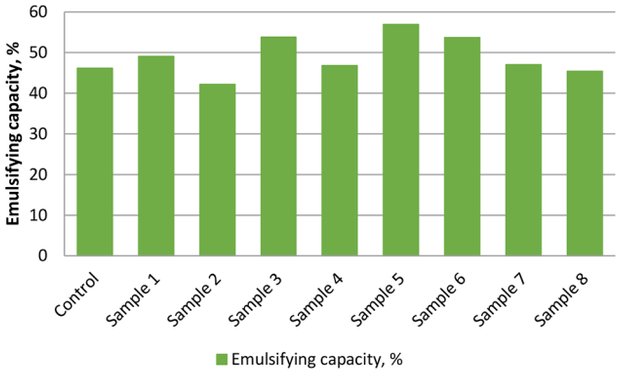

Figure 5. The value of the emulsifying ability in the minced meat of semifinished products in the dough covering

According to the results of the emulsifying capacity obtained (Figure 5), all experimental samples using hemp seed processing products have higher values than the control, except for sample No. 2, the recipe of which included pork and vegetable protein. The most important was sample No. 5 with beef, pork, and hemp seed flour, which was 56.97%. In experimental samples using hemp seed protein, the best combination was with red meat broiler chickens.

The "water activity" indicator is an essential indicator that shows the state of moisture in the food product

and the direction of moisture-mass exchange. This indicator characterises the presence of water in a state that can be involved in biochemical reactions and can be used by microorganisms for their vital activities.

The water activity (A_w) in dumpling samples was investigated after their defrosting, which allowed assessing the state of moisture in the product after freezing. The values of water activity are presented in the diagram in Figure 6.

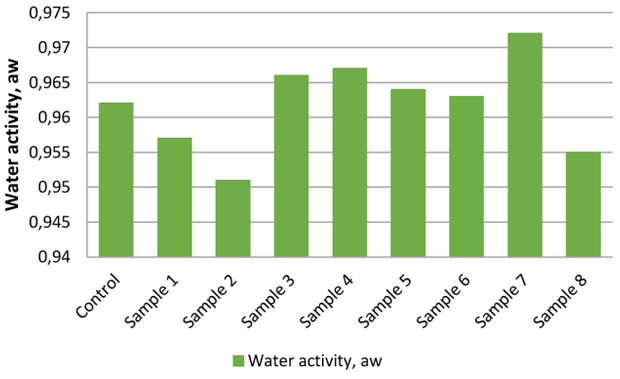

Figure 6. Value of water activity in samples of defrosted dumplings

All the samples of dumplings under study showed acceptable values for meat products of this assortment group in the range of 0.951-0.967 A_w, except for sample No. 7 using hemp seed flour and red meat of broiler chickens, where the value was at the level of 0.972 A_w.

The water activity value of the control sample was at the level of 0.962 A_w, the lowest water activity values were shown by samples using beef and pork with protein from hemp seeds at the level of 0.957 A_w and 0.951 A_w, which is a good indicator for the microbiological safety of this group of products. The lowest water activity of the samples using hemp seed flour was the sample containing the white meat of broiler chickens.

Based on a review of literary sources, it is possible to conclude on the relevance of developing products with a combined composition. Considering the prospects of non-conventional protein-containing raw materials in Ukraine, products processed from hemp seeds are of particular interest.

The study [36] of the effect of hemp seed flour on the functional and technological properties of meat-rich breads from the mechanically separated poultry meat of turkey showed their increase compared to the analogue, the recipe of which included wheat flour. The moisture content in the experimental samples increased and amounted to 70.03-77.13%, and the moisture binding and emulsifying capacity increased by 15-20% on average.

According to research [42], the use of 5% hemp seed processing products in the composition of pork loaves, the moisture content in recipes using flour and protein were at the level of 63.04% and 62.96%, respectively.

The data were obtained by researchers [36; 42] testify to the high efficiency of hemp seed processing products in the composition of meat and meat-containing products. However, the comparison of the values of the functional and technological indicators of minced meat based on diverse types of meat raw materials and their change during the freezing process is still under studied.

The freezing process directly affects the moisture in the meat, and according to research [43], it varies for diverse types of meat depending on the morphological composition of the raw material.

The obtained results of research on minced meat for dumplings before freezing confirm the data obtained by other researchers [36; 42]. Products processed from hemp seeds with meat raw materials of different origins did not significantly differ in moisture content from the control sample and had values higher than 65.0%. Moisture change after defrosting shows a considerable decrease in the samples using white broiler chicken meat and hemp seed protein, but all other plant-based samples showed better values than the control. Such results indicate better binding of moisture by plant protein-containing raw materials and reduction of its freezing.

The change in moisture during freezing also influences the moisture-binding capacity of minced meat. WBCw when using beef and pork with hemp seed protein was higher than the control and a similar sample with flour, but the loss of this indicator after defrosting was the highest. A sample using pork and hemp seed flour revealed no changes in WBCw.

The moisture-binding capacity to the mass of moisture in the sample after defrosting showed uneven changes. According to the results of the study, the combination of broiler chicken meat with hemp seed processing products gives the highest values. This is explained by the higher content of fibre and carbohydrates in flour.

The redistribution of moisture during the freezing process can cause changes and affect the formation of a stable meat emulsion. Comparing the combination of meat raw materials with vegetable protein-containing raw materials, the best emulsifying ability with flour is given by beef and pork, and with protein by broiler chicken meat.

The state of moisture after defrosting influences the chemical processes occurring in the raw meat and the development of microorganisms. All samples developed had values in the range suitable for meat products – 0.967 Aw, except for the sample with red broiler chicken meat and hemp seed meal.

According to the results, semifinished products in a dough shell using hemp seed processing products give stable indicators after freezing, which proves the relevance of further research.

Conclusions

The data obtained from the analysis of literary sources indicate a considerable amount of scientific research on the development of combined meat-vegetable products using vegetable proteins. The presented results of studies on the use of hemp seed processing products for frozen semifinished products in the dough covering testify to the high cryostability of the minced dumpling base when hemp seed flour is used in the minced meat.

Studies of water activity have shown that the addition of vegetable protein-containing preparations based on hemp seed processing products to the composition of the formulation allows reducing the Aw value by 0.005-0.011 Aw in samples using beef and pork compared to the control, and to ensure high values of the functional and technological indicators of the minced meat filling.

The study of the effect of freezing on model samples of minced meat filling and dumplings showed that in the process of cryogenic influence, there is a redistribution of moisture content in minced meat fillings and dumpling dough and a partial decrease of the WBCw indicator by 0.09-5.68%, except for the sample using white chicken meat – broilers and hemp seed flour. At the same time, it was proven that the selective combination of flour and protein from hemp seeds allows increasing the effectiveness of such a combination to stabilise the functional and technological indicators of semifinished products in the dough covering.

Further research will be aimed at developing frozen semifinished products in a dough covering of a combined composition using hemp seed processing products to ensure a high balance of protein and fatty acid composition of semifinished products in a dough covering.

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Вплив заморожування на характеристики напівфабрикатів у тістовій оболонці з використанням нетрадиційної білокумісної сировини

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Анотація. Актуальність дослідження зумовлена збільшенням зацікавлення альтернативними джерелами білка, для вирішення проблеми забезпечення населення біологічно повноцінними продуктами харчування комбінованого складу. Метою роботи є дослідження впливу заморожування на стабільність вологовмісту напівфабрикатів у тістовій оболонці з використанням різних видів м'ясної сировини, протеїну й борошна з продуктів переробки насіння конопель. Для дослідження було складено вісім рецептур фаршів із використанням яловичини, свинини, червоного та білого м'яса курчат-бройлерів із борошном та протеїном із насіння коноплі в кількості 20 % до загальної маси фаршу. У зразках визначались показники вмісту вологи, вологозв'язуюча, емульгуюча здатність виробів до заморожування та після розморожування та активність води в розморожених виробах. В дослідних зразках виявлено суттєву різницю в стабільності вологовмісту напівфабрикатів, залежно від поєднання в рецептурах напівфабрикатів борошна і протеїну насіння конопель і традиційних видів м'ясної сировини під впливом заморожування. Визначено, що за показниками емульгуючої здатності краще поєднання має борошно з насіння конопель із м'ясом яловичини та свинини, а протеїн з м'ясом курчат-бройлерів. Усі модельні зразки фаршів мали значення вищі за 40 %, а всі зразки окрім поєднання протеїну конопель зі свининою, були вищими за контрольний. Дослідження значень активності води в розморожених пельменях були в межах норми до 0,970 Aw, а зразок із використанням протеїну з насіння коноплі та свинини мав найнижчий показник у 0,951 Aw. Проведені дослідження свідчать про доцільність селективного комбінування продуктів переробки насіння конопель із різними видами м'ясної сировини в складі напівфабрикатів у тістовій оболонці. Поєднання різних видів нетрадиційної білокумісної сировини в складі заморожених напівфабрикатів у тістовій оболонці потребує врахування їхньої технологічної сумісності для забезпечення можливості реалізації розроблених рецептур при виробництві пельменів в умовах промислового виробництва

Ключові слова: рослинні білки, протеїн, борошно з насіння коноплі, заморожені напівфабрикати, вологовміст, активність води

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Meat Production and Growth of Internal Organs and Adipose Tissue in Bulls, Obtained from the Selection of Their Parents According to the Index of Similarity of System B Antigens of Blood Groups

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Abstract. During reproductive crossing, the genetic diversity of animals increases and the problem of consolidating livestock by type and productivity arises. Blood group antigens are one of the factors that indicate genetic variability, so they can be used as markers when selecting parent pairs. The purpose of this study was to analyse the meat productivity, development of internal organs and accumulation of adipose tissue in 18-month-old bulls derived from different selection of their parents according to the index of antigenic similarity (r_{as}) of the B system of blood groups at the first stages of a complex reproductive cross between Simmental and grey Ukrainian cattle with breeders of Charolais and Chianina breeds. According to the value of r_{as}, the bulls were divided into two groups. In the first – from a homogeneous selection of parents (over 0.268; n=9); in the second – from heterogeneous (r_{as} up to 0.267; n=7). After slaughtering the bulls, the meat productivity, mass, and output of the head, liver, lungs, and other organs and glands of internal secretion were determined. Intermuscular, interstitial, perirenal, pregastric, intestinal, and pericardial fat were separated and weighed. With homogeneous selection of parents, their sons, in comparison with their peers from heterogeneous mating, show a tendency to increase the content of muscles (by 4.2%), fat tissue in carcasses (by 12.4%), including between muscles (by 1.1 points). There is 11.6% less pulp per kilogram of bones, 17.2% worse muscle tissue index, 7.8% less absolute weight of liver, 10.0% of kidney, 27.8% of heart, head – by 2.0% and lungs – by 11.6%. In bulls, from the heterogeneous selection of parents with r_{as} to 0.267, there is 7.2% more fat tissue in the body, including internal fat tissue by 7.8%, the relative mass of bones is 0.8 points higher. The practical use of homogeneous selection according to antigens of blood groups of crossbreed parents allows improving the morphological composition of the carcasses of their offspring. Heterogeneous selection promotes better development of internal organs, which are less valuable slaughter products

Keywords: meat breeding, reproductive crossing, homogeneous selection, heterogeneous selection

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Introduction

During the breeding of the Ukrainian beef cattle breed created by complex reproductive crossing of Chianina (3/8), Charolais (3/8), Simmental (1/8), grey Ukrainian (1/8) cattle, there is a deterioration of productivity characteristics due to lack of justification of methods of selection of parents. At the current stage, polymorphic erythrocyte antigens of the B system of blood groups are increasingly used for the selection of animals to achieve a certain level of heterogeneity of livestock, they are ambiguously related to the reproductive capacity, growth rate and viability of animals. Selection of parents with low similarity of system B blood group antigens has a positive effect on offspring. In pure-bred breeding, the use of homogeneous mating almost always leads to a negative effect – a decrease in the viability, fertility, milk yield and meat productivity of livestock. This creates prerequisites to believe that the heterogeneous selection of parents by blood group factors in breed populations will contribute to the preservation of genetic variability and higher productivity of offspring.

The meat productivity of bulls, obtained from the selection of parents based on blood group factors in cattle of Ukrainian breeds at the first stages of complex reproductive crossing, has been understudied. Many issues regarding the influence of parental selection on the growth of internal adipose tissue and organs of the offspring are still understudied as well. Therefore, it is worth investigating the influence of the selection of parental pairs according to the index of similarity (r_{as}) of antigens of the B system of blood groups on meat productivity and the growth of internal organs and adipose tissue of bulls obtained at the first stages of complex reproductive crossing, for the foremost importance of their stock in production beef.

The use of the B blood group system is currently one of the methods for predicting the productivity of cattle. Numerous studies on the Ukrainian beef cattle breed indicate ambiguous results of the relationship between blood groups and signs of its productivity. It was proved [1] the negative influence of homogeneous selection of parents after them on the sperm productivity of offspring. Thus, the volume of ejaculate is 7.4% greater in Prydniprovskyi type bulls obtained from heterogeneous selection than in peers from homogeneous selection, and by 9.1% in Chernihiv type bulls. In terms of sperm motility, animals obtained from parents with a lower index of antigenic similarity (r_{as}) outperform peers by 6.5 and 9.8%, respectively. In terms of sperm concentration – by 2.4 and 16.7%. An increase in the difference between father and mother in erythrocyte antigens increases the life expectancy of their sons. The opposite feature was obtained [2] on cows. Due to the increase in the antigenic similarity of the parents in terms of blood group factors, their daughters tend to increase in live weight and reproductive capacity.

The amount of adipose tissue in animals varies depending on the species [3], breed [4], age [5] and feeding [6]. The problem of the growth of internal adipose tissue in animals obtained from varied selection of parents for r_{as} is not properly covered. Fat under the skin, between the muscles and in the middle of the muscles is usually examined [7]. Information on visceral fat in different depots would be useful in explaining differences in slaughter yield (carcasses) levels. The accumulation of fat is also of significant importance due to its connection with the increase in feed consumption for live weight gain [8]. Its distribution by fat depots is simultaneously the subject of accounting for the generation of waste in cattle. About 1/4-1/3 of the main chemical components: water, protein, and fat are found in parts of the body that are not part of the carcass [3]. The importance of beef fat, which has a low nutritional value in the processing industry, is decreasing. Healthy nutrition is aimed at reducing the calorie content of products and partially replacing fats of animal origin with triglycerides with polyunsaturated fatty acids, introducing raw materials of plant origin into recipes. Beef fat in burger patties is replaced with tiger nut oil emulsion [9]. In sausages, it is replaced by jelly-containing emulsion systems, including peanut and linseed oil [10]. In cutlets – olive oil for reducing the share of internal fatty tissue in animals for slaughter [11].

By-products after animal slaughter have nutritional value. Liver, heart, tongue, kidneys are an essential source of protein, including essential amino acids, vitamins, and mineral elements [12]. Cattle liver is used as a raw material to produce pasta and pastes [13]. The kidneys, lungs, and heart contribute to increased absorption of non-heme iron [14]. In cattle of similar origin, the weight of offal is influenced by pre-slaughter live weight [15]. The total amount of edible and inedible offal substantially depends on the breed and age of animals [16]. The weight of testes depends on age and puberty and increases with intensive feeding [17].

Currently, in the Ukrainian meat breed, the coverage of the features of meat productivity, the deposition of internal adipose tissue and organs and glands in bulls from parents with different similarity index of antigens of the B system of blood groups is necessary to produce beef efficiently and purposefully with a higher yield of its valuable components. *The purpose of this study* was to determine the influence of the selection of parental pairs according to the B blood group system on the characteristics of meat productivity, the distribution of internal adipose tissue, and the growth of organs and glands of cattle obtained at the initial stages of complex reproductive crossing.

Materials and Methods

The analysis was carried out in 2021 based on the materials of the production activity and breeding records of the breeding plant "Volya" of the Zolotonoskyi district of the Cherkasy Oblast, collected in creating the Ukrainian meat breed of cattle. It was created by complex reproductive crossing of mother stock of the Simmental and grey Ukrainian breeds with Charolais and Chianina breeds. After verifying the authenticity of the origin of the bulls by blood group factors, 2 groups were formed according to the value of the antigenic similarity index of the parents: Group I – r_{as}=over 0.268 (from homogeneous selection, n=9) and Group II – r_{as}=up to 0.267 (from heterogeneous selection, n=7). At the same time, local bulls were raised in a herd. After the end of rearing, two balanced groups of animals were selected at the age of 18 months. Before slaughter, the permissible difference in live weight and age between animals did not exceed 5% (Table 1).

***Table 1**. Live weight and age of bulls from homogeneous and heterogeneous selection of parents before slaughter*

Feature	Groups of animals according to the value of the index of antigenic similarity (r_{as})			
	over 0.268 (n=9)		up to 0.267 (n=7)	
	M	lim	M	lim
Age, days	547	from 520 to 574	547	from 520 to 574
Live weight, kg	594	from 588 to 600	580	from 570 to 590

To calculate the index of antigenic similarity of the parents, erythrocyte antigens of cattle according to the B system of blood groups, published in the catalogue [18], were used. The index was calculated according to the formula cited in the paper [19]:

$$r_{as} = \frac{S}{n_1 + n_2 - S} \quad (1)$$

where r_{as} is the ratio of antigenic similarity of parents; S is the number of coincident antigens in the father and mother; n_1 is the total number of antigens detected in the mother; n_2 is the total number of antigens detected in the father.

The conditions for rearing bulls met the requirements of the technology of specialised meat cattle breeding. Until the age of 6-7 months, the animals were reared under suckling. After weaning from their mothers until the age of 8 months, they were accustomed to a typical diet and conditions of confinement. In the period from 8 to 18 months of age, intensive rearing of bulls was carried out. The general level of their feeding was calculated to obtain average daily gains from 1,000 to 1,200 g. The amount of feed consumed by animals was individually monitored. The list of fodder that was fed to the animals depended on the season of the year. In the spring and summer period, they fed the grass of crops according to the scheme of the green conveyor and compound feed of their production. It comprised corn grain 25%, barley – 30%, wheat bran – 25%, sunflower grist – 15%, minerals and vitamins – 4.5%, salt – 0.5%. In the autumn-winter period, a large part of the diet consisted of hay, silage, and root vegetables. The mass of fodder eaten by each bull was calculated every decade (two days in a row) by weighing the given fodder and its residues. During the period from 8 to 18 months, there was no significant difference in the consumption of all feed by the bulls (Table 2).

***Table 2**. Feed consumption by bulls from 8 to 18 months of ageter*

Feed	r_{as} 0.268 or more	r_{as} up to 0.267
	M ± m	M ± m
Concentrated, feed units	1480±31,5	1407±58,5
Concentrated, %	49,5±0,85	46,8±0,64
Rough, feed units	482±53,7	493±52,8
Rough, %	15,7±1,57	15,9±1,41
Juicy, feed units	543±35,9	554±60,4
Juicy, %	17,9±1,00	18,1±1,59
Green, feed units	536±41,7	568±57,0
Green, %	17,4±1,69	19,2±2,09
Total, feed units	3032±77,6	3017±124,7
Per 1 kg of weight gain, feed units	8.9±0.44	9.3±0.67

To determine the meat productivity of the animals, they were slaughtered at the Cherkasy meat processing plant per the requirements of DSTU 4673:2006 [20] and DSTU 3938-99 [21]. Before that, they were weighed before and after a 24-hour fasting period with free access to water (pre-slaughter live weight). After slaughter, the slaughter weight (of a pair of carcasses) was determined. According to its relation to the pre-slaughter live weight, the slaughter yield (carcasses) was calculated. Net weight gain (Ng) for each day of life was determined per the ICAR requirements [22] according to the formula (2):

$$Ng = \frac{slaughter\ weight\ (carcass), kg \times 1000}{age\ at\ slaughter, days} \quad (2)$$

After cleaning the carcasses, the absolute mass of trimmings and their share of the slaughter weight (carcass) were determined. The left half-carcasses of the bulls were buried. Subsequently, the mass of bones, muscle tissue, including higher, first, second grade, tendons and ligaments, and fat tissue was weighed. Adipose tissue was weighed and divided into subcutaneous (subcutaneous) and intermuscular fat per DSTU 3938-99 [21]. Perirenal fat was separated from the kidneys from the inner side of the lower back and pelvis. The fat covering the stomach was separated from the internal omentum, and the fat surrounding the intestine and deposited in the mesentery was also separated. The mass of total adipose tissue was calculated as the sum of internal fat and fat from the carcass.

After deboning, the muscle-bone ratio was determined as the ratio of muscle tissue to bones [3]. The index of muscle tissue was determined by the ratio of muscle tissue to the mass of bones, fat tissue, and tendons and ligaments [23]. After slaughter, the mass of offal was determined, including head with horns, liver, lungs, heart, kidney, brain, and testicles and their ratio (%) to pre-slaughter live weight.

After slaughter, the weight of a pair of skins was determined on the scales without the remains of muscle and fatty tissue (if their weight did not exceed 500 g), blood clots and impurities and "bulk". The length of the skin was measured along the spine from the upper edge of the neck midway between the horns to the line connecting the ends of the buttocks. Width was measured along the line located in the middle third of the skin. Before measuring, the skin was spread out on the table, folds and other irregularities were smoothed out without stretching it in length and width.

During the statistical processing of the data, the average values (M) by group, the statistical error of the average (±m), the difference between the averages and its probability were determined. To characterise the degree of variability of signs, the coefficient of variability (Cv, %) was calculated as the ratio of the mean square deviation to the average value for the group.

Results and Discussion

Under homogeneous selection of parents according to the index of antigenic similarity, their sons have a tendency to increase live weight and weight after starvation, compared to peers born from ancestors under heterogeneous selection (Table 3). Due to the heterogenous selection, the bulls have somewhat more (by 7.1%) adipose tissue, including internal (by 7.8%). The obtained data indicate a tendency to precocity in animals under the influence of heterogeneous selection of parents by blood group factors. Precocious animals are prone to early obesity [24].

***Table 3**. Slaughter signs of bulls at the age of 18 months, obtained from varied selection of parents by r_{as}*

Feature	over 0.268			up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Live weight, kg	9	594±16.5	7.9	7	580±24.1	10.2
Live weight after 24-hour starvation, kg	9	562±14.8	7.4	7	559±19.0	8.3
Slaughter weight (carcass), kg	9	342±12.6	10.4	7	341±13.5	9.7
Slaughter yield (carcasses), %	9	60.8±0.77	3.6	7	61.0±0.91	3.6
Net increase, g	7	597±24.6	10.1	7	594±27.0	8.2
Total adipose tissue, kg	7	20.9±2.96	7.2	4	22.4±2.75	4.8
Internal adipose tissue, kg	9	14.1±1.34	26.9	7	15.2±1.46	23.6
Internal adipose tissue to total, %	9	67.5±0.23	26.4	7	67.9±0.23	20.6

This leads to a 4.5% increase in feed consumption (feed unit) per kilogram of live weight gain (Table 2). More intense deposition of fat is associated with an increase in precociousness, which is combined with a decrease in the size of animals. Relatively more precocious cattle for beef production are less efficient due to reduced meat productivity and higher feed costs per unit of production. For the formation of adipose tissue, animals spend more feed nutrients than for the formation of the muscle part of the carcass.

In the bulls from heterogeneous selection, there is a tendency towards weight decrease (by 2.5%) of half-carcasses compared to peers from homogeneous selection (Table 4).

***Table 4**. Morphological composition of half-carcasses of bulls obtained from varied selection of parents by r_{as}*

Feature	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Half-carcass weight, kg	7	174.5±5.78	14.2	7	170.3±6.87	16.8
Bones, %	8	16.2±0.23	0.6	7	17.0±0.46	1.1
Muscle tissue, kg	8	133.2±4.60	12.2	7	127.8±4.55	11.1
Muscle tissue, %	8	76.3±1.17	3.1	7	76.0±1.62	4.0

Table 4, Continued

Feature	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Including high grade, %	8	19.9±2.35	6.2	4	20.4±3.08	5.3
First grade, %	8	41.1±3.18	8.4	5	43.0±9.05	18.1
Second grade, %	8	39.0±1.72	4.5	4	38.2±2.94	5.1
Tendons and ligaments, %	8	3.7±0.41	1.1	7	3.8±0.59	1.4
Adipose tissue of the carcass to the total, %	6	32.5±0.84	1.9	4	32.1±0.35	0.6
Including subcutaneous fat to total, %	8	22.5±2.81	7.4	4	23.2±3.32	5.7
Fat between the muscles, %	6	10.0±1.65	3.7	4	8.9±2.70	4.7
Trimmings, kg	4	4.9±0.33	12.0	3	4.6±0.97	30.0
Crops, %	4	0.9±0.08	16.0	3	0.8±0.17	30.2
Musculoskeletal ratio	6	4.7±0.12	0.3	4	4.2±0.21	0.4
Index of muscle tissue	6	3.2±0.19	0.4	4	2.9±0.19	0.3

They are inferior in the content of muscle tissue, but they tend to increase the relative amount of pulp of the highest and first grades and to decrease the amount of the second grade. For beef of the highest grade, which includes muscle tissue without fat, tendons, and ligaments in animals from heterogeneous selection, it is 0.5 points more. Beef of the second grade, which according to the sausage classification includes a large amount of fat between the muscles, which was not separated during ageing, has 0.8 points more in bulls from homogeneous selection.

Buckeyes obtained from parents by homogeneous mating prevail by 12.4% of their peers from heterogeneous origin in terms of the content of fatty tissue between the muscles in the carcass. Fat between muscles leads to their displacement [3]. Therefore, more accumulation of this fat in cattle due to homogeneous selection has a noticeable effect on the expressiveness of its meat forms, which is characterised by less angularity and better development. A greater proportion of adipose tissue between muscles in homozygous animals is also subject to excessive waste formation from them. In the carcasses of animals from homogeneous selection, fatty tissue under the skin is worse (by 0.7%). In it, reserve fats, which perform supporting, protective, and heat-insulating functions in the body, and energy reserves and water depots are deposited less.

The most active accumulation of adipose tissue under the skin in cattle occurs in the period from 7 to 12 months of life, and between the muscles – from 12 to 18 months [5]. Homogeneous selection of parents by r_{as} in the Ukrainian beef cattle breed has the maximum positive effect on the normal growth of fat tissue of 18-month-old bulls between the muscles, which improves the nutritional properties of beef, due to its much higher growth rate during this period. With a homogeneous selection of parents, a decrease in the accumulation of subcutaneous adipose tissue can be observed in sons. According to data [7], homozygosity is negatively related to fat and its thickness in the back of the body. Evaluation [25] in pure-bred populations of Charolais, Limousin, Simmental, Hereford, and Angus beef cattle also proved that homozygous animals have a lower fat mass in the carcass. The analysis of the yield and quality of beef according to muscle tissue indices and the muscle-bone ratio shows a pronounced tendency towards the improvement of the listed traits in bulls due to homogeneous selection. For each kilogram of bones, they have more pulp. These cattle also have a better index of muscle tissue.

Due to heterogeneous selection, the level of deposition of internal adipose tissue is 7.8% higher in bulls (Table 5). They have a higher percentage of fat around the kidneys and from the intestines, but less from the foreskin and pericardium.

***Table 5**. The output of internal fat in 18-month-old bulls obtained from varied selection of parents by r_{as}*

Feature	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Live weight after starvation, kg	9	562±14.8	7.4	7	559±19.0	8.3
Internal adipose tissue, kg	9	14.1±1.34	26.9	7	15.2±1.46	23.6
Internal adipose tissue, % to pre-slaughter live weight	9	2.5±0.23	26.4	7	2.7±0.23	20.6
Including fat from stomachs, kg	8	4.0±0.60	41.3	4	4.2±1.01	40.3
Fat from stomachs, %	8	28.4 ±1.56	21.1	4	27.6±2.75	24.9
Pericardial fat, kg	8	1.0±0.12	33.7	4	0.8±0.28	59.7
Pericardial fat, %	8	7.1±0.70	37.0	4	5.3±1.96	81.2

Table 5, Continued

Feature	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Perirenal fat, kg	8	3.1±0.89	78.6	4	3.6±0.92	42.6
Perirenal fat, %	8	22.0±1.89	36.3	4	23.7±2.97	31.3
Fat from intestines, kg	8	6.0±0.39	17.5	4	6.6±0.69	17.6
Fat from intestines, %	8	42.5±3.26	26.8	4	43.4±2.99	16.3

Perirenal fat is formed early, later – subcutaneous and other fats [5; 6]. Perirenal fat contains the least amount of moisture and protein, and the highest percentage (about 90%) of extracted fat [3]. Adrenal fat has the lowest value. Therewith, it is associated with increased feed costs during animal rearing. One of the disadvantages of excessive deposition of internal adipose tissue is its negative correlation with the content of fat inside the muscles [26]. In animals prone to accumulation of internal fat, the degree of marbling of beef will decrease. Thus, this fat not only does not have an exceptional value, but factually requires added costs for its production and is unprofitable. A considerable amount of the homogenous selection of pericardial fat in bulls can be explained by the propensity of some such individuals to excessive obesity and the manifestation of heart failure, which is often observed during intensive breeding of cattle for meat [27]. Excessive deposition of fat on the omentum in cattle under the same conditions of its maintenance is caused by genetic loci [28]. The genes involved in proteolysis, transcription, transport, and immune functions, and oxidative processes differ among cattle at different live weight gains and feed consumption [29].

The homogenous selection of parents in bulls leads especially to a pronounced suppression of the growth of internal organs: liver by 7.8%, kidneys – by 10.0%, heart – by 27.8%, head – by 2.0%, lungs – by 11.6% (Table 6). Worse development of the lungs leads to a decrease in redox reactions.

***Table 6**. The mass of organs and tissues that are not part of the carcass in bulls obtained from varied selection of parents by r_{as}*

Organ	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Head, kg	9	19.6±0.87	12.6	4	20.0±1.16	10.0
Head, %	6	3.3±0.11	7.7	4	3.4±0.11	5.5
Liver, kg	6	6.4±0.26	9.2	4	6.9±0.62	15.7
Liver, %	6	1.2±0.05	9.1	4	1.2±0.06	8.1
Lungs, kg	6	4.3±0.15	7.5	4	4.8±0.83	30.1
Lungs, %	6	0.8±0.02	7.3	4	0.8±0.14	30.3
Kidneys, kg	6	1.0±0.13	29.6	4	1.1±0.11	18.2
Kidneys, %	6	0.2±0.04	49.0	4	0.2±0.03	28.6
Intestines, kg	4	8.0±0.52	11.3	3	8.4±0.33	5.6
Intestines, %	4	1.4±0.14	17.5	3	1.5±0.11	10.4
Spleen, kg	4	1.3±0.28	36.8	3	1.2±0.29	35.2
Spleen, %	4	0.2±0.06	39.9	3	0.2±0.04	29.0
Abomasum + Rumen, kg	4	12.0±0.39	5.7	3	13.1±0.52	5.6
Abomasum + Rumen, %	4	2.2±0.10	8.1	3	2.3±0.02	1.4
Tongue, kg	4	1.5±0.07	8.3	3	1.6±0.24	21.1
Tongue, %	4	0.3±0.01	3.5	3	0.3±0.03	15.6
Heart, kg	4	1.8±0.08	8.0	3	2.3±0.27	16.4
Heart, %	4	0.3±0.02	9.2	3	0.4±0.03	9.5

Bulls from parents with r_{as} up to 0.267 have a better developed tongue, intestines, abomasum, and rumen. Animals from homogeneous selection have a tendency to decrease the absolute and relative mass of the head, which may be conditioned upon the ossification of the skull in the early stages of ontogenesis. Due to earlier ossification of cartilage, these animals have a shorter head, thinner and lighter bones, which is reflected in their mass. Regardless of the composition of the carcasses, the increase in offal and internal fat adversely affects the yield of the carcass. Therefore, it is important to find an opportunity to change this ratio in the desired direction, since the cost

of by-products is substantially inferior to the price of the carcass.

The largest rate of accumulation of adipose tissue from the large and small omentaries and around the kidneys in bulls occurs in the period from 7 to 12 months [5]. Fat is most intensively deposited around the heart from 12 to 18 months of life of animals. According to the data obtained in the study, the mass of the heart decreases in bulls due to homogeneous selection, and the amount of fat deposited around it is greater. This is compensated by an active reduction in the amount of fatty tissue in the intestine and around the kidneys.

38 significant single-nucleotide polymorphisms that influence the weight of internal organs have been established [30], which indicates the genetic condition of the output of by-products in animals, which can manifest as a result of the concentration of similar genes and the reduction of their diversity. These data confirm the possible dependence of the development of the organs of bulls on the selection of parents. The mass of the glands of internal secretion is also greater in bulls from parents with a ratio of antigenic similarity (r_{as}) up to 0.267, which indicates the specific features of the secretory activity of these glands in them (Table 7). An enlarged thyroid gland leads to a weakening of the constitution of animals.

***Table 7**. The mass of the glands of internal secretion of bulls, obtained from varied selection of parents by r_{as}*

Gland	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Pancreas, g	4	321±26.7	46.3	3	323±4.1	5.8
Brain, g	7	392±22.2	54.4	4	447±53.6	92.8
Testicles, g	4	609±37.0	64.1	3	660±88.6	125.3
Thyroid, g	4	25.2±4.50	30.9	3	28.1±3.34	16.8
Pituitary gland, g	3	2.4±0.30	17.5	3	2.6±0.11	6.0

Heavy and large skins are obtained from animals of both groups (Table 8). Bulls, obtained from the selection of parents with a lower index of antigenic similarity, have a greater mass and width of the skin and a slightly shorter length than those of the same age.

***Table 8**. Sizes and weight of skins in bulls, obtained from varied selection of parents by r_{as}*

Indicator	Over 0.268			Up to 0.267		
	n	M±m	Cv, %	n	M±m	Cv, %
Skin, kg	6	49.2±2.29	10.4	4	52.3±2.04	6.8
Skin, % of pre-slaughter live weight	6	8.7±0.20	5.2	4	9.1±0.23	4.5
Length of the skin, m	6	2.1±0.12	12.9	4	2.0±0.14	11.5
Width of skin, m	6	2.1±0.09	9.1	4	2.2±0.11	9.1

Therefore, the great similarity in blood group factors in the genotypes of animals originating from different breeds leads to a desirable increase in the level of heterozygosity by origin with an increase in the number of erythrocyte alleles, which is the reason for the increase in the meat productivity traits of the offspring. At the first stages during the creation of the Ukrainian beef cattle breed using the homogeneous selection of parents according to the index of antigenic similarity, one of the important issues in their sons was a decrease in the weight of the liver, lungs, heart, kidneys, and glands of internal secretion.

Pairing of animals related by genotype, but not similar in phenotype and genealogically, counteracts the growth of homozygosity. Therefore, the probability of depression decreases. Preservation of heterozygosity according to type of body structure and origin during homogenous mating for r_{as} is explained by the presence among homozygous animals of individuals with satisfactory meat productivity. All other things being equal, such individuals, formally homozygous but biologically the most heterozygous, factually retain their advantages. Notably, the parents of the bulls under study were hybrids, which are described by great genetic variability. The results of homogeneous and heterogeneous selection based on the index of antigenic similarity of parents during pure-bred breeding may substantially differ from those obtained in this study.

Conclusions

Bulls obtained from homogeneous selection of parents according to antigens of the B system of blood groups show a tendency to increase pre-slaughter live weight, as well as increase the content of muscle and fatty tissue in carcasses. Due to the heterogenous selection of parents in the carcasses, bulls have more adipose tissue in the body and a greater relative mass of bones. They have a better developed number of internal organs.

Thus, in the first stages of complex reproductive crossing, greater similarity in blood group factors in the genotypes of parents who come from different breeds leads to a decrease in the level of heterozygosity in erythrocyte antigens of the B system of blood groups, which is associated with an improvement in the meat productivity of the

offspring. During the selection of inbred parents, a heterogeneous selection based on blood group factors should be carried out to reduce the amount of adipose tissue scraps from carcasses, increase the weight of the head, liver, lungs, heart, kidneys and endocrine glands, or homogeneous selection to improve the morphological composition of the carcasses.

The prospect of further research lies in the comparison of the performance and interior indicators of crossbred and pure-bred animals obtained under the same variant of parent selection according to ratios of antigenic similarity. This will expand the knowledge of selection methods in genetically diverse and relatively homogeneous cattle populations.

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М'ясна продуктивність та ріст внутрішніх органів і жирової тканини у бугайців, отриманих від підбору їх батьків за індексом подібності антигенів системи В груп крові

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Анотація. Під час відтворювального схрещування зростає генетична різноманітність тварин і постає проблема консолідації худоби за типом і продуктивністю. Антигени груп крові є одним з факторів, які вказують на генетичну мінливість, тому можуть бути використані як маркери під час підбору батьківських пар. Метою даного дослідження було проаналізувати м'ясну продуктивність, розвиток внутрішніх органів і накопичення жирової тканини у 18-місячних бугайців, що походять від різного підбору їх батьків за індексом антигенної подібності (r_{as}) системи В груп крові на перших етапах складного відтворювального схрещування симентальської і сірої української худоби із плідниками порід шароле та кіанської. За величиною r_{as} бугайців розподілили у дві групи. У першу від гомогенного підбору батьків (понад 0,268; n=9); у другу від гетерогенного (r_{as} до 0,267; n=7). Після забою бугайців визначали м'ясну продуктивність, масу і вихід голови, печінки, легень та інших органів і залоз внутрішньої секреції. Відокремлювали і зважували жир міжм'язовий, полив, навколонирниковий, із передшлунків, із кишківника та навколосерцевий. За гомогенного підбору батьків у їх синів, порівняно з ровесниками від гетерогенного спаровування, проявляється тенденція до підвищення вмісту м'язів (на 4,2 %), жирової тканини у тушах (на 12,4 %), у тому числі між м'язами (на 1,1 пункти). На кілограм кісток припадає м'якуша менше на 11,6 %, гірший на 17,2 % індекс м'язової тканини, абсолютна маса печінки менша на 7,8 %, нирок – на 10,0, серця – на 27,8, голови – на 2,0 і легень – на 11,6 %. У бугайців від гетерогенного підбору батьків із r_{as} до 0,267 на 7,2 % більше жирової тканини у тілі, у тому числі внутрішньої на 7,8 %, відносна маса кісток більша на 0,8 пункти. Практичне використання гомогенного підбору за антигенами груп крові помісних батьків дозволяє поліпшити морфологічний склад туш їх потомків. Гетерогенний підбір сприяє кращому розвитку внутрішніх органів, які є менш цінними продуктами забою

Ключові слова: м'ясне скотарство, відтворювальне схрещування, гомогенний підбір, гетерогенний підбір

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The Performance of Egg Hens When Using a Prebiotic Preparation

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Abstract. The relevance of this study is conditioned upon the active introduction of prebiotic preparations into the practice of feeding poultry and the need to determine the impact of their use on quantitative and qualitative indicators of productivity. In this regard, this study is aimed at determining the effect of the introduction of the prebiotic preparation Actigen in the diet of laying hens on their level of productivity and morphological parameters of eggs. Using an integrated approach, the level of egg productivity of chickens was investigated for the introduction of the preparation into the mixed feed in the amount of 500 g/t for 6 weeks. Assessment of poultry at 52 weeks of life indicates a slightly higher level of egg production of chickens of the experimental group – 198.6 pcs against 196.2 pcs in the control group (the difference is 1.22%) and the safety of livestock – 97.50% against 97.00% in the control group. It was found that the mass of eggs obtained from chickens of the experimental group was higher by 1.09 g ($p<0.05$). A lower level of variation (Cv) of the "egg mass" trait of the poultry of the experimental group (3.05%) than in the control group (3.51%) is positive, and indirectly indicates the level of uniformity of the herd in live weight. It was established that the weight of egg white and yolk of hens in the experimental group was 1.04 g and 0.37 g higher, respectively, than in the control group. The difference between groups is not statistically significant, but it shows the direction of their changes. In the eggs of the experimental group, the large diameter of the egg white was smaller compared to the control group by 1.93%, and the small diameter by 3.56%. The height of the dense layer of white and yolk, which are objective indicators of egg quality, were greater in the experimental group ($p<0.001$) compared to the control group, which is positive, this difference was 21.54% and 20.00%, respectively. According to the indicators of the energy value of eggs, no substantial differences were found between the experimental groups. The obtained data (increase in the level of egg production of poultry, preservation of livestock, egg weight, improvement of egg quality indicators of chickens of the experimental group) indicate a positive effect of the introduction of the prebiotic preparation Actigen on the level of egg productivity of poultry. The materials of this paper are of practical value for the work of poultry enterprises specialising in the production of food-grade chicken eggs

Keywords: prebiotic, egg production, laying hens, Actigen, egg mass, white, yolk

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Introduction

In the countries of the European Union, during the production of livestock products, antibiotics and growth stimulants have been abandoned for more than a decade, being replaced with alternative products [1]. The use of pro- and prebiotics in animal feeding is becoming increasingly relevant, especially after the ban on the use of antibiotics as growth promoters in the EU, starting in 2006 [2]. To minimise infectious diseases in animal husbandry and reduce the use of antibiotics, manufacturers make efforts to improve the health of animals through improving sanitary and hygienic conditions, ensuring biosafety and a high culture of technological process, as well as preventing diseases through the use of vaccines and other preventive means, namely the use of beneficial bacteria contained in various feeds (probiotics), indigestible feed, promoting the growth and reproduction of probiotic bacteria (prebiotics) or replacement preparations (intestinal bacterial flora, etc.).

Poultry producers in Ukraine are actively implementing the technology of producing eggs and poultry meat without antibiotics in their farms, replacing them with alternative products [3; 4; 5], in particular, they use prebiotic preparations.

Prebiotics are carbohydrates that are not digested by endogenous enzymes but form a fermenting substrate for the intestinal microflora. Their use is aimed at supporting the development of such favourable microorganisms as lacto- and bifidobacteria, which have a positive effect on the intestinal microflora [6].

The greatest prebiotic activity is inherent in non-starchy oligo- and polysaccharides, whose molecules are bound by beta-glycosidic bonds. Without beta glycosidases in the enzyme system (due to the impossibility of splitting these bonds), oligo- and polysaccharides are not digested and contribute to the creation of an environment favourable for beneficial microorganisms [7].

Prebiotic activity can be described by individual substances of egg white origin, vitamins, and their derivatives [6].

Numerical studies [8; 9; 10] have confirmed the effectiveness of using prebiotic preparations in the production of poultry products – in terms of livestock safety, feed costs, growth rate of young animals, indicators of overall body resistance.

According to the results of the studies [8; 11; 12], the use of probiotics and immunomodulatory preparations is one of the ways to correct the functional state of the central and peripheral organs of immunogenesis of broiler chickens, which provides an increase in the specific resistance of the bird's body during the formation of the immune response and the intensity of post-vaccination immunity.

The introduction of prebiotic preparations (mannan oligosaccharides and fructooligosaccharides) into the diets of broiler chickens contributes to the development of internal organs, an increase in average daily gains in live weight, and quality indicators of meat [9]. It was found [10] that the use of a prebiotic and its combination with a probiotic contributed to an increase in egg production, egg quality, and improvement of biochemical and haematological parameters of egg chickens. It was shown [13] that the use of yeast biomass in the production of poultry products increases the efficiency of nutrient use and poultry productivity, suppresses the growth of opportunistic and pathogenic intestinal microflora, stimulates immunity, improves economic production results, and guarantees environmental safety of products.

One of the prebiotic preparations is Actigen, which was developed by Alltech specialists based on the achievements of nutrigenomics. Actigen is a mannan-enriched fraction – these are specific carbohydrates that are isolated from the outer layer of the cell wall of the yeast *Saccharomyces cerevisiae*. For the use of the drug [14; 15] confirmed the improvement of indicators of growing broiler chickens (live weight, average daily gains, feed conversion), improvement of slaughter indicators, positive changes in biochemical indicators of blood, immune status [15]. In studies [16], there is a correction of the composition of the intestinal microflora of chickens towards reducing the amount of opportunistic microflora with an increase in safety indicators, average daily growth, and feed conversion. The use of Actigen in duck breeding [17] promotes the activation of normal intestinal microflora, does not affect the concentration of LFA, lactate, and the pH level of the contents. Under production conditions, a hygienic assessment of the effect of the preparation on productivity is given: an increase in live weight of ducks, average daily weight gain, and bird safety.

Given the positive effect of prebiotic preparations on the intestinal microflora of poultry, the question of the influence of the above-mentioned preparations on quantitative and qualitative indicators of poultry productivity remains relevant.

The purpose of this study was to investigate the level of poultry productivity and the morphological parameters of eggs obtained from laying hens of the "Dekalb White" cross with the use of the prebiotic preparation Actigen in the diet of poultry, which is an active concentrate of mannan oligosaccharides (MOS) isolated from the cell walls of the yeast *Saccharomyces cerevisiae*.

Materials and Methods

The study was conducted in the conditions of a poultry enterprise to produce food eggs in the Zaporizhzhia Oblast in 2019-2020. In the experiment, a control and experimental groups of poultry were formed, 200 heads of laying hens of the Dekalb White cross. Chickens were kept in cage batteries, the microclimate parameters met the standards, according to the recommendations of this cross [18]. For feeding the bird, mixed feed was used, which in terms of nutritional value corresponded to its age, physiological state, and recommendations of the originator company. Actigen (Alltech Ink.) was added to the compound feed of the experimental group's poultry from 46 weeks of age. According to the instructions of the manufacturer Alltech, Actigen should be introduced into the mixed feed at the rate of 400 g/t. Based on previously conducted comprehensive studies of the quality of feed of the grain group on the Ukrainian market, it was recommended to increase the dosage of Actigen to 500 g/t. After 6 weeks of using the preparation, 100 eggs were selected from the chickens of the experimental groups for morphological studies. The mass of eggs was determined by individual weighing on a scale with an accuracy of up to ±0.01 g.

The egg shape index was determined as the ratio of a small diameter to a large one, expressed as a percentage, measurements were made using the IM-1 indexometre. After breaking the egg, large diameters of dense white and yolk were determined on a horizontal surface with a calliper – along the hailstones, small diameters – across them. The height of the yolk and dense white layer was determined using a micrometre. The mass of the shell, white, and yolk of eggs were determined after they were broken – by individual weighing on a scale with an accuracy of 0.01 g, followed by determining their relative mass to the mass of the egg.

At the age of 52 weeks, the birds were determined to lay eggs for the initial laying hen, and the preservation of the flock was assessed.

The energy value of eggs was calculated according to Equation 1 [19]:

$$EV=M\times(1.911-0.268\times Cw/y), \quad (1)$$

where *EV* is the energy value of eggs, kcal; *M* is the mass of eggs, g; *Cw/y* is the ratio of white and yolk mass; 1.911 and 0.268 are constant coefficients.

The results were statistically processed using MS Excel software using variational statistics methods.

Results and Discussion

When conducting the experiment in a poultry farm, the egg production of chickens for 52 weeks of life was higher in the poultry of the experimental group – 198.6 pcs against 196.2 pcs in the control group (the difference is 2.4 eggs, or 1.22%).

In terms of the level of survival of the flock up to 52 weeks of age, the advantage of the birds of the experimental group by 0.50% was noted (97.50% versus 97.00% in the control group).

Morphological parameters of eggs obtained from laying hens of experimental groups are presented in Table 1.

***Table 1**. Morphological parameters of chicken eggs*

Indicator	Control group	Research group
Egg weight, g	65.05±0.417	66.14±0.372*
Egg shape index, %	75.29±0.395	76.00±0.404
Weight, g: shells	8.30±0.068	8.51±0.083*
egg white	35.87±0.433	36.91±0.911
egg yolk	18.46±0.290	18.83±0.634
Ratio of white mass to yolk mass	1.96±0.041	2.02±0.068
Content, %: shells	12.88±0.115	12.76±0.103
egg white	55.80±1.335	55.21±0.756
egg yolk	28.48±0.952	28.39±0.428
Large diameter, cm: white	9.34±0.164	9.16±0.106
egg yolk	4.14±0.041	4.17±0.043
Small diameter, cm: white	8.14±0.144	7.85±0.102
egg yolk	3.99±0.033	3.96±0.044
Height, mm: white	4.08±0.109	5.20±0.213***
egg yolk	14.04±0.429	18.00±0.386***

***Note:** * – p<0.05, *** – p<0.001 – probability of difference between the experimental groups and the control group*

Analysing the results of the studies (Table 1), it was found that the mass of eggs obtained from chickens of the experimental group was higher by 1.09 g (the difference is statistically significant p<0.05), which in terms of 1,000 eggs is 1.090 kg. The authors of this study note a lower level of variation (Cv) of the "egg mass" characteristic of birds of the experimental group (3.05%) than in the control group (3.51%), which is positive for industrial production.

According to the analysis of individual egg components, it was found that the egg white mass was 1.04 g higher in the experimental group, the same dependence was observed for the yolk mass, where the difference was 0.37 g. The difference between groups is not statistically significant, but it shows the direction of their changes. According to the weight of the shell, the difference was 0.21 g for a probable difference between the groups (p<0.05).

No substantial differences were found in the relative content of egg components; a slightly higher content of shell, white, and yolk was noted in the poultry of the experimental group (by 0.12%, 0.59%, and 0.09%, respectively).

According to the state of the egg contained, poured on a horizontal surface, it can be concluded that the egg is fully functional. An inferior egg is described by a flattened yolk, blurred borders of liquid and dense layers of white, and the contents of the egg occupy a large area. A full-fledged egg is described by a spherical shape of the yolk, the boundaries of a thick layer of white are clearly marked, a dense layer of white repeats the shape of the egg, the contents of the egg occupy a small area. The conducted organoleptic study indicates the usefulness of eggs of chickens of experimental groups. The results of measuring large and small white diameters showed that

in the experimental group, the large diameter was smaller compared to the control group by 1.93%, and the small diameter – by 3.56%. The small yolk diameter was also smaller in the eggs of the experimental group, although this difference was insignificant and amounted to 0.75%. The height of the dense layer of white and yolk are indicators that allow objectively assessing the quality of eggs. Thus, the height of the dense layer of white and yolk was higher in the experimental group compared to the control group, which is positive, and indicates a higher quality of such eggs. This difference was 21.54% and 20.00%, respectively. There was a highly significant difference between the groups ($p<0.001$).

The ratio of white mass to yolk was 1.96:1 and 2.02:1, respectively, for the control and experimental groups.

According to the calculations, the caloric value of the eggs of the control group was 90.20±1.013 kcal, the experimental group was 90.66±1.261 kcal, i.e., the eggs of the experimental group have higher values, but the difference between the groups is not probable.

For the use of poultry in the conditions of industrial farms, it is important to evaluate the productivity of poultry according to the main characteristics – the level of laying, quality indicators of eggs, preservation of livestock, etc., as well as determining the level of realisation of the genetic potential of productivity. The main indicators of egg productivity of poultry, which primarily determine the effectiveness of using poultry in the farm, are egg production for the initial laying hen, egg weight, and livestock safety. In this study, a higher level of manifestation of signs was established in the birds of the research group, which indicates a positive effect of the introduction of a prebiotic drug into the compound feed on the level of egg productivity and preservation of birds.

A comparison with the normative values of the laying index per initial laying hen (according to the Hendrix Genetics BV company [20] – 213 eggs) shows that it is lower by 14.4 units, or 6.76%, and 16.8 units, or 7.89%, the level for the birds of the experimental and control groups, respectively, which is 93.24% and 92.11% of the standard level of laying per initial laying hen for the cross. The preservation of the birds of the experimental group was 0.2% higher than the level recommended by the company developing the cross – 97.3%; however, the control group had a lower (by 0.3%) indicator level. Comparison with the standard cross egg mass value, which is 63.1 g [20], indicates a higher level of this indicator for chickens of experimental groups – by 1.95 g, or 3.09%, for the control group and 3.04 g, or 4.82%, for the experimental group. The results obtained indicate a fairly high level of realisation of the genetic potential of poultry productivity in the farm.

The established egg mass level in poultry groups indirectly indicates an elevated level of herd uniformity in live weight based on the correlation between these traits [21].

The revealed greatest difference between the relative content of egg components in chickens of experimental groups – in terms of relative white content – confirms the existing biological pattern of changes in the mass of egg components with an increase in their mass [19].

Upon assessing the quality of food eggs, it is important to identify the energy value (caloric content) of this product. The total content of nutrients that a chicken egg contains is determined by the size and components of the egg, namely the mass of white and yolk. The caloric content of an egg has a direct relationship with the weight of the egg and the white:yolk ratio, which allows calculating the caloric content of the product by considering the energy coefficients of white, fat, and carbohydrates contained in the egg. It was found [19] that for eggs weighing 50-70 g, the ratio of white mass to yolk is 1.896-2.142:1, which was confirmed by the study (1.96-2.02:1).

Egg white contains 10-11% protein and a small amount of carbohydrates (0.8-0.9%), its caloric content is 16-17 kcal. Egg yolk is characterised by a high level of protein (up to 18%) and fat (31-33%), its caloric content is 16-17 kcal [19]. That is, the caloric content of egg yolk is 4 times higher than the caloric content of egg white. Such considerable differences in the caloric content of the main components of the egg determine the role of their ratio in calculating the energy value and are a prerequisite for calculating the caloric content of eggs of chickens of experimental groups and establishing higher values for chickens of the experimental group.

Conclusions

The introduction of the prebiotic preparation Actigen in the amount of 500 g/t in the compound feed for feeding laying hens for 6 weeks led to changes in the level of productivity:

– the highest level of egg production of chickens of the experimental group – 198.6 pcs against 196.2 pcs in the control group (the difference is 2.4 eggs, or 1.22%) at 52 weeks of life;

– in terms of the level of livestock safety, the indicators of poultry in the experimental group are higher by 0.50% (97.50% vs. 97.00% in the control group);

– the mass of eggs obtained from chickens of the experimental group was higher by 1.09 g (the difference is statistically significant at $p<0.05$). A lower level of variation (Cv) of the "egg mass" trait of the poultry of the experimental group (3.05%) than in the control group (3.51%) is positive, and indirectly indicates the level of uniformity of the herd in live weight;

– a higher level of egg white mass (by 1.04 g) and yolk (by 0.37 g) was found in the poultry of the experimental group;

– the height of the dense layer of white and yolk was higher in the experimental group compared to the control group (by 21.54% and 20.00%, respectively), which is positive, and indicates the highest quality of such eggs;

– the caloric content of eggs of chickens in the control group was 90.20 kcal, the experimental group – 90.66 kcal, i.e., the indicators of eggs of chickens in the experimental group are higher.

The results obtained indicate a positive effect of Actigen administration on the level of egg productivity of poultry and are of practical value for the work of poultry enterprises specialising in the production of food-grade chicken eggs. It is promising to continue conducting research on the impact of the prebiotic preparation Actigen on the quantitative and qualitative indicators of egg productivity of chickens, specifically to extend the productive use of poultry.

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Продуктивність яєчних курей за використання пребіотичного препарату

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Анотація. Актуальність дослідження зумовлена активним впровадженням у практику годівлі сільськогосподарської птиці пребіотичних препаратів і необхідністю визначення впливу їх використання на кількісні і якісні показники продуктивності. У зв'язку з цим, робота спрямована на визначення впливу введення пребіотичного препарату Актиген до раціону курей-несучок на їх рівень продуктивності та морфологічні показники яєць. За використання комплексного підходу досліджено рівень яєчної продуктивності курей за введення препарату до складу комбікорму у кількості 500 г/т впродовж 6 тижнів. Оцінювання птиці за 52 тижні життя свідчить про дещо вищий рівень несучості курей дослідної групи – 198,6 шт. проти 196,2 шт. у контрольній групі (різниця становить 1,22 %) та збереженості поголів'я – 97,50 % проти 97,00 % у контрольній групі. Встановлено, що маса яєць, отриманих від курей дослідної групи, була вищою на 1,09 г ($p<0,05$). Менший рівень варіації (Cv) ознаки «маса яєць» птиці дослідної групи (3,05 %), ніж в контрольній (3,51 %), є позитивним, а також опосередковано свідчить й про рівень однорідності стада за живою масою. Встановлено, що маса білка та жовтка яєць курей дослідної групи була на 1,04 г та 0,37 г відповідно вищою, ніж у контрольній групі. Різниця між групами не є вірогідною, але показує напрям їх змін. У яєць птиці дослідної групи великий діаметр білка був меншим порівняно з контрольною групою на 1,93 %, а малий діаметр – на 3,56 %. Висота щільного шару білка і жовтка, які є об'єктивними показниками якості яєць, були більшими у дослідній групі ($p<0,001$) порівняно з контрольною групою, що є позитивним, ця різниця становила відповідно 21,54 % і 20,00 %. За показниками енергетичної цінності яєць суттєвих відмінностей між піддослідними групами не встановлено. Отримані дані (підвищення рівня несучості птиці, збереженості поголів'я, маси яєць, покращення показників якості яєць курей дослідної групи) свідчать про позитивний вплив введення пребіотичого препарату Актиген на рівень яєчної продуктивності птиці. Матеріали статті становлять практичну цінність для роботи птахівничих підприємств, спеціалізацією яких є виробництво харчових курячих яєць

Ключові слова: пребіотик, несучість, кури-несучки, Актиген, маса яєць, білок, жовток

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