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вул. Героїв Оборони, 15, м. Київ, 03041, Україна
E-mail: info@animalscience.com.ua
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Editors office address:
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony, Kyiv, Ukraine
E-mail: info@animalscience.com.ua
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Influence of geometric parameters of screw nozzles of a twin screw extrusion press on the oil output

Maksym Hudzenko*, Volodymyr Vasyliv, Mikhailo Mushtruk, Marija Zheplinska, Igor Palamarchuk, Zinaida Burova, Viktor Sarana

National University of Life and Environmental Sciences of Ukraine
03041, Henerala Rodimtseva Str.19, Kyiv, Ukraine

Abstract. The relevance of the study is due to the search for rational geometric parameters of screw nozzles and the identification of the influence of the compression ratio of twin screw extrusion presses on the oil compression process. An important criterion in this paper is the indicator of the value of oil yield to obtain economic profit. From the analysis of optimisation methods in similar studies, the following variable geometric parameters of screw nozzles were selected for twin screw extruders: axial pitch, channel width between turns, rig width of the turn, and nozzle length. Two sets of experimental working bodies with modified geometric parameters were manufactured based on theoretical calculations and computer modelling to improve the working bodies of the EK 75/1200 twin screw extrusion press. Their theoretical compression ratio is determined, which is 5.50 and 4.33, respectively. It is also defined for the basic set of working bodies, which was recommended by the manufacturer, which was 4.69. It is established that the general nature of changes in the free volume along the length of the screw shaft is accompanied by an uneven decrease from 40 to 80% toward the press cake output. From the reviewed scientific literature, it was identified that the nature of changes in the free volume of turns along the length of the screw shaft characterises the correctness of its design. However, after analysing the results of the work performed, it was determined that the selection of rational geometric parameters of the working bodies should be considered in conjunction with other structural parameters, which will further intensify the oil compression process. It is experimentally confirmed that the oil yield

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**Corresponding author*

depends on the degree of compression due to the geometric parameters of the screw nozzles. The oil yield increased by 0.9% when using a set of working bodies of set 1 when compared with the basic set of working bodies from the manufacturer's factory (set 2) in terms of volume of processed raw materials per unit will bring additional profit. It was determined that with the production volume of 50 tons of oil with an improved set of working bodies (set 1), the economic effect amounted to UAH 19,250

Keywords: oil production, double screw extrusion press, improvements, geometric parameters

Relevance

Over the past ten years, the area planted with oilseeds in Ukraine has grown substantially. From 1998 to 2020, sunflower production increased 6.7 times (from 2.26 to 15.254 million tons), while seed exports decreased by almost 17 times. The capacity for processing oilseeds increased 9.2 times (from 2.6 million tons to 24.0 million tons per year) and continues to grow as a result of the construction of new plants and the reconstruction and modernisation of existing ones. Sunflower oil production increased 16.3 times (from 432.8 thousand tons to more than 7.0 million tons). The fat-and-oil industry of Ukraine is export-oriented. The internal market consumes up to 10% of the total oil production in Ukraine [1]. The oilseed processing facilities created in Ukraine allow the processing of all grown crops (sunflower, soy, rapeseed). However, due to the constant increase in production capacity and mass export of soybean seeds, rapeseed, and partial export of sunflower seeds, processing enterprises are not fully loaded, which creates competition for raw materials in the internal market [2].

1,200 business entities are engaged in processing oilseeds in Ukraine. Therewith, the industry is characterised by a fairly high concentration of production: more than 90% of oil is produced by 51 specialised enterprises of large and medium capacity [3]. In small-capacity workshops, unrefined oil is usually produced by pressing. Basically, these workshops were created by agricultural enterprises to generate additional profit from processing their own agricultural products. Their products are focused mainly on the needs of the population of villages and district centres. Since the mid-90s of the 20th century, the range on the market among equipment for oil production has increased rapidly. Press equipment of low capacity (from 50 to 450 kg/h) was very diverse in the design of presses and the complexity of lines. However, most of them used unnecessarily energy-intensive, labour-intensive, and bulky complexes of machines and presses for oil production. Therefore, after a certain period of time, many manufacturers of unprofitable pressing equipment quit the market. Among the few manufacturers of equipment for oil production that remained in demand by processing enterprises, were manufacturers of twin screw extrusion presses. They occupied a certain niche among pressing equipment with a capacity of 150-500 kg/h. During the operation of twin screw extrusion presses, there is no need to use auxiliary equipment for preparing

oilseeds: rudders, roller machines, roasters. This allowed substantially simplifying the technology of processing oilseeds by combining the operations of heat treatment, grinding, forming (granulating) the press cake, and pressing vegetable oil in one machine, which is certainly beneficial for raw material processing in small volumes. Notably, among other advantages of such extrusion presses is that they do not require complex installation and large rooms, can be serviced by unqualified workers, and within 2 hours they can be converted to other types of oilseeds. In addition, it is possible to press out the oil of unhulled sunflower seeds with twin screw extrusion presses [4].

Oil-pressing screw presses belong to the group of continuous machines, the main working body of which is a cylinder with one or more set screw shafts placed in it. Numerical values of the geometric parameters of the working path of the press substantially affect the characteristics of oil compression processes: productivity, oil yield, long-term operation, and power costs. Therefore, the study of geometric parameters of working bodies remains a very relevant issue for further substantiation of their rational values and determination of economic feasibility.

Analysis of Recent Studies and Papers

The main principle of operation of the screw press is to move oilseeds along the working chamber and compress it with a screw shaft. Compression of raw materials is conducted by reducing the free volume of the channels of the working area of the screw shaft, which is achieved by shifting the pitch, reducing the depth of the channel and the internal diameter of the seer cylinder. Therewith, there is a wide variety of specific combinations of these geometric parameters [4, 5, 6].

In the study [7], the influence of the design parameters of a screw shaft, the screw groove of which is made in the form of a curved triangle, on the energy indicators of a screw oil press is proved. These theoretical dependencies allow for calculating the total power consumption of an oil press.

Oil yield is one of the most important variables in the oil extraction process, so analysing this parameter is extremely important. Papers [8, 9, 10] are devoted to the modelling and optimisation of technological and design parameters for oil extraction. In the papers [11, 12], mathematical models have been developed that consider the parameters of controlling the pressing process with improved press characteristics. The optimal geometric parameters of the screw shaft design and optimal operating conditions for maximum oil yield were determined, and the influence of many parameters that affect the oil yield from the screw press was investigated.

The shortage of cost-effective oil press options is very noticeable in agricultural countries. Science-based advanced presses are the perfect solution to this particular problem. In the study [13], the design parameters of the screw press were improved. The screw length, pitch diameter, heating temperature, and rotation speed were determined to have a substantial impact on the oil yield efficiency.

The mechanical press method of oil extraction is the most common in the world. However, most screw presses used for this purpose

leave about 8-14% of the oil in the press cake. A modified press was designed and developed based on the new principle of two-stage single-feed compression to improve the efficiency of oil extraction [14].

The paper [15], which contains an analysis of the use of twin screw extruders, deserves attention. It provides a comprehensive overview of the key parameters that affect the productivity of the oil pressing process. Therewith, considerable attention is paid to the development of innovative processes using twin screw extruders.

From the conducted literature research, it was determined that in the scientific literature more attention is paid to improving single screw oil presses than twin screw ones [4]. There are quite a lot of papers [16, 17, 18] in which the rheology of material behaviour in the geometric space of the channel is well described, formulas for calculating screw presses and extruders are given, and the effect of mixing and grinding working bodies of twin screw extruders related to the processing of rubber mixtures and plastics is described. From the standpoint of mathematical modelling, twin screw extruders are much more complex than single screw extruders, and therefore for a long time the choice of geometric parameters and processing modes was based on practical experience and experimental data, and, in addition, they had limited application due to a more complex design [4].

Little attention is paid to the problem of investigating the influence of geometric parameters of the oil pressing path and screw nozzles on the process of oil production in screw presses in the Ukrainian scientific literature. Insufficient coverage of issues related to the scientific justification of rational parameters and design of working bodies in twin screw extruders substantially hinders their technical development, leads to the appearance of imperfect equipment and unnecessary costs for its manufacture and operation. Therefore, there is a need to supplement the existing ideas about the interaction of special grinding working bodies with transporting and compressing screw nozzles and the development of grinding units for twin screw extrusion presses.

The purpose of the study is to determine the rational geometric parameters of screw shafts of twin screw extrusion presses through theoretical analysis and experimental studies. The main task of the study was to offer the best design and technological solutions, considering the characteristics of existing analogues of extrusion presses for oil pressing and rational geometric parameters of modern screw nozzles.

Materials and Methods

Experimental studies were conducted in production conditions on the extrusion press production facilities of SPE Extruder (Kharkiv) to determine the rational geometric parameters of the screw shafts of twin screw extrusion presses for the efficiency of the oil extrusion process. The research methodology included conducting preparatory works of the same type and experiments, namely – setting the maximum operating modes of the extruder for sunflower, rapeseed, and soybean seeds, determining the humidity of the selected batch of seeds for experiments. When performing experiments, generally accepted methods were used from literature sources and developed in the course of the study. The design-technological parameters of

the extrusion press were controlled by various measuring devices. The choice of devices and measuring equipment was made on the condition that they provide the accuracy of measurements regulated by standardised methods. Processing of experimental data and graphic design of the work was conducted using computer software: Microsoft Office Excel.

Main Material Presentation

During the development and operation of screw presses of various designs, extensive experience has been accumulated. From the beginning of pressing, the seed passes from one physical state to another until the oil and press cake are released. The method of their separation (decomposition) and consideration in parts is used to examine these processes. Notably, such separation in most cases is purely conditional, since such parts are interconnected and have an impact on previous and subsequent processes. Therewith, each of the processes in a complex processing system can take place simultaneously (in parallel) or simultaneous-sequentially, which is implemented inside the pressing path of the extruder, where oilseeds, along with transportation, grinding, mixing, are subjected to heating and pressing.

Improving the quality of oil pressing in extrusion presses, in contrast to classic oil presses, is achieved by replacing traditional turns (screw nozzles) with two structural and technological zones (power, compression) with screw shafts with four main zones: power, compression, grinding and mixing, final pressing. As a result, twin screw extrusion presses are distinguished by longer screw shafts, which is associated with the introduction of special mixing and grinding elements into their design [20].

The working shaft of twin screw extruders is made as a set (Fig. 1) and consists directly of a shaft-rod *1*, on which screw nozzles are put on *3, 4, 6, 7*, triangular cam nozzles *5*, intermediate or mounting rings, if necessary, which are attached to the shaft by a spline or, preferably, keyway connection.

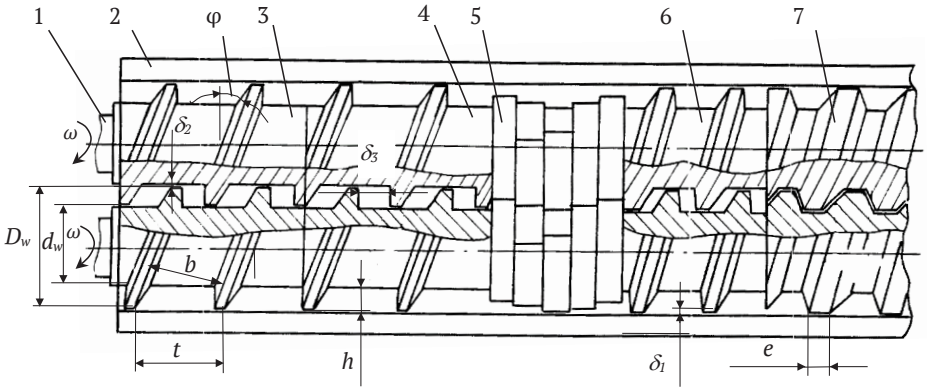

Figure 1. Geometry of the screw channel of a twin screw extrusion press: 1 – shaft; 2 – case; 3, 4, 6, 7 – screw nozzles; 5 – triangular cam nozzles

The outer surface of the screw nozzles and cams together with the inner surface of the housing form a screw channel. The screw nozzle (auger) and channel are characterised by external and internal diameters D_w and d_w, screw step t, channel height h, channel width b, rig width e, helical line lifting angle φ, the gap between the cylinder wall and the coil rigs δ_1, the gap between the rigs of one screw and the core of another δ_2, the gap between the side surfaces of the coil rigs δ_3, the length of the screw nozzles and the working area of the shaft, etc.

When describing a screw pressing mechanism, the principle of its division into sections is used. In general, a section is an elementary screw mechanism with conditionally constant parameters of the pressing process. The section can end with a matrix or compression gate – a section of the machine where the screw turn is interrupted and the flow section decreases [4].

In twin screw extrusion presses with hooked screws, the screw channels are divided by turns of conjugated screws into separate C-shaped volumes. Complete extrusion of C-shaped volumes due to the mutual hooking of the screw shafts ensures equal time of the material processing in the channels of the screw nozzles, and this is an important factor so that the oil-containing material does not overheat. However, the need to ensure geometric compatibility of the screws implies the presence of gaps δ_1, δ_2, which violate the isolation of C-shaped volumes and lead to material flow between them.

Compression of oil-containing material in the screw press during its movement through the working chamber is conducted due to a decrease in the free volume of channels in the working area of the screw shaft. The difference in the operating principles of twin screw and single screw extruders is due to different mechanisms for creating pressure in the processed material. In twin screw extruders, unlike single screw ones, there is a push-out effect of the turns of the conjugated shafts. If in a single screw extruder the ability to increase pressure is determined by the depth of the screw shaft, then in a twin screw extruder – by the geometric degree of closure of the screw channel (compression degree), which is determined from the Formula [4]:

$$k_{cc} = \frac{ie}{t - ie}, \quad (1)$$

where e – width of the screw nozzle rig, t – screw pitch, and i – number of screw thread entries.

Value k_c shows which part of the channel cross-section overlaps, and characterises the compulsion to transport the processed material to the forming tool of the extruder and the ability of the augers to gain pressure.

In a screw press, the degree of compression of oil-containing material is the ratio of the free volume of the previous turn to the free volume of the next one.

$$k_{\text{ом}} = \frac{V_{\text{в1}}}{V_{\text{в2}}}, \quad (2)$$

where $k_{ом}$ – degree of compression of the oil-containing material; $V_{\text{в1}}$, $V_{\text{в2}}$ – respectively, the free volume of the first (previous) turn and the next, m^3.

The seed mass, if it gets to the first transportation turn, has a large number of cavities between them, which should be eliminated as soon as possible. Therefore, the free volume of

subsequent nozzles should be sharply reduced. At the end of the shaft, the free volume of the last nozzles should change less intensively, since the inner surface of the oil-containing material decreases due to compression of the capillaries of the gel part, the volume of which is relatively small. The nature of changes in the free volume of turns along the length of the screw shaft characterises the correctness of its design, and the degree of compression of the oil-containing material created by the screw characterises it from the quantitative side.

In a twin screw oil press with unidirectional shaft rotation, the diameter of the screw nozzles and the cylindrical surface of the case around them and the height of the turns of the screw nozzles are constant along the entire length of the working part of the screw shaft. Accordingly, the mass is compacted only by reducing the volume of the C-shaped section of the screw channels of each subsequent screw nozzle. This is done by stepwise reducing the pitch of the turns of the screw nozzles and changing the width of the rig of the turn. The width of the turn rig can vary from larger to smaller and vice versa, which means that there are a large number of options for changing configurations to find rational parameters. The pressure force generated by the screw nozzles depends on the screw thread pitch of the screw. Greater pressure forces can be created by reducing the pitch, but simultaneously reducing productivity.

The analysis of geometric parameters of three sets of working bodies of a twin screw extrusion press (set No. 2 – recommended by the manufacturer, sets No. 1 and No. 3 – experimental screw nozzles made based on the calculations of the study and partially by the manufacturer, respectively) is conducted. Calculations are made based on their geometric parameters for determining the free volume in each nozzle (screw nozzle "SN" and cam nozzle "CN") and the theoretical degree of compression in the working chamber. Usually, their number, type, and size differ depending on the oilseeds that are planned to be processed.

The results of determining the theoretical degree of compression of oil-containing material in the working chamber for three sets of working bodies (for sunflower seeds) of the EK 75/1200 extrusion press (SPE "Extruder", Kharkiv) by formula (2) are displayed in Table 1.

Table 1. *Degree of compression of sunflower seeds along the pressing path of the screw shaft of the working bodies*

Nozzle number													Total compression degree	
SN №1	SN №2	CN №1	SN №3	CN №2	SN №4	SN №5	CN №3	SN №6	CN №4	SN № 7	SN №8	SN № 9	SN №1/ SN № 9	Set
1	1.58	1.29	0.70	1.25	0.74	1.10	1.25	1.75	0.72	1.54	1.06	1.08	5.50	No. 1
1	1.70	1.29	0.80	1.25	0.80	1.12	1.11	1.86	0.67	1.49	1.06	1.08	4.69	No. 2
1	1.83	1.29	0.68	1.25	0.76	1.10	1.25	1.64	0.72	1.54	1.01	1.08	4.33	No. 3

The total degree of seed compression obtained by dividing the free volume in the zone of the first conjugate pair of screw nozzles by the free volume of the last pair of screw nozzles is only theoretical, which to a certain extent characterises the screw shaft. The nature of changes in the free volume and compression ratio of material along the length of the working path of the press in each conjugate pair of screw nozzles (SN), cam nozzles (CN) of the three analysed sets of working bodies is displayed in the diagram (Fig. 2) and chart (Fig. 3).

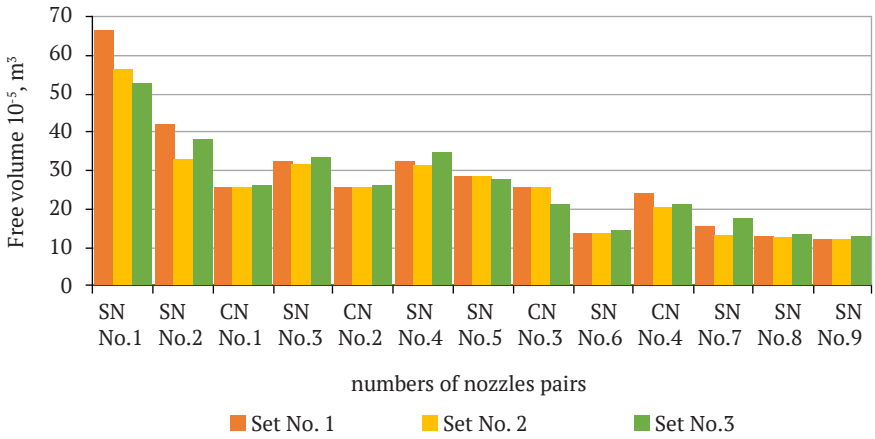

Figure 2. Change in the free volume within the conjugate pair of the screw (SN) and cam nozzles (CN) along the pressing path of the screw shaft

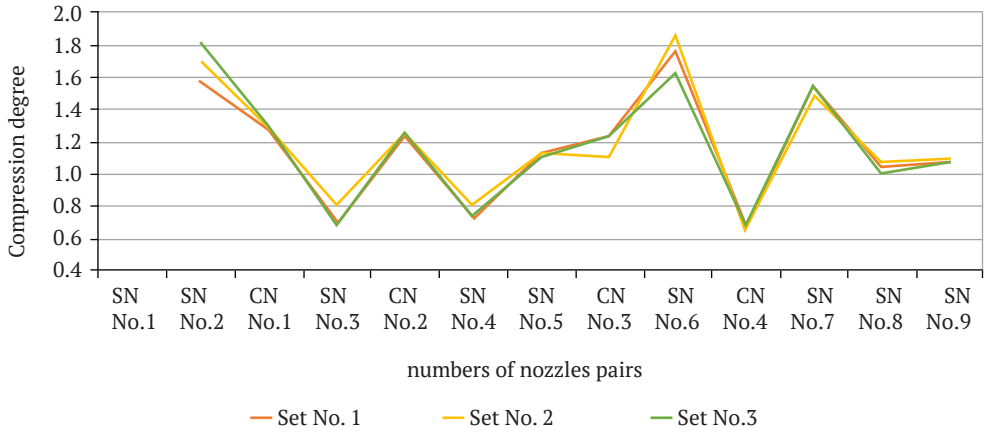

Figure 3. Change in the compression ratio of material within the conjugate pair of the screw (SN) and cam nozzles (CN) along the pressure path of the screw shaft

The difference in the position of the compression ratio curves of the material within the conjugated pairs of screw nozzles of sets of working bodies along the length of the pressing path of the screw shaft shows a smooth (smaller) or larger angle of the nature of changes in geometric parameters (screw pitch *t*, channel width *b*, rig width *e*) of the nozzles. The next step of the study was to identify the influence of the calculated geometric parameters of the analysed sets of working bodies of twin screw extrusion presses on the oil yield experimentally (Fig. 4).

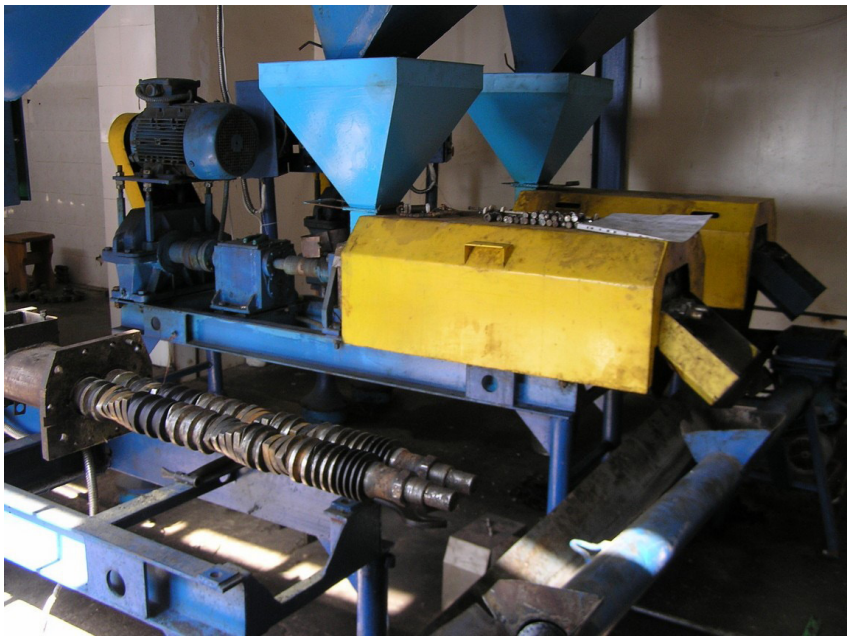

Figure 4. General view of experimental extrusion presses EK 75/1200

Based on previous studies with modes and possible technological adjustments, rational design, and technological parameters of the upgraded extrusion press were established. The temperature of the first and second heating zones of the cases for sunflower seeds was 125-130°C. The size of the gap in the matrix for sunflower seeds was 5.0 mm. The angular velocity of the screw shaft is 6-7 rad/s, the time of technological influence on the oil-containing material in the press path is 60-75 s. Their use allowed for increasing the productivity of the machine and reducing energy costs for the oil pressing process.

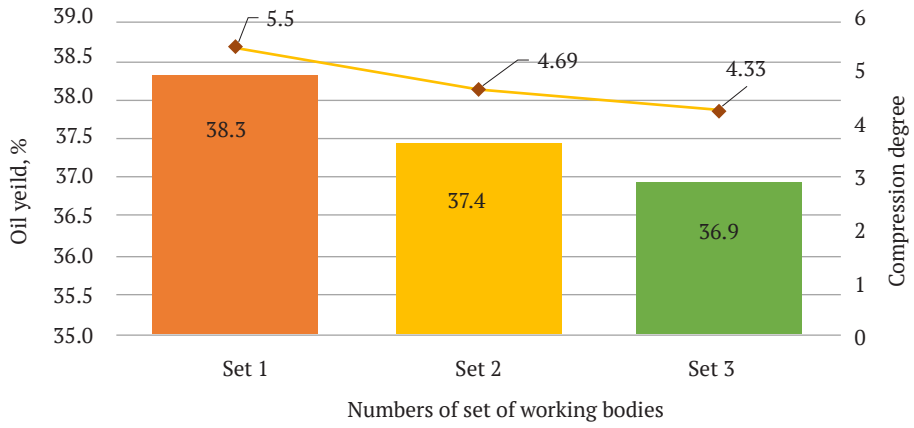

Figure 5. Dependence of sunflower oil yield and compression degree on the set of working bodies of installed nozzles

Studies conducted with sets of working bodies with different geometric parameters confirmed their effect on the oil yield. Even with the same operating modes and technological adjustments of the extrusion press, changing the geometric parameters of the first and second nozzles already affects the throughput of the number of seeds captured by the turns of the screw nozzles. However, further changes in the press path, namely a decrease in the free volume in the next screw nozzle, caused an increase in pressure at their edges, followed by a decrease in it in the cam nozzle groups. A rather rapid increase in pressure leads to a greater load on the engine. Notably, the change in the performance of the extrusion press also affected the oil yield. However, it should be considered in conjunction with the energy consumption of the machine. These statements may be the subject of further research on the improvement of twin screw extrusion presses.

Conclusions

The theoretical degree of compression determined for three sets of working bodies of a twin screw extrusion press for processing sunflower seeds according to calculations is 5.50, 4.69, and 3.33, respectively. It has been experimentally confirmed that the oil yield depends on the degree of compression due to the geometric parameters of the screw nozzles. The general nature of changes in the free volume in the zones of nozzle groups is accompanied by an uneven decrease of 40-80% toward the press cake output. The selection of rational geometric parameters of working bodies should be considered in conjunction with other structural parameters, which will allow intensifying the oil pressing process.

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Вплив геометричних параметрів гвинтових насадок двогвинтового пресекструдера на вихід олії

Максим Миколайович Гудзенко, Володимир Павлович Василів, Михайло Михайлович Муштрук, Марія Михайлівна Жеплінська, Ігор Павлович Паламарчук, Зінаїда Андріївна Бурова, Віктор Володимирович Сарана

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони 15, м. Київ, Україна

Анотація. Актуальність дослідження зумовлена пошуком раціональних геометричних параметрів гвинтових насадок та виявлення впливу показника ступеню стискання двогвинтових пресекструдерів на процес відтискання олії. Значущим критерієм в даній роботі обрано показник величини виходу олії з метою отримання економічного прибутку. З проведеного аналізу методів оптимізації в аналогічних дослідженнях для двогвинтових екструдерів обрано наступні змінні геометричні параметри гвинтових насадок: крок черв›яка, ширина каналу між витками, ширину гребня витка та довжину насадки. На основі теоретичних розрахунків та комп'ютерного моделювання по вдосконаленню робочих органів двогвинтового пресекструдера ЕК 75/1200 виготовлено два комплекти експериментальних робочих органів зі зміненими геометричними параметрами. Визначено їх теоретичну ступінь стискання, яка становить, відповідно, 5,50 та 4,33. Також її визначено для базового набору робочих органів, який був рекомендований заводом виробником, яка склала 4,69. Встановлено, що загальний характер зміни вільного об'єму по довжині шнекового валу супроводжується нерівномірним зменшенням від 40 до 80% в сторону виходу макухи. З оглянутої наукової літератури стало відомо, що характер зміни вільного об›єму витків по довжині шнекового валу характеризує правильність його конструкції. Однак, проаналізувавши результати виконаної роботи, виявили, що підбір раціональних геометричних параметрів робочих органів слід розглядати в комплексі з іншими конструкційними параметрами, що дозволить додатково інтенсифікувати процес відтискання олії. Експериментально підтверджено, що вихід олії залежить від ступеня стискання, обумовленого геометричними параметрами гвинтових насадок. Збільшений вихід олії на 0,9 % при застосуванні комплекту робочих органів набору 1 при порівнянні з базовим набором робочих органів від заводу виробника (набір 2) у перерахунку на одиницю об'єму переробленої сировини принесе додатковий прибуток. Визначено, що при обсязі виробництва 50 т олії з вдосконаленим набором робочих органів (набір 1) економічний ефект склав 19250 грн

Ключові слова: виробництво олії, двогвинтовий пресекструдер, удосконалення, геометричні параметри

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Examination of thermophysical characteristics of food products

Z. Burova[1], S. Ivanov[2], T. Roman[3], V. Vasiliv[1], M. Zheplinska[1], M. Mushtruk[1], I. Palamarchuk[1], V. Sarana[1], M. Gudzenko[1]

[1]National University of Life and Environmental Sciences of Ukraine
[2]Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine
[3]National University of Food Technologies

Abstract. The development of food, biotechnological, and processing industries, the invention of new ingredients, optimisation and improvement of technological processes require reliable information about the main thermophysical characteristics of raw materials and materials of biological origin. This paper presents the results of the cooperation of specialists from leading universities and scientific institutions of Ukraine, embodied in the developed methods of analysing the parameters of thermodynamic and mass transfer processes and determining the thermophysical characteristics of the latest substances and products using modern metrologically certified devices and information-measurement systems. The main problem in analysing materials of biological origin is the inhomogeneity and heterogeneity of the structure of samples. It is demonstrated that it is advisable to determine the coefficient of effective thermal conductivity of bulk materials and cereals in a stationary thermal mode on a device for determining the thermophysical characteristics of materials and thermal effects, equipped with heat flow and temperature sensors, in which a symmetric scheme of the thermometric measurement method is implemented. The simultaneous use of four measuring cells allows for performing a synchronous comparative analysis of several samples, and the rotary-clamping mechanism helps to minimise contact resistances. The developed method of measuring the coefficient of effective thermal conductivity considers the features of bulk food products and substantially improves the accuracy of the examination by introducing a correction for the contact resistance of the wall layer. Long-term observations allow for analysing thermolabile materials, examining thermal effects in samples, and evaluating volumetric and integral heat generation. It is necessary to use the STA system to conduct calorimetric studies of a wide range of biological materials and substances with the necessary accuracy, which

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*Corresponding author

implements methods of step-by-step scanning and synchronous thermal analysis to determine the specific heat capacity, the heat of evaporation, and the ratio of free and bound moisture in non-homogenous materials. These characteristics are necessary parameters for analysing the kinetics and optimisation of heat and mass transfer processes, in particular, drying, in the calculation and design of technological equipment

Keywords: inhomogeneous materials, coefficient of effective thermal conductivity, heat dissipation, specific heat capacity, heat of evaporation, drying

Relevance

The main task of the food industry is to process agricultural products into high-quality food products. It should be conducted with the lowest financial and material costs, which is impossible without using the achievements of modern science. Science is the basis of modern technologies. Any technology is a set of processes by which raw materials are converted into the final product. Deep knowledge of the regularities of processes conducted during food production allows for intensifying processes, creating new types of apparatuses, and developing methods for optimal process control.

Most of the processes of food, biotechnological, and processing industries are thermal, the speed of which is described by the laws of heat transfer (heating, cooling, condensation), and mass transfer – diffusion, which are characterised by the transfer of one or more components of the initial substance from one phase to another (drying, sorption, rectification, etc.). Most often, these processes are interrelated and occur simultaneously. Many papers by Ukrainian and foreign researchers are devoted to the examination of the laws of heat and mass transfer.

But any such calculation is impossible without knowledge of the basic thermophysical characteristics of materials and substances, which include, in particular, the coefficients of heat and temperature conductivity, specific heat capacity, heat of evaporation, and their temperature dependences. Usually, such data is taken from the reference literature, and until recently, specialists in the food and processing industries used well-known reference books [1; 2]. Currently, modern editions have been published [3; 4] containing the main thermophysical characteristics of semi-finished products and products necessary for calculating processes and equipment for the food industry. In addition to tabular data, the thermophysical parameters of many products, especially bulk and non-homogeneous ones, are presented in the form of empirical dependencies. This allows for performing technological and engineering calculations with a certain accuracy, which is currently insufficient for research works.

The invention of new ingredients, the creation of food products based on them, and the development of technological processes for their manufacture require updating the existing base of thermophysical characteristics. This requires additional research on a modern instrument base. Imported instruments can meet all the requirements for accuracy and reproducibility of measurement results, but the main problem with their use is the need for periodic calibration to ensure proper metrological indicators.

The specialised scientific Institute of Technical Thermophysics (ITTP) of the National Academy of Sciences of Ukraine has accumulated more than half a century of experience in determining the main physical parameters of thermodynamic and mass transfer processes in various sectors of the national economy. The achievements of thermometry, electronics, and metrology of heat flow measurements are embodied in devices and systems for precision measurements of thermal conductivity and heat capacity of materials and substances, the study of energy effects in the physicochemical and biological processes of the food and processing industry.

Research Analysis

Difficulties in obtaining qualitative and adequate information about the thermophysical characteristics of substances of biological origin are usually associated with their inhomogeneity and heterogeneity of structure. For example, bulk food materials – crops and cereals as objects of research have specific physical characteristics: flowability, self-sorting, and duty cycle. Mechanisation and automation of grain processing processes in the flow [5], the use of pneumatic and vibrotransport, the introduction of new drying methods [6] require definitions of their heat, temperature, and thermal conductivity, heat capacity, ability to self-heat [7; 8].

Therewith, the thermodynamic parameters of air, which is an integral part of the grain mass and affects all the processes that occur with it, play a huge role. In particular, air gaps contribute to the transfer of heat by convection and the movement of moisture in the form of steam. Due to self-sorting, the porosity of the grain mass, that is, the presence of gaps between its solid particles filled with air, can be uneven. The porosity and bulk density of grain also depend on the shape, elasticity, size, and surface condition of solid components. These factors together lead to variability in the value of contact resistance between material particles and should be considered when developing a measurement methodology, because they can substantially distort the results of examination of thermophysical characteristics.

Calorimetric studies are used to calculate the thermodynamic characteristics of substances, chemical equilibria, establish a relationship between the thermodynamic characteristics of a substance and its properties and structure, and draw up thermal balances of technological processes in the food, biotechnological, and pharmaceutical industries [9]. Differential scanning calorimetry (DSC) is used to obtain reliable calorimetric information about the material during its linear or stepwise heating or cooling. DSC is also used to determine the melting point and assess the degree of purity of substances, investigate the kinetics of drying, lyophilisation, and crystallisation processes, investigate the stability and thermal decomposition of substances and determine their shelf life, determine the glass transition temperature of amorphous substances, etc. [10]. DSC in combination with thermogravimetric analysis (TGA) forms a method for synchronous thermal analysis of materials and substances (STA).

Now there is a wide range of foreign devices for synchronous thermal analysis, the principle of operation of which is based on the simultaneous determination of mass reduction and the amount of heat consumed by liquid evaporation. Their versatility and wide temperature range are their undoubted advantages. However, most of them are poorly adapted for analysing samples of plant origin, the liquid in which is a

mixture of water and numerous complex substances (saccharides, organic acids, plant pigments, colloidal solutions of pectins, essential butyric acids, aldehydes, alcohols, terpenes, etc.). Another negative factor is that the size of the crucibles of modern devices is calculated for a weight of the order of a milligram, which is very small and not informative for plants due to the size of their cells.

Analytical determination of the specific heat of evaporation of plant raw materials is also associated with substantial difficulties and is often almost impossible since it is necessary to calculate simultaneously the characteristics of a mixture of several liquids and insoluble substances [11]. This is especially important when calculating and optimising the parameters of the drying process of any raw material of plant origin, which is associated with the removal of moisture, free and bound [12]. The experimental method of synchronous thermal analysis is much more appropriate for this purpose.

The purpose of the study is the development of a methodology for measuring the coefficient of effective thermal conductivity of bulk food products, in particular, cereals and crops, and examination of the specific heat capacity and heat of moisture evaporation during the drying process of biological raw materials.

Materials and Methods for Analysing Thermal Conductivity

Various experimental methods for determining the thermophysical characteristics of bulk materials, including stationary and non-stationary heat flow, are known – probe and non-contact – optical [13; 14]. The presence of air between the particles of bulk materials allows for predicting that their thermal conductivity is commensurate with the thermal conductivity of heat-insulating materials, therefore, the method of analysing the coefficient of thermal conductivity regulated in ISO 8301-1991 can be applied to them [15].

The essence of the thermometric method regulated in ISO 8301 is to create a stationary heat flow through a flat sample directed perpendicular to its front (largest) surfaces. The coefficient of thermal conductivity is determined by the results of measurements of the thickness of the sample, the difference in the temperature values of its working surfaces and the surface density of the heat flow that passed through the sample, provided that it is unidirectional and uniform.

Studies are conducted in a stationary thermal mode on a device for determining the thermophysical characteristics of materials and thermal effects, developed at the ITTP of the National Academy of Sciences of Ukraine, which implements a symmetric scheme of the thermometric method [16]. The device, which is displayed in Figure 1, is an information-measurement system consisting of a functionally combined thermal unit 1, which is displayed in Figure 2, an electronic unit 2 with a built-in temperature control device for the reference junctions of thermocouples and a computer with specialised software 3.

Main technical characteristics of the device:

• range of measured heat flux density 5…500 W/m^2;

• limits of permissible relative error ±3%;

• operating temperature range minus 40°C…180°C;

• sample size:

– 1 sample 250×250×(10…120) mm;

– 4 samples Ø100×(10×50) mm.

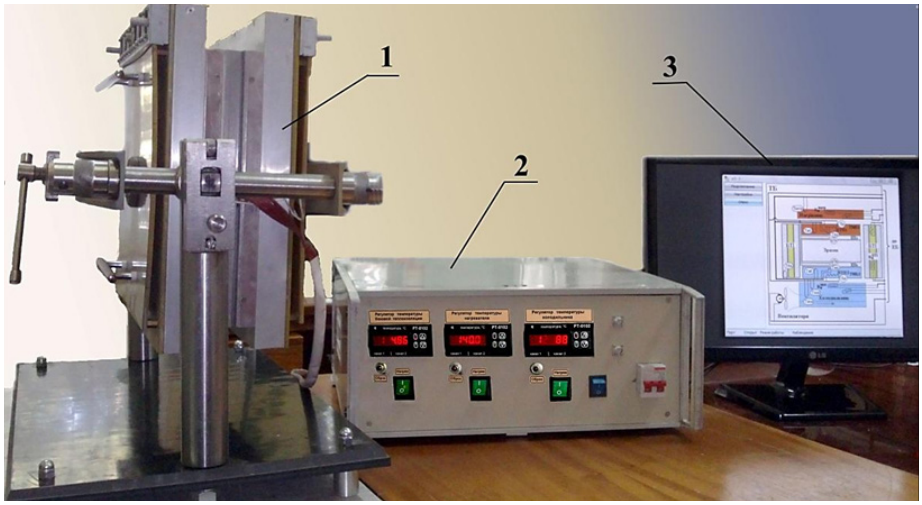

Figure 1. Appearance of the device (operating position):
1 – thermal unit, 2 – electronic unit, 3 – software

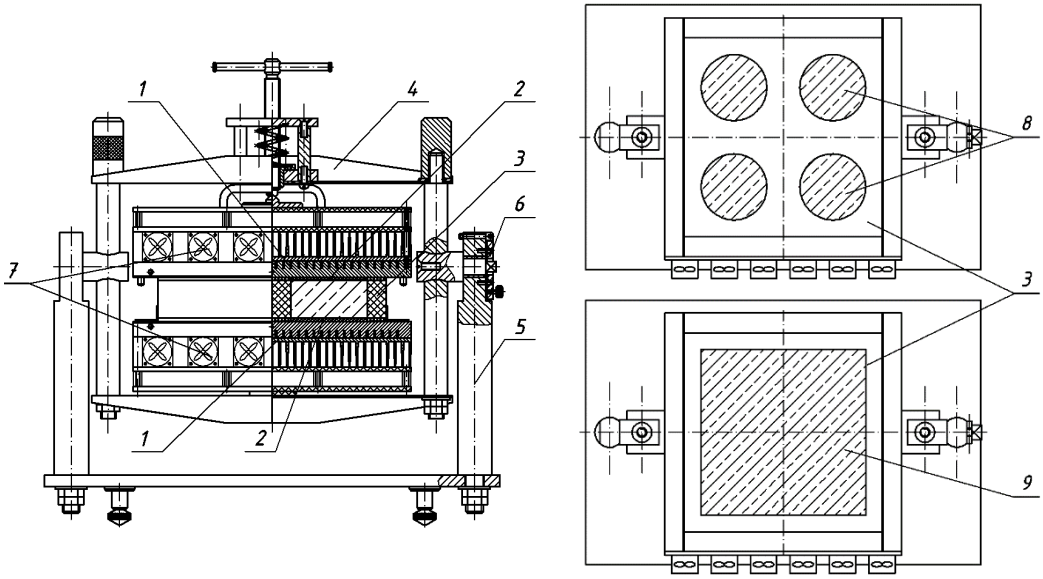

Figure 2. Scheme of the thermal unit of the device: 1 – temperature control units; 2 – heat-measuring units; 3 – thermal insulation inlay; 4 – rotary clamping device; 5 – guide posts; 6 – retainer; 7 – fan units; 8, 9 – measuring cells

A characteristic design feature of this device is the presence of a rotary mechanism, which allows setting the heat unit in the working position at an angle of 90°, as presented in Figure 1. This allows ensuring the necessary accuracy of measuring the heat flow and temperature of samples during the experiment. When assembled, four (8, Fig. 2) or one (9, Fig. 2) measuring cell, designed to accommodate samples of experimental material and provide the necessary thermal and temperature conditions. The use of four measuring cells allows for performing a synchronous comparative analysis of four samples at once.

The temperature control units 1 with the inlay 3 installed between them and the prototypes are placed in the rotary-clamping device 4, which is a frame structure on the guide posts 5 and is designed to fixate the samples and minimise the contact resistances between them and the heat-measuring units in the measuring cells. The force is set by means of a screw mechanism with a power spring. The structure is rotated by an angle of 90° and set to the working position (vertical, Fig. 1), securing with a retainer 6.

The software of the device is designed for long-term (from several hours to several days) indication and recording of the values of temperature and density of heat flow in the sample for further processing and analysis of thermal processes, calculation of thermal resistance and coefficient of effective thermal conductivity of samples of bulk materials.

Calculation formula for the coefficient of thermal conductivity λ, W/(m*K), has the form:

$$\lambda = h \cdot (\Delta T / \bar{q} - R_{\text{K}})^{-1}, \quad (1)$$

where: h – thickness of the prototype equal to the thickness of the thermal insulation inlay, m; $\Delta T = T_{\text{B}} - T_{\text{H}}$ – temperature difference T_B and T_H, respectively, the upper and lower working surfaces of the sample, K; $\bar{q} = 0{,}5 \cdot (q_{\text{B}} + q_{\text{H}})$ – mean value of the heat flux density, W/m^2, passing, respectively, through the upper q_B and the lower q_H working surfaces of the sample; R_K – correction for the total contact thermal resistance of the measuring cell, which is determined during calibration of the device, m*K/W.

The value of the coefficient of thermal conductivity of samples of the experimental material is determined as the mean value, considering the measurement error according to the formula:

$$\bar{\lambda}_T = \frac{1}{N} \sum_{i=1}^{N} \lambda_{T,i} + \delta\,, \quad (2)$$

where: $\bar{\lambda}_T$ – mean value of the coefficient of thermal conductivity for the temperature value T; $\lambda_{T,i}$ – value of the thermal conductivity coefficient i- th sample at temperature T; N – number of samples; δ –measurement error.

Research results of samples of grain mass in the range of average temperature values from 35 to 70°C are displayed in Fig. 3.

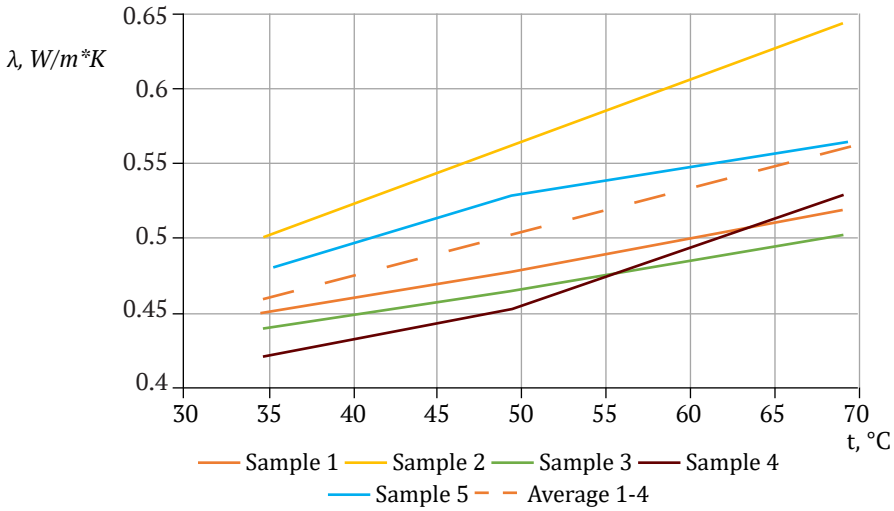

Figure 3. Results of the examination of the coefficient of effective thermal conductivity of grain mass

Samples 1 through 4 were examined simultaneously in cells Ø100 mm, and sample 5 was examined in a 250×250 mm frame. The bulk density of all samples was within ±3%. The average graph for the four samples correlates well with the results obtained for sample 5.

The device can also be used to study the thermal effects that accompany the examination of thermolabile materials, for example, in the presence of heat release in samples. Therewith, the information and measurement system records and processes signals from primary sensors throughout the entire process time, resulting in graphs of changes in heat fluxes on the sample surfaces, as presented in Figure 4.

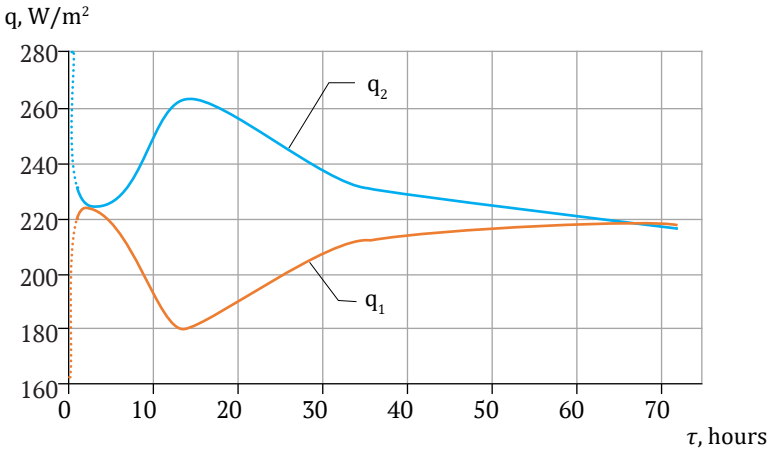

Figure 4. Graphs of changes in the surface density of heat flow on sample surfaces during heat release at a temperature of 20°C

The following formula is used to determine the volumetric heat release:

$$q_v = \frac{(q_2 - q_1)}{h} \quad (3)$$

Values of integral heat releases Q_τ, kJ/m^3, for the time τ, are obtained using the formula:

$$\boldsymbol{Q_\tau} = \int_{\tau_0}^{\tau} qv\, \boldsymbol{d\tau}, \quad (4)$$

where τ - current time value, h, τ_0 – value of the heat release start time, h.

The results of calculations of heat release of chicken droppings samples in four temperature conditions are presented in Figure 5.

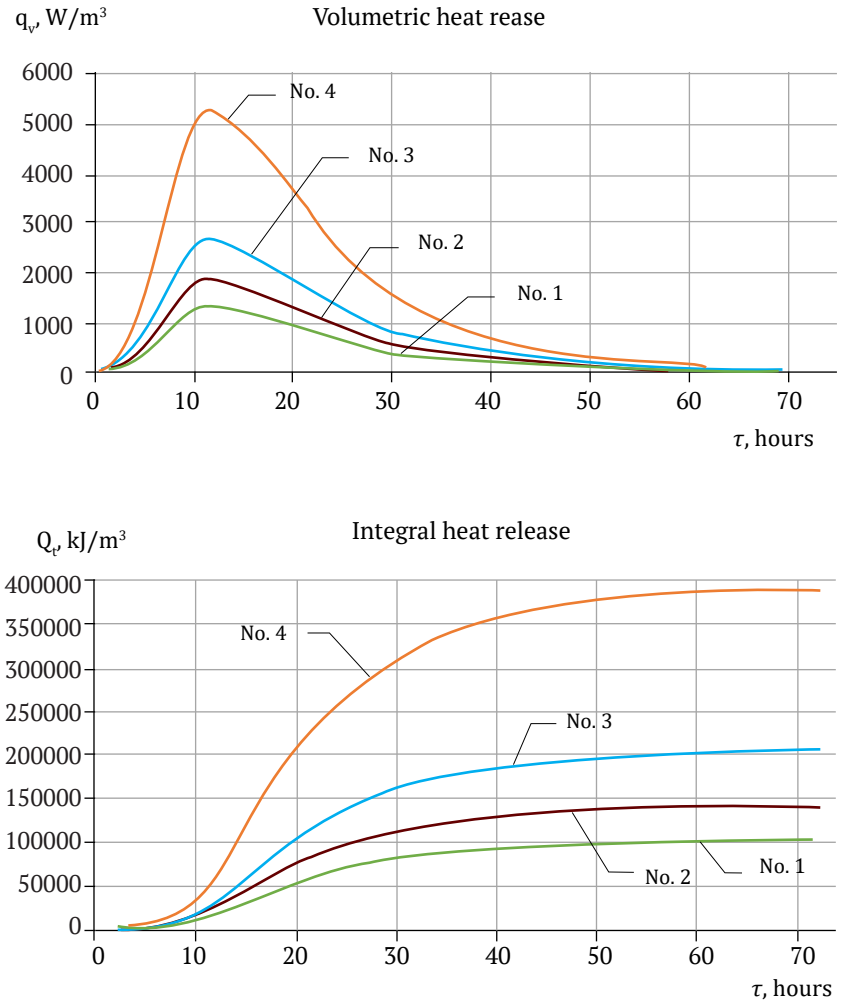

Figure 5. Volumetric and integral heat release of samples in temperature conditions: No. 1 – 20°C, No. 2 – 30°C, No. 3 – 40°C, No. 4 – 50°C

Therefore, the presence of a limited volume of cells allows for maintaining the same bulk density of the material in different experiments, and measurements simultaneously on

four samples give a substantial gain in time. Comparison of experimental data for different sample thicknesses allows compensating for the influence of the contact resistance of the wall layer on the result of measurements of the thermal conductivity of bulk grain material.

The method of conducting long-term studies enables the investigation of the thermal effects and changes in sample parameters during heat release in real time, which expands the functionality of the device.

Materials and methods for analysing the heat capacity and heat of evaporation

As mentioned above, it is advisable to use the synchronous thermal analysis (STA) method for analysing the processes of dewatering plant raw materials, which covers the following analysis methods:

- differential microcalorimetry – measurement of the expenditure of energy for a phase transition in the test sample,
- thermogravimetry – recording changes in sample mass loss over time.

The STA system developed by ITTP of NAS of Ukraine combines calorimetric and thermogravimetric analyses and allows determining with sufficient reliability the specific heat of evaporation during the drying of a thin layer of wet dispersed material and liquids in the chemical, microbiological, pharmaceutical, and food industries [17]. The appearance and block scheme are presented in Figure 6.

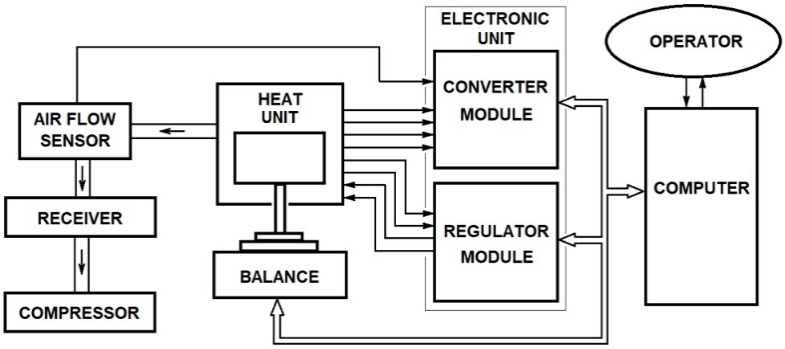

Figure 6. Appearance and block scheme of the STA system

The STA system is an information and measurement complex of a functionally combined thermal unit, analytical scales, compressor, electronic unit, and personal computer with the appropriate software. The main difference between this system and its well-known analogues is the ability to perform measurements under the optimal temperature regime, maintaining the surface temperature of the product approximately equal to the temperature of the dynamic medium. This is achieved due to the fact that the calorimeter platform has independent temperature control.

The object of research can be both pure liquids (water, alcohols, organic solvents) and various materials: food and vegetable products (grain, vegetables, fruits, etc.), pharmaceuticals, lacquers, paints, etc. for determining the evaporation of both free and material-bound liquids.

Main technical characteristics of the STA system:

- range of measured specific heat of evaporation from 500 to 2500 J/g;
- limits of the permissible relative error of measuring the specific heat of evaporation ±0.5%;
- temperature range from 18 to 105°C;
- limits of the permissible error of temperature measurement ±0.5 K;
- range of mass values of the sample of the test solid is from 1 to 5 grams.

In the thermal unit of the installation, the scheme of which is presented in Fig. 7, there is a working chamber with a replaceable calorimetric platform for analysing samples.

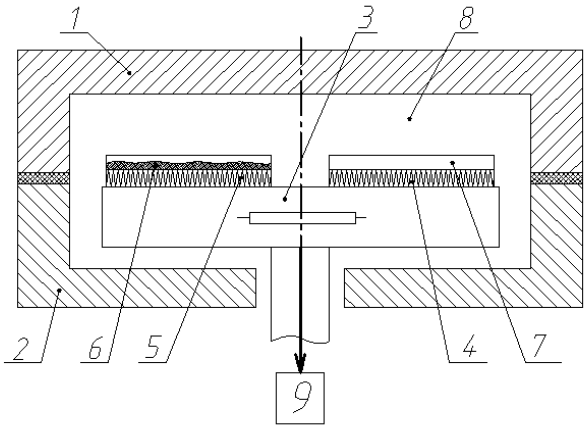

Figure 7. Schematic diagram of the working chamber of the heat unit : 1 – upper thermostatic unit; 2 – lower thermostatic Unit; 3 – calorimetric platform with the main electric heater; 4,5 – heat flow sensors; 6 – cell with a sample of the test substance; 7 – reference cell; 8 – working chamber; 9 – analytical scales

The working chamber is formed by two thermostatic units with built-in heaters, which allows for maintaining an isothermal mode in the working chamber during the experiment. The calorimetric platform is mounted on a coaxial rack, which is placed on analytical scales used to record the mass reduction of the wet sample during the drying process. Therewith, the platform is not mechanically connected to the static elements of the thermal unit, and electrical communication is conducted using a special collector consisting of loop-shaped radially arranged wires with a diameter of 0.03 mm. This design of the current collector minimises the impact of electrical wires on mass measurement.

Replaceable calorimetric platforms are represented by three versions of calorimetric cells (Fig. 8), which expands the range of types of materials suitable for the study, depending on their characteristics.

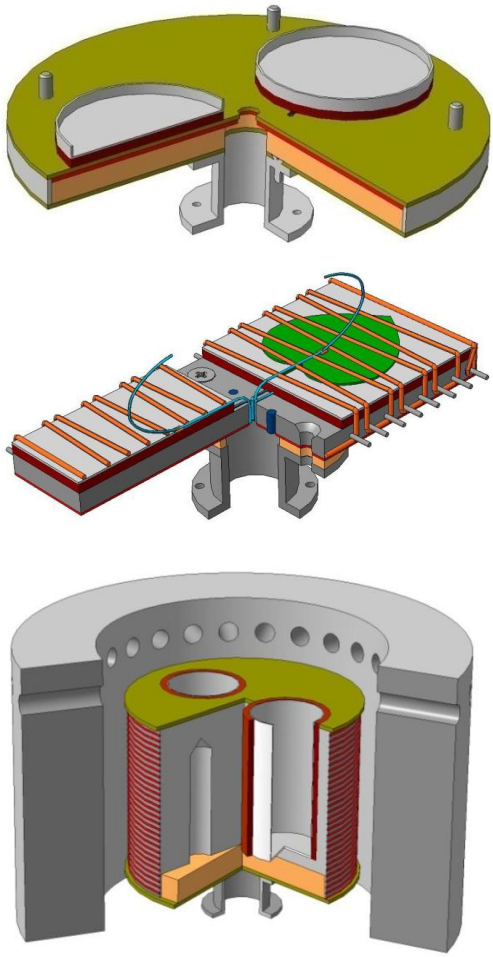

Figure 8. Variable calorimetric platforms with open cells, flat cells with sample fixation and high cylindrical cells

In each of the designs, the cells are made as similar as possible in both geometric and thermophysical parameters. Each cell is equipped with heat flow sensors (HFS). One cell is a working cell and is intended for placing the test sample in it. The second cell is a reference cell and remains empty during the experiment, or serves to place the comparison substance. The platform contains an electric heater and two platinum resistance thermometers, one of which registers the platform temperature, and the second is part of the platform temperature control system.

The open-cell calorimetric platform is equipped with two cup-shaped open cells with heat flow sensors under the bottom of each of them. Such a platform is designed to examine the heat of evaporation of solvents from solutions, pasty materials, liquid homogeneous samples, and the heat capacity of solid samples with a prepared surface that provides thermal contact with the flat bottom of the cell.

The platform with high cylindrical cells is designed for analysing samples with a dispersed structure and high thermal resistance between particles. A special feature of this platform is that the heat flow sensors of the cells are located on the perimeter along the cylindrical walls of the cell. This allows for obtaining correct information about the thermophysical and thermodynamic characteristics of inhomogeneous materials due to the almost complete coverage of the sample by the heat flow sensor. This platform is convenient for analysing the heat capacity of a wide range of materials, including wet samples of moderately large sizes.

Determining the specific heat of evaporation of liquids from some materials may be difficult due to changes in their geometric parameters during drying. Deformation during drying of samples such as leaves of medicinal plants, thin sections of parenchymal tissues of fruits, some organic thin-leaf materials, and sections of tissues of small thickness leads to a disruption of the thermal contact of the sample with the flat surface of the cell. This introduces an additional error or completely distorts the measurement information. For such studies, a platform with flat cells of rectangular shape with heat flow sensors under the bottom of each and a sample holder – a flexible tape of small diameter was developed.

The system implements the possibility of using two different research methods: the method of synchronous thermal analysis for analysing the heat of evaporation and the method of step-by-step scanning, regulated by ISO 11357-4:2014 [18], for analysing the heat capacity. The preparation of the sample for the study also differs depending on the structure and characteristics of the sample material, and the type of calorimetric platform chosen.

During the study of the specific heat capacity, the temperature range in which the measurement will be performed is divided into equal intervals (steps) of sufficient duration to establish an equilibrium state in the working chamber of the system and maintain it for at least 20 minutes. If the temperature of the heaters increases to the next interval, the heat flow sensors of the cells record the amount of heat that is spent on heating the working cell with the sample and the reference cell to the set temperature. The signals of all primary temperature and heat flow sensors are recorded by the information-measurement system, processed, and displayed on the computer monitor in the form of graphical dependencies (Fig. 9).

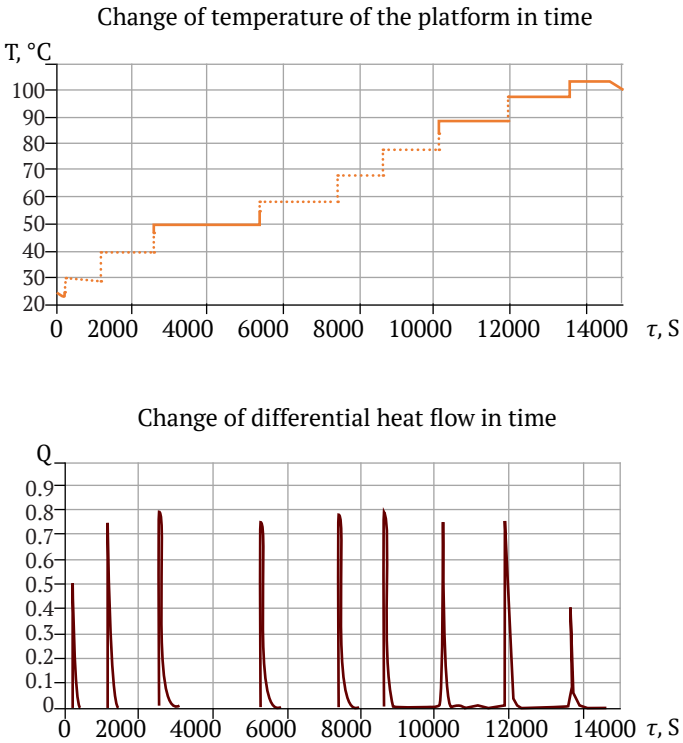

Figure 9. Graphs of step-by-step temperature changes and corresponding heat flow values over time

The value of the specific heat capacity for a single interval is calculated by the formula:

$$c = 1/m \cdot \left| \int_{\tau_1}^{\tau_2} \Delta Q(\tau) d\tau / \Delta T - C_K + \Delta C_{BAL} \right| \quad (5)$$

where: m – mass of the test sample; ΔQ – difference in heat fluxes recorded by the working cell and the reference cell for the time from τ_1 to τ_2 (interval duration); ΔT – difference in temperature values between intervals; ΔC_{BAL} – parameter that considers the difference of the thermophysical parameters of the working cell and the reference cell; the heat capacity of the container C_K is considered if the test sample is in the container and the reference cell is empty.

During the study of the specific heat of evaporation by synchronous thermal analysis, the dependence of the mass loss of the sample over time and the amount of heat that is spent on the evaporation of liquids from the sample in an isothermal medium for the corresponding period of time is recorded. The study continues until the evaporation of liquids from the sample stops, which is determined by the cessation of the decrease in mass readings and the stabilisation of the signal of the heat flow sensors of the cells.

Mean value of the specific heat of evaporation over the time interval from the initial moment τ_i until the final moment τ_j is calculated using the formula:

$$\bar{r}_{ij}(T,m,\tau) = \frac{\int_{\tau_i}^{\tau_j}[Q_1(T)-Q_2(T)+Q_{HT}(T)]d\tau}{m(\tau_i)-m(\tau_j)} \quad (6)$$

where: Q_1 – heat flow passing through the working cell; Q_2 – heat flow passing through the reference cell; Q_{HT} – uncontrolled heat exchange of the sample with the medium, which is not detected by heat flow sensors; $m(\tau_i)$ – $m(\tau_j)$ – loss of mass of the sample over time from the moment τ_i until the moment τ_j.

Study results

Researchers of ITTP of the National Academy of Sciences of Ukraine, the National University of Food Technologies, and the National University of Life and Environmental Sciences of Ukraine conducted a number of studies of some food products and plant raw materials intended for the production of biofuels using the STA system. The purpose of these studies was not only to determine the thermophysical parameters of the samples but also to establish temperature and time parameters and optimise the drying process.

Thus, based on thermophysical experiments, experimental-statistical models of the drying process of the stem and cap of a cultivated Champignon mushroom (Fig. 10) are created, the expediency is proved, and a technological scheme for separate drying of Champignon is developed [19; 20].

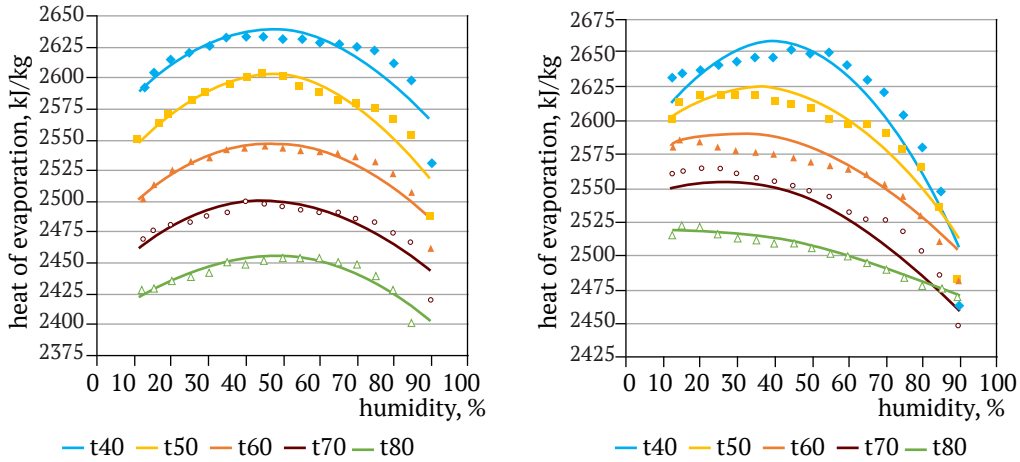

Figure 10. Dependences of changes in the heat of evaporation on humidity at different temperatures during the drying of the mushroom: a – stem, b – cap

The total increase in the specific heat of evaporation of moisture from native tissues of the cap at different temperatures compared to the table value for evaporation of pure water from the free surface is ~9%, and the nature of its dependence on humidity correlates with the dynamics of changes in the state of free and bound water in the case of dewatering of the fungus. A gradual increase in the total heat consumption for evaporation almost from the very beginning of the drying process of fungal tissues leads to a decrease in the proportion of free water and an increase in the proportion of bound moisture. In the further development of

this study, to solve the problem of determining the ratio of free and bound moisture in inhomogeneous materials, the concept of a cryocalorimeter for analysing the energy of the phase transition of moisture in a material is proposed [21].

Investigating the latest materials, for example, solutions for the manufacture of biodegradable polymer packaging and their dewatering parameters from 69-72% in the initial substance to 6% in the dried film/coating in production conditions is of interest [22].

Conclusions and Prospects

Food production technologies are constantly progressing, and the product range of processing enterprises in the industry is constantly increasing. Modern science offers a wide range of studies of the parameters of thermodynamic and mass transfer processes and the determination of the thermophysical characteristics of the latest substances and products. Positive is the fact that Ukraine has its own material and technical base of metrologically certified devices and systems for measuring temperature and heat flow, thermal resistance, coefficients of thermal conductivity, and heat capacity of various materials and substances.

The developed method of measuring the coefficient of effective thermal conductivity considers the specific features of studies of bulk food products and enables the introduction of a correction for the contact resistance of the wall layer of bulk materials, which substantially increases the accuracy of analysing their thermal conductivity. The possibility of long-term observations allows for analysing thermal effects in samples and calculating volumetric and integral heat dissipation.

The STA system provides the ability to determine the specific heat capacity by step-by-step scanning and the heat of evaporation by synchronous thermal analysis during the study of a wide range of substances and products of biological origin.

Studies of the thermophysical characteristics of non-homogenous materials and substances will allow for optimising production processes and further developing technologies in the food, biotechnological, and processing industries.

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Дослідження теплофізичних характеристик харчових продуктів

З. А. Бурова1, С. О. Іванов[2], Т. О. Роман[3], В. П. Василів[1], М. М. Жеплінська[1], М. М. Муштрук[1], І. П. Паламарчук[1], В. В. Сарана[1], М. М. Гудзенко[1]

[1]Національний університет біоресурсів і природокористування України
[2]Інститут технічної теплофізики НАН України
[3]Національний університет харчових технологій

Анотація. Здорове харчування є одним з найважливіших елементів збереження здоров'я та зміцнення імунітету нації, неодмінною умовою досягнення активного довголіття нинішніх та майбутніх поколінь. Винайдення нових інгредієнтів та створення харчових продуктів на їхній основі, розробка нових та вдосконалених наявних технологій потребує достовірної інформації про основні теплофізичні характеристики сировини та матеріалів біологічного походження для розрахунку й оптимізації тепло масообмінних процесів переробки і виробництва. Сучасна наука пропонує широке коло досліджень параметрів термодинамічних та масообмінних процесів, визначень теплофізичних характеристик новітніх речовин та продуктів із застосуванням метрологічно атестованих приладів та інформаційно-вимірювальних систем. Основною проблемою під час дослідження матеріалів біологічного походження є їхня негомогенність та неоднорідність структури зразків. Визначення коефіцієнта ефективної теплопровідності сипких матеріалів та круп доцільно проводити в стаціонарному тепловому режимі на приладі для визначення теплофізичних характеристик матеріалів і теплових ефектів, у якому реалізована симетрична схема теплометричного методу вимірювань із застосуванням сенсорів теплового потокутатемператури. Використання чотирьох вимірювальних комірок дає можливість проводити синхронний порівняльний аналіз декількох зразків, а поворотно-притискний механізм сприяє мінімізації контактних опорів. Розроблена методика вимірювань коефіцієнта ефективної теплопровідності враховує особливості сипких харчових продуктів та значно підвищує точність дослідження їхньої теплопровідності через введення поправки на контактний опір

пристінного шару. Можливість проведення довготривалих спостережень дає можливість досліджувати термолабільні матеріали, аналізувати теплові ефекти в зразках, оцінювати об'ємнета інтегральнетепловиділення. Калориметричні дослідження широкої гами біологічних матеріалів та речовин із достатньою точністю можна проводити на системі STA, у якій реалізовано методи покрокового сканування та синхронного теплового аналізу для визначення питомої теплоємності та теплоти випаровування, дослідження співвідношення вільної та зв'язаної вологи в негомогенних матеріалах. Ці характеристики є невід'ємними параметрами під час дослідження кінетики тепломасообмінних процесів, зокрема сушіння, для розрахунку і проєктування технологічного обладнання. Дослідження теплофізичних характеристик негомогенних матеріалів та речовин дадуть змогу оптимізувати виробничі процеси та надалі розвивати технології харчової, біотехнологічноїта переробної галузі

Ключові слова: неоднорідні матеріали, коефіцієнт ефективної теплопровідності, тепловиділення, питома теплоємність, теплота випаровування, сушіння

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Revival of the resource potential of cattle breeding as a factor in the development of competitiveness of enterprises of the dairy product subcomplex of the agro-industrial complex of Ukraine

Viktor Yemtsev*, Nataliya Slobodyaniuk

National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Abstract. Permanent crises in the Ukrainian economy, the devaluation of the hryvnia, the decline in incomes of the population and its purchasing power, increased competition on the world market, and the constant increase in world prices for food and non-food products created new realities of functioning of enterprises of the dairy sub-complex of the agro-industrial complex of Ukraine and led to its transformation. Therefore, the study of the reasons for the existence of these trends is very relevant. *The purpose of the study* is to assess the current state of the sub-complex and the development of practical recommendations for improving the efficiency of its functioning. The performed study was based on the use of methods: qualitative analysis and synthesis, economic-statistical analysis, comparisons, analytical and logical generalisations, etc. At the beginning of 2021, the total number of cattle in Ukraine was 2.874 million heads and over the past 10 years decreased by 1.952 million heads, including cows by 0.958 million heads. Milk production remains small-scale. In 2020, 9.263 million tonnes of milk were produced (17.66% less than in 2010). A substantial reduction in the volume of milk supplies for processing led to a reduction in the number of processing enterprises in 2020 by 69.14% compared to 1990. The main factors of transformation of the dairy sub-complex in Ukraine include: reduction of the number of cows, insufficient quantity of high-quality dairy raw product and their non-compliance with the regulations and standards of the European Union, low technological level of milk production, insufficient control over the quality of raw product, lack of modern equipment, high capital and labour intensity of production processes, rising prices for energy and other resources, reduced consumption of dairy products due to low purchasing power, increased competition in the world and internal markets of dairy products, etc. The conducted research should help to solve and highlight the main functional

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**Corresponding author*

problems of milk processing enterprises that operate in the agro-industrial complex of Ukraine, the results of the above-mentioned studies can be useful and relevant for the revival of dairy cattle breeding in the post-war period

Keywords: dairy cattle breeding, dairy industry, dairy raw product, milk processing, dairy products market

Relevance

Milk and dairy products are valuable food products, the world consumption of which is constantly growing both in connection with the overall growth of the world's population and the increase in their consumption in some countries (China, Vietnam, etc.), which is associated with an increase in the standard of living of the population of these countries. According to a study by IFCN experts, the growth of global milk production in 2019 was mainly due to India, Oceania, Africa, and the Middle East [1]. However, this increase was 1.4% and was substantially lower than the long-term average (2.3%).

In 1990, Ukraine ranked 6th in the world in the world ranking of milk-producing countries, with milk production volumes of 24.5 million tonnes. In 2020, the country ranked 22nd in the world ranking (among 123 countries – the main milk producers, producing 98% of the total world production) [2]. It is the reasons for the development of these trends in its functioning and the current state of affairs in the dairy product subcomplex of the agro-industrial complex of Ukraine that requires additional research.

Analysis of recent research and publications

A comprehensive study, assessment, and analysis of the state of enterprises of the dairy subcomplex of the agro-industrial complex of Ukraine and the prospects for their development is considered in the papers of many researchers. Among them are the papers of N. Belinska, P. Berezivskyi, V. Boyko, I. Evsieieva, M. Ilchuk, T. Mostenska, N. Oliadnichuk, M. Parkhomets, V. Radko, P. Sabluk, N. Shiian, I. Fedulova, and many others. These researchers investigated important issues related to the development of the feed base, breeding work, conditions for keeping dairy herds, optimising the organisational and economic mechanism of functioning of sub-complex enterprises, and ensuring the growth of their competitiveness. However, dynamic changes in the global and internal markets and the introduction of modern innovative technologies, equipment, and products require constant identification and clarification of trends in the development of sub-complex enterprises to develop effective tools for managing their functioning and developing competitiveness.

The purpose of the study is to assess the current state of the dairy sub-complex of the agro-industrial complex of Ukraine, trends in functioning, and factors of its transformation, development of practical recommendations for stabilising and improving the efficiency of its activities and competitiveness.

Materials and Methods

The study was based on the use of methods: qualitative analysis and synthesis, economic-statistical analysis, comparison, analytical and logical generalisation, etc.

Results

As a result of the changes that have taken place in the country over three decades, in 2020 the overall structure of agricultural production has changed: horticulture production – 79.1%, livestock production – 20.9% (Fig. 1). Therewith, the structure of agricultural production in agricultural enterprises changed even more and in 2020 amounted to 83.8% and 16.2%, respectively [3].

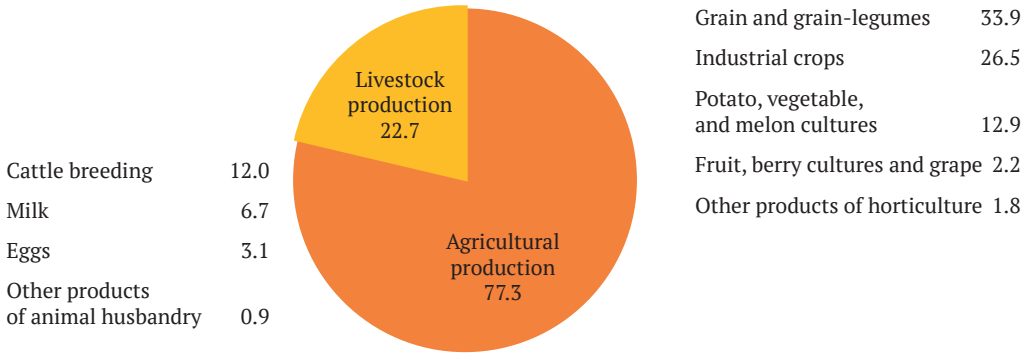

Figure 1. Structure of agricultural products in 2020, % (Statistical Yearbook of Ukraine for 2020)

The results of the conducted research indicate that the root cause of the current state of affairs in the Ukrainian animal husbandry and dairy product subcomplex of the agro-industrial complex is the existing trends in dairy cattle breeding, namely, the reduction in the number of cows and milk production. This was due to a decrease in the number of all types of animals, including cattle. Thus, according to the results of the study, at the beginning of 2021, the total number of cattle in Ukraine amounted to 2.874 million heads, which is 7.1% less than at the beginning of 2020 (Table 1). Therewith, the number of cattle in agricultural enterprises decreased to 1.008 million heads, and the number of dairy cows decreased to 423.9 thousand heads, which is 2.6% less than at the beginning of 2020 [4]. The results of the study show that today Ukraine has the smallest number of cattle in the last 120 years. All this ensured the invariability of the negative trend towards a decrease in the number of dairy farms, on average, by 4.3% per year and a decrease in milk production by an average of 2.3% per year, in contrast to the existing positive trend of growth in milk production in the world [5].

Table 1. *Dynamics of cattle and cow productivity in Ukraine (at the end of the year) [6]*

Years	1990	2010	2015*	2016*	2017*	2018*	2019*	2020*	2020/ 2010 pp.%
Cattle, thousand heads:	24 623	4826	3884	3750	3683	3531	3092	2874	59.55
Including cows, thousand heads	8 378	2631	2167	2109	2018	1919	1788	1673	63.6

Table 1. Continued

Years	1990	2010	2015*	2016*	2017*	2018*	2019*	2020*	2020/ 2010 pp.%
Including in households, thousand heads	2 186	2042.1	1733.5	1662	1551	1551.2	1451.6	1349.9	66.1
Per cow, kg of product of all categories	2863	4082	4644	4735	4820	4922	4976	5129	125.6
Average annual milk yield kg of milk per cow in agricultural enterprises	2941	3975	5352	5643	6025	6190	6101	6634	166.9

Note: ** – excluding the temporarily occupied territory of Crimea, Sevastopol, and parts of the temporarily occupied territories in Donetsk and Luhansk regions*

Therewith, households at the beginning of 2021 reduced the number of cattle to 1.865 million heads, including the number of dairy cows to 1.249 million heads, or by 6.4% compared to the number at the beginning of 2020 [7]. That is, the reduction in the number of cattle and cows in households has a higher rate than in agricultural enterprises engaged in cattle breeding. Notably, quantitative indicators of the number of cattle and cows in private farms of the population raise some doubts due to the fact that, for various reasons, the identification of livestock in them is still not completed, although the state should have ensured its implementation before 2015.

Analysis of the data in Table 1 allows concluding that over the past 10 years alone, the number of cattle in the country has decreased by 1.952 million heads, including cows by 0.958 million heads, which indicates the persistence of a negative trend in the development of meat and dairy cattle breeding and in the volume of milk production and supply to processing enterprises (Table 2).

The reduction in the number of cows, despite their increasing productivity in farms of all categories (by an average of 2% per year), led to a decrease in the production of high-quality dairy raw product (Table 1 and 2). Thus, according to the results of the conducted research, Ukraine produced 9.263 million tonnes of milk in 2020 (7.1% less than in 2019). Of these, 2.761 million tonnes (1.2% more) – in agricultural enterprises and 6.502 million tonnes (6.3% less) – in households [8].

All this led to a 2.2% reduction in factual milk consumption per capita, which in 2020 was only 53.13% of the scientifically based consumption standards for milk and dairy products. Despite the preservation of livestock in agricultural enterprises, successful seasonal laying of feed and high purchase prices for milk, according to the results of three quarters of 2021, milk production in Ukraine continued to decline by 6.1% compared to the corresponding period in 2020. Although agricultural enterprises are improving the quality of milk, fat, and protein content, there is still no substantial increase in milk volume, which would compensate for the reduction in milk production in households. This is hindered by the focus of agricultural enterprises on crop production, the lack of external investment, global inflation, currency volatility, the land market factor, etc.

All this has led to a reduction in the consumption of milk and dairy products per capita. Thus, if in 1990 the average consumption of one person was 373 kg/year of dairy products (calculated in terms of milk), then in 2010 this figure decreased to 206 kg/year, and in 2020 the

average consumption of one person was only 201.5 kg/year (Table 2).

Most milk in 2020 was produced in the Poltava – 734.2 thousand tonnes (3.2% less than in 2019), Vinnytsia – (728.4 thousand tonnes; 4.6% less), and Khmelnytskyi (651.5 thousand tonnes; 2.5% more) regions. The lowest volumes of milk production in 2020 were in the Luhansk, Donetsk, and Zaporizhia regions [9].

Table 2. *Dynamics of milk production and processing volumes in Ukraine [10]*

Indicators	2010	2015*	2016*	2017*	2018*	2019*	2020*	2020 to 2010, %
Milk produced, thousand tonnes	11249	10615	10382	10281	10064	9963	9 263	82.34
Milk delivered to processing enterprises, in total, thousand tonnes:	4793	4251	4183	4348	4179	3868	3299	68.8
Including from enterprises, thousand tonnes	2193	2744	2512	2689	2720	2750	2566	117.12
Including from the population, thousand tonnes	2544	1346	1198	1239	1089	870	733	28.8
Marketability level, %	42.6	40.0	40.2	42.3	41.2	38.8	35.61	83.6
Milk consumption per capita, kg/year	206.4	209.9	209.5	200.0	197.7	200.5	201.9	97.8

Note: ** - The data are provided without considering the temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol, and without considering the temporarily occupied territories in Donetsk and Luhansk regions*

The results of the analysis of the dynamics of milk production volumes allow concluding that there has been a transformation of the raw product base of the milk processing industry not only in terms of volumes but also the quality of milk received by processing enterprises (Table 2 and 3). 10 years ago the ratio of the volume of milk delivered by different categories of producers for processing to the enterprises of the milk processing industry was about 50:50, in 2020 the share of households in the total volume of milk transferred to processing enterprises was only 22.8%. That is, there was a sharp reduction in the volume of supplies for processing low-quality, but cheap, milk from farms, which agricultural enterprises are not able to compensate for by increasing the supply of high-quality product.

Notably, the quality and safety of milk delivered for processing by agricultural enterprises are steadily growing. According to the results of the analysis, there was an increase in the share of milk of the extra and first grade categories (Table 3). Thus, the share of extra grade raw product in the total volume of milk received for processing increased from 27.2% in 2019 to 34.6% in 2020. However, the share of top grade milk decreased, respectively, from 35.9% to 34.2% and first grade – from 32.3% to 30.4 %. The share of the second grade sharply decreased from 3.7% to 0.6% [11].

Table 3. *Dynamics of the structure of milk quality received for processing from agricultural enterprises, % of the total volume [12]*

Year	Extra	Top grade	First grade	Second grade	Non-grade
2010	4.4	31.3	59.3	4.1	0.9
2015*	10.3	35.2	49.6	4.7	0.2
2016*	15.4	38.8	44.46	6.74	0.3
2017*	16.4	36.7	37.9	8.7	0.3
2018*	21.6	38.1	32.9	7.1	0.3
2019*	27.2	35.9	32.3	3.7	0.2
2020*	34.6	34.2	30.4	0.6	0.2
2020 to 2010, %	7.46 times	109.26	51.26	14.6	22.2

**– The data are provided without considering the temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol, and without considering the temporarily occupied territories in Donetsk and Luhansk regions*

Notably, there was a rise in quality in households, but only on paper. The share of second-grade milk delivered by the population for processing decreased from 83.2% to 18.4%, while first-grade milk, on the contrary, increased from 12% to 79.9% without almost any noticeable changes in the technology of milk production, storage, and delivery [7]. That is, milk processing enterprises in the conditions of a shortage of raw product could not refuse to accept milk for processing from households and, thus, are trying to fulfil the requirements of new legislative acts on the quality and safety of milk by mixing milk of the population and agricultural enterprises.

This is confirmed by the fact that in Ukraine, sanitary quality control of milk is conducted only in 14.8% of households engaged in milk production (Statistical collection Livestock of Ukraine, 2020). Therewith, milk quality control occurs only in 8.4% of households that cultivate 0.5 hectares of land or less, 17.1% of households with a land area of 0.51 – 1 hectares and 28.3% of households with a land area of more than 1 hectares.

Table 4. *Dynamics of the number and production capacity of milk processing enterprises in Ukraine [7]*

	1990	2000	2007	2010	2014*	2019*	2025 (forecast)	2019 to 1990, %
Number of enterprises	643	447	354	287	252	192	157	29.86
Total production capacity, million tonnes	18.6	13.9	13.46	12.7	12.0	9.8	8.1	52.69
Average capacity, thousand tonnes	28.9	31.1	38.02	44.2	47.6	51.04	51.6	176.6

Note: **– The data are provided without considering the temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol, and without considering the temporarily occupied territories in Donetsk and Luhansk regions*

The results of the conducted research show that if the existing negative trends in the dynamics of milk production and supply volumes for processing continue, 1-2 large milk processing enterprises will disappear annually in Ukraine. This is confirmed by the results of the analysis of changes in the number and level of processing capacities of milk processing enterprises (Table 4). The results of the analysis demonstrate that if at the end of 1990 there were 643 processing enterprises operating in the country, then in 2020 there were only 192 (of which 178 were functioning) or 29.86% compared to 1990 [13] although, mostly old low-capacity enterprises were closed. The result of this process was an increase in almost twice the average production capacity of milk processing enterprises. However, even these capacities, due to the lack of raw product, are used on average, by 30-40%.

The conducted analysis of production indicators of the main types of dairy products (Table 5) indicates that until 2014 there were positive trends in the production of milk, fresh cheese, and fermented milk, fermented milk products, and since 2014 there has been a decrease in production for all types of products. Among the main groups of dairy products, the largest market share is accounted for by whole milk, which accounts for approximately 84.0% in quantitative terms, cheese (with a market share of approximately 8.0%) and butter (with a market share of 5.0%).

The results of the analysis allow concluding that 80 of the most powerful milk processing enterprises today produce 75-85% of Ukrainian dairy products from whole milk. The owners of these enterprises value their reputation and therefore invest substantial funds in the modernisation of production, in innovative technologies to improve the quality of dairy products, monitor, and promptly respond to changes in market conditions, constantly improve and expand the range to optimise the production process, increase production volumes and profit of enterprises. They are also prompted to do this by the problem of adapting milk and dairy producers in Ukraine to European requirements, which became particularly acute after the annexation of Crimea and the loss of the russian market.

Table 5. *Production of dairy products in Ukraine [14]*

Indicator	Years									Growth rate from 2020 to 2010, %
	2010	2012	2014	2015	2016	2017	2018	2019	2020	
Processed milk liquid, thousand tonnes	822.3	911.6	1116.5	965.6	926.2	954.1	997.9	969	982.3	19.5
Butter, thousand tonnes	92.3	88.6	114	100.9	101	102.3	105.1	91.6	87.5	-5.3
Powdered milk and cream, thousand tonnes	68.7	63.1	66.7	60.9	58.8	45.3	37.4	34.5	35.3	-48.4
Fresh unfermented cheese and fermented milk cheese, thousand tonnes	78.5	79	74.7	67	69.6	68.7	72.8	64.1	81.4	3.7

Table 5. Continued

Indicator	Years									Growth rate from 2020 to 2010, %
	2010	2012	2014	2015	2016	2017	2018	2019	2020	
Hard cheeses, thousand tonnes thousand tonnes	207	168	130	122.6	113.1	105.6	96.3	86.1	85.2	-58.3
Fermented milk products, thousand tonnes	497	489	473	426.1	420.2	410.2	405.2	415.3	443.2	-10.9

The main areas of technological innovations in the milk processing industry are the use of energy-saving and low-waste technologies, low-temperature processing to preserve the health benefits of milk, nanotechnology, technology for extending the shelf life, etc. In addition, current trends in the dairy market in recent years are relevant areas for improving the range of dairy products: healthy nutrition; increasing demand for lactose-free milk; active development of the vegetable milk sector, which does not contain cholesterol, lactose and casein.

This encourages enterprises of the dairy sub-complex of the agro-industrial complex to increase production volumes of products that are attractive segments for export to the EU, CIS, Asia, and Africa (Fig. 2).

Today, Ukrainian dairy products are exported to 104 countries around the world. 145 enterprises are engaged in export. The main types of exported dairy products in 2020 were: butter ($49 million and 9th place in the world in terms of product exports), milk and cream dry or condensed ($45 million 19th place), cheeses ($24 million and 25th place), whey ($10 million and 10th place), milk and cream non-concentrated ($12 million and 26th place), etc. [15].

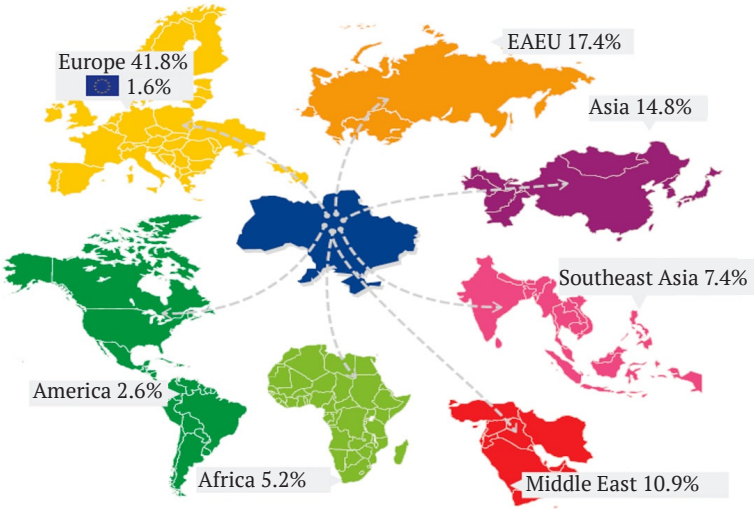

Figure 2. Geography of dairy exports in 2020 [8]

However, due to the reasons mentioned above and the high requirements of importers regarding the quality and safety of products, the volume of Ukrainian exports of dairy products tends to decrease (Fig. 3).

Thus, the export of dairy products in 2020 is only 29.0% of its volume in 2011. Moreover, in 2020, Ukraine became a net importer of dairy products both in value terms and in physical volumes. Exports of Ukrainian dairy products currently account for only 0.8% of world exports.

Therefore, considering the competitiveness of milk processing enterprises and their products in the world and internal markets, to make a high-quality dairy product, several components are needed: high-quality raw product, modern equipment, and qualified personnel. Admittedly, for enterprises to use the product quality and safety system as the basis for organising production and are certified according to international quality management and control standards ISO 9000, 14000, 22000, and HACCP.

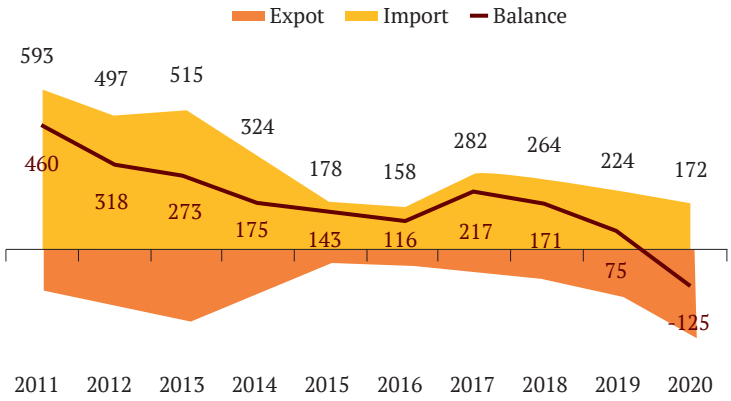

Figure 3. Dynamics of dairy export volumes, $ million [8]

Based on this, it would be economically feasible for a processor who would like to export its products profitably to have one modern plant with a processing capacity of at least 500 thousand tonnes of milk per year. However, the creation of such an enterprise in Ukraine requires a powerful raw product zone in which 5-6 modern commercial dairy farms will function with a population of 10 thousand cows each and with a capacity of 10 tonnes of milk per cow per year.

The results of the study allow identifying abnormally hot weather and loss of feed among the factors that directly or indirectly affected the reduction in milk production during 2020. In this regard, there was a substantial increase in prices (December 2020 to December 2019) for feed wheat by 57%, feed corn – 82%, sunflower meal – 126%, soybean meal – 74% [11]. In dairy cattle breeding, the problem of an insufficient amount of feed to meet the requirements of feeding technology also remains, because to have high productivity of animals, it is necessary to use balanced feeding rations. In the opinion of the study, the increase in feed prices will continue, because the global trend of rising prices for agricultural products continues. From

this, it can be concluded that a further rise in the price of grain will lead to an increase in the price of mixed feed, and therefore the production of meat and milk will remain low-profitable or even, for many farms, may become unprofitable Therefore, agricultural enterprises should focus their efforts both on increasing the number of livestock and on the real introduction of innovative technologies and reengineering of production and business processes.

Table 6. *Dynamics of average purchase prices for milk for agricultural enterprises and profitability of its production*

Years	2000	2005	2010	2012	2014	2016	2018	2019	2020
Price, UAH/tonne	630	1127	2938	2662	3588	5461.8	7602.4	8198.2	11.64
Profitability,%	-6.1	12.2	18.0	2.3	11.1	18.6	16.1	20.6	20.4

The profitability of milk production depends on the cost of its production and the level of the purchase price, which depends on the volume of supply, indicators of milk quality and safety, the availability of cold logistics, etc.

It is the increase in feed prices that directly affects the cost of production of livestock products and leads to an increase in prices for it. Thus, milk prices in 2020 were: extra – 12.15 UAH/kg, top – 11.7 UAH/kg, first –11.08 UAH/kg. The mean price is 11.64 UAH/kg. The range of price fluctuations for medium and large batches of extra grade milk by region was: North and Centre – 11.7-12.45 UAH/kg; South – 11.7-12.45 UAH/kg; East – 11.6-12.4 UAH/kg; West – 11.6-12.35 UAH/kg [7].

The results of the analysis show that in Ukraine, prices for extra and top grade milk are higher than in some EU countries. This leads to the fact that Ukrainian dairy products have a low level of competitiveness in foreign markets and opens up the possibility of importing dairy products from EU countries (Fig.3).

Ukraine has a huge potential in dairy production, and the sustainable development of this industry is possible, but only if there are cheap and long-term loans, appropriate professional education, and a stable national policy regarding the conditions of functioning of the dairy sub-complex of the agro-industrial complex. Notably, in 2018, the state programme for feeding young cattle in private farms was launched, by resolution of the Cabinet of Ministers of Ukraine No. 107 of February 7, 2018, "On approval of the procedure for using funds provided for in the state budget to support the livestock industry". This resolution provided budget assistance to households on an irrevocable basis for raising young animals up to 13 months of age in the amount of 2500 UAH/head. However, already in 2019, the population began to be massively denied subsidies, and in 2020 they were completely cancelled.

Substantial amounts of investment are needed for the development and stable functioning of dairy cattle breeding and the milk processing industry. Thus, to increase the number of cows to 2.1 million heads by 2030, milk production – to 11 million tonnes and process 9 million tonnes, it is necessary to invest UAH 9-11 billion annually in the industry. The state should take an active part in this, taking the EU model as an example, where up to 50% of producers' expenses for the construction of new

farms are compensated by the state. With the restoration of the Ministry of Agrarian Policy, it is necessary to develop a strategy for the development of dairy cattle breeding and milk processing industry, which would include state support for breeding work and genetic renewal of the herd, state involvement in the investment of new buildings, reconstruction and modernisation of existing dairy complexes, the development of cooperation of various forms, farming, infrastructure development for cold logistics, etc. However, regarding the real involvement of the state in supporting the agro-industrial complex and, in particular, dairy cattle breeding, by cancelling the special VAT regime for agricultural producers in 2017, the government undertook to allocate at least 1% of the volume of agricultural GDP to programmes of state support for the agro-industrial complex until 2021 – that is, about UAH 7 billion. However, not a single year since the adoption of this decision, the total amount of state support did not correspond to the declared amount, and only UAH 4.5 billion is planned for 2021.

As for the issues of increasing the production of high-quality and safe milk and its supply for processing, the future lies in the concentration of production due to vertical and horizontal integration for large enterprises and cooperation for farms and households. Cooperation between milk producers and processors is necessary to survive and be present on the world market, which will ensure the settlement of price relations between the parties and not lose the volume of milk production. This can be facilitated by the new Law of Ukraine "On agricultural cooperation", which comes into force on 15.11.2020. By combining into one of 4 types of cooperatives (service, production, processing, or multi-functional which can operate with or without profit), they can ensure the stability of production volumes, quality, and safety of milk and get the opportunity to work with large processors. This is confirmed by the results of investigating the experience of Poland, where about 200 thousand family farms with an average number of 10 cows function. Thus, with a total number of cows of about 2 million heads and an average productivity of 6.5 tonnes/year, the country produces 13.5 - 14.6 million tonnes of milk per year and ranks 6th in Europe and 13th in the world [11]. The price of Polish raw milk is 9-11% lower than the European average and 5% lower than the global average. In such conditions, the export of Polish milk and dairy products is characterised by a high level of competitiveness in foreign markets, including the internal market of Ukraine.

Conclusions and Prospects

The main factors of transformation of the dairy sub-complex in Ukraine include: reduction of the number of cows, insufficient quantity of the high-quality dairy raw product and their non-compliance with EU regulations and standards, low technological level of milk production, insufficient control over the quality of raw product, lack of modern equipment, high capital and labour intensity of production processes, rising prices for energy and other resources, reduced consumption of dairy products due to low purchasing power, increased competition in the global and internal markets of dairy products, etc.

Negative factors that hinder the development and stable functioning of the subcomplex are also:

- low level of investment attractiveness of the subcomplex due to the long payback period and insufficient level of state support for its functioning and development;

- the need to allocate substantial areas of agricultural land for forage crops, hayfields, and pastures, which is quite problematic for enterprises engaged in animal husbandry in the context of the opening of the land market.

Many issues of stabilising and improving the efficiency of dairy cattle breeding (reproduction and preservation of cows, increasing their productivity, reducing production costs, improving the quality and safety of products, and increasing the profitability of the industry) should be solved at the micro level, that is, in enterprises based on a rational organisation of production in accordance with regional location, specialisation, and their specific features. In the opinion of the study, the priority areas of state regulation and support for increasing milk production are:

- increasing the level of concentration of production and organisation of management of existing enterprises based on specialisation and cooperation, creating integrated agro-industrial formations or corporate organisations on market mutually beneficial terms for all participants in the technological chain: breeding – feed production – cultivation and production of milk – processing – saly of finished products;

- creating a favourable investment climate to improve the material and technical base of dairy cattle breeding, including by attracting private investment, implementing structural adjustment of the industry as a priority for its development in large specialised agricultural enterprises or integrated agricultural formations;

- development of breeding-genetic work, increasing the role of breeding plants, breeding farms, using the best samples of Ukrainian and foreign gene pools;

- formation of an effective economic mechanism in the field of pricing, financial-credit relations, leasing relations, factoring development opportunities;

- providing a high-quality feed base based on advanced technologies for harvesting and storing feed, ensuring the development of intensive resource-saving technologies aimed at producing high-quality and competitive products.

The problems of functioning of the milk processing sub-complex of the agro-industrial complex can be solved by implementing the concept of state support for animal husbandry for 2021-2023 and the national strategy for the development of the dairy industry 2021-2030, developed by the Ministry of Economy in a dialogue with industry associations.

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Відродження ресурсного потенціалу скотарства як фактор розвитку конкурентоспроможності підприємств молокопродуктового підкомплексу АПК України

Віктор Іванович Ємцев, Наталія Михайлівна Слободянюк

Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Перманентні кризи в українській економіці, знецінення гривні, зниження доходів населення та його купівельної спроможності, посилення конкуренції на світовому ринку, а також постійне підвищення світових цін на продовольчі й непродовольчі товари створили нові реалії функціонування підприємств молокопродуктового підкомплексу АПК України та призвели до його трансформації. Тому дослідження причин існування цих тенденцій є дуже актуальним. Мета дослідження є оцінка сучасного стану підкомплексу та розробка практичних рекомендацій щодо підвищення ефективності його функціонування. Виконані дослідження базувались на застосуванні методів: якісного аналізу та синтезу, економіко-статистичного аналізу, порівнянь, аналітичних та логічних узагальнень тощо. На початок 2021 року загальне поголів'я великої рогатої худоби в Україні становило 2,874 млн голів і за останні 10 років скоротилось на 1,952 млн голів, у тому числі, корів на 0,958 млн голів. Виробництво молока залишається дрібнотоварним. У 2020 році було вироблено 9,263 млн т молока (на 17,66 % менше, ніж у 2010 році). Значне скорочення обсягів постачання молока на переробку призвело до скорочення у 2020 році кількості переробних підприємств на 69,14 % проти 1990 року. До основних чинників трансформації молокопродуктового підкомплексу Україні належать: зниження поголів'я корів, недостатня кількість якісної молочної сировини та її невідповідність регламентам і стандартам Європейського Союзу, низький технологічний рівень виробництва молока, недостатній контроль за якістю сировини, відсутність сучасного обладнання, висока капітало- і трудомісткість виробничих процесів, зростання цін на енергетичні та інші ресурси, зниження рівня споживання молочних продуктів через низьку купівельну спроможність, зростання конкуренції на світовому та внутрішньому ринках молочної продукції тощо. Проведені дослідження повинні допогти розв'язати і вказати на основні функціональні проблеми молокопереробних підприємств, які функціонують в агропромисловому комплексі України, результати вищезазначених досліджень можуть бути корисними та актуальними для відродження молочного скотарства у післявоєнний період

Ключові слова: молочне скотарство, молочна галузь, молочна сировина, переробка молока, ринок молочної продукції

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Microstructural analysis of cooked sausages with spelt flour

Larysa Bal-Prylypko*, Volodymyr Khomych, Svitlana Usenko, Valentyna Israelian, Maryna Nazarenko

National University of Life and Environmental Sciences
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Abstract. In a market economy, it is especially important to produce and provide the population with marketable, high-quality, and safe food products. Given its valuable chemical composition, spelt flour is a promising raw material of vegetable origin intended for improving meat products. Therefore, the purpose of the study is to clarify the features of the structure of boiled sausages and the microstructure of their components that arise during technological processing when spelt flour is added to minced sausage, using histological research methods that substantiate the microstructural analysis of control and experimental samples. The study highlights the results of the examination of microstructural analysis of sausages with the addition of spelt flour, which affects the structure formation of boiled sausages during technological processing. The study presents drawings of sections of control and experimental samples under a microscope. The main components of rubbed minced meat, which contains spelt flour, were examined and analysed to introduce new high-tech solutions that will be competitive not only in the Ukrainian, but also in the European market. Studies of histology specimens of control samples of rubbed minced meat and stained with hematoxylin and eosin identified that minced meat is represented by an inhomogeneous mass of pink-red colour with numerous vacuoles of various sizes and shapes. Sections of the samples show inclusions of spelt flour, which are located in vacuoles very similar to vacuoles with tissue fluid, but unlike the latter, they have a fibrous structure. It is established that through histological studies, which form the basis of microstructural analysis, it is possible to clearly identify all the components of minced meat from which sausages are made. The obtained results allow for expanding the range of sausages, and the use of spelt flour — enriching the finished product with biologically active substances such as dietary fibre, natural antioxidants, micro- and macronutrients

Keywords: sausages, spelt flour, histological studies, minced meat, microstructural analysis

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**Corresponding author*

Relevance

In the context of rapid growth in the world population, the problem of providing it with a sufficient amount of food products is becoming more acute. The state of nutrition of the population of Ukraine is characterised by a deficiency of many essential nutritional factors, accompanied by an imbalance in the main nutrients (proteins, fats, carbohydrates) and a pronounced deficiency of macro- and microelements, vitamins, etc. Therefore, modern food technologies provide for the creation of products that are characterised not only by high organoleptic properties but also by a balanced amino and fatty acid composition, enriched with the content of omega-three fatty acids, macro- and microelements, vitamins, and dietary fibre [1], [2].

The advantage of boiled sausage products is their high nutritional and biological value. However, the conventional technology of their manufacture is characterised by a high cost of raw materials.

Analysis of Recent Studies and Papers

Increasing the efficiency of the production of boiled sausages due to cheap plant raw materials without changing the quality indicators is a very urgent problem [3]. High-protein plant crops are now used to solve it: soy, peas, lentils, barley, etc. The modern food market offers a wide range of various additives of plant origin intended for the production of meat products [4].

Considerable attention should be paid to the appearance of new ingredients with improved functional properties, which include spelt flour [5].

Spelt is known for its healing properties. Flour is made from grain grown without the use of chemical exposure in the western and south-eastern regions of Ukraine. It preserves all the useful components contained in the grain: vitamins A, E, Group B, and the entire complex of amino acids, macro- and microelements [6], [7].

Spelt flour is a fine cream powder with a neutral taste and a light nutty smell, with a dry, uniform texture. The grinding sise according to DSTU 46.004 is 99.2%.

Spelt is characterised by a high protein content – 17.4%. The total content of dietary fibre in spelt is 14.3%, but the cellulose content is much lower – 2.1%, compared to conventional types of plant raw materials [8]. The rich vitamin and mineral composition of spelt can be explained by its specific ability to absorb nutrients from the soil better than free-threshing wheat [9], [10].

Currently, histological methods of composition identification are most widely used to control the quality of meat products. The use of such methods allows giving both a qualitative and quantitative assessment of the raw components of meat products, which form the basis of microstructural analysis [11].

The purpose of the study is to identify the features of the structure formation of boiled sausages and the microstructure of their components that arise during technological processing in the case of adding spelt flour to minced sausage by methods of histological studies, which substantiate the microstructural analysis of control and experimental samples.

Materials and Methods

The material for the research was 2 types of samples of boiled sausages (4 samples each). Control samples contained, in addition to

minced meat, pink salmon caviar, nori seaweed, vegetable components, salt, and spices (TS U 10.1 – 37792346-002:2021). Spelt flour was added to the test samples.

The research was conducted in the histological laboratory of the Department of Animal Anatomy, Histology, and Pathomorphology named after academician V.G. Kasyanenko of the National University of Life and Environmental Sciences of Ukraine.

Histological studies were performed according to the generally accepted methodology [12]. Samples with a length of 1.5-2 cm were cut out of the selected material, labelled, and fixed in an 8% aqueous solution of neutral formalin for 6 days. The recorded samples were washed with running tap water for 4 hours and dehydrated in ethyl alcohol of increasing concentration (60%, 70%, 80%, 95%, and 100%). In each solution, they were kept for 12 hours [13]. The dehydrated material was compacted with paraffin and blocks were made, from which sections with a thickness of 6-11 microns were made using an MS-2 sledge microtome. The latter were placed on slides. The sections were stained with hematoxylin and eosin, Van Gieson's stain, and placed into balsam [14], [15]. The resulting histology specimens were examined using an Olympus light microscope.

Research Results

Studies of histology specimens of control samples of rubbed minced meat and stained with hematoxylin and eosin identified that it is represented by a heterogeneous mass of pink-red colour (crushed muscle tissue) with numerous vacuoles of various sizes and shapes. They can be rounded, oval, heart-shaped, or slit-shaped. Most vacuoles are filled with air (Fig. 1), and some of them contain a pink-red substance (tissue fluid) (Fig. 2) and filamentous nori algae (Fig. 3). Most of the identified algae have a pronounced membrane and are formed by oval, square, or rectangular cells (Fig. 4).

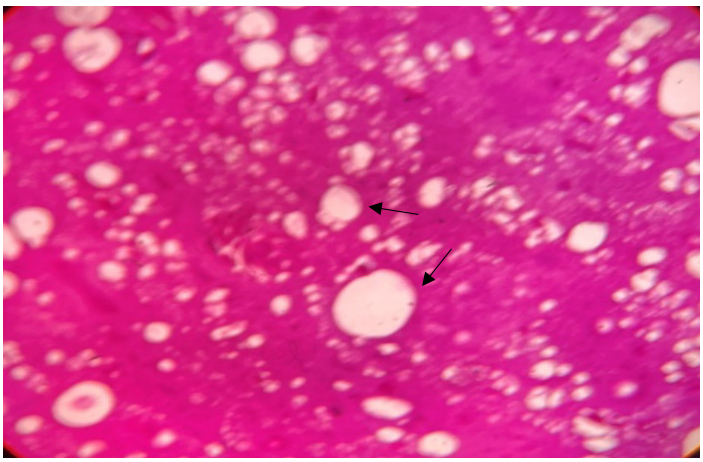

Figure 1. Vacuoles with air in the sausage of the control sample (shown by arrows). Hematoxylin and eosin dyeing. Magnification ×100

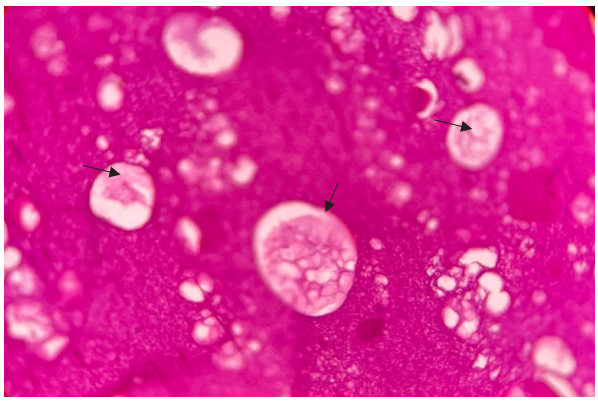

Figure 2. The substance is pink-red in the vacuoles of the sausage of the control sample (shown by arrows). Hematoxylin and eosin dyeing. Magnification ×100

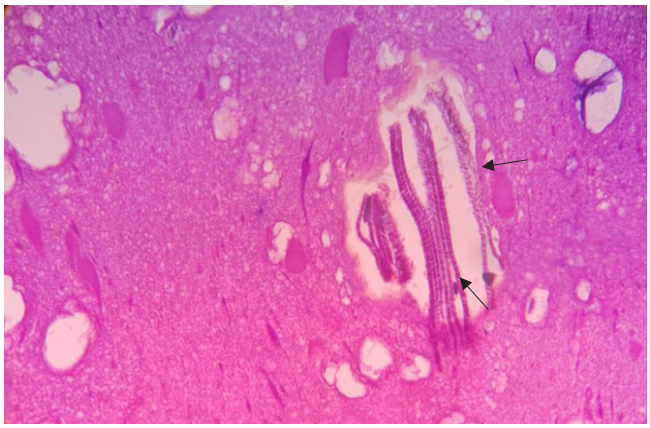

Figure 3. Filamentous nori algae (arrows) in the sausage of the control sample. Hematoxylin and eosin dyeing, ×100

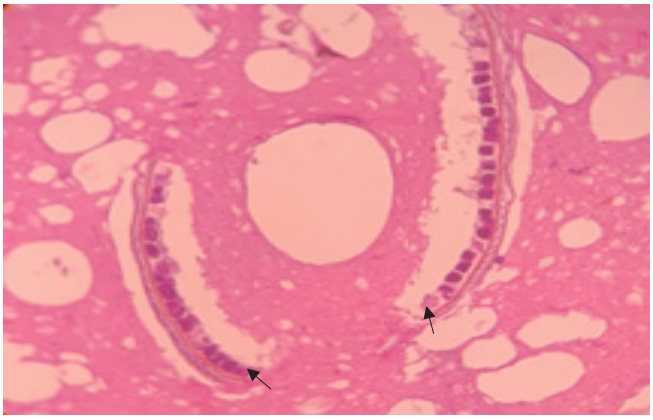

Figure 4. Nori algae cells (arrows) in the sausage of the control sample. Hematoxylin and eosin dyeing. Magnification ×200

In some cells, purple nuclei are visible. Also in this minced meat, individual fragments of completely non-destroyed muscle fibres are noticeable, which are cut along and across the transverse striation and the nuclei are not pronounced in them (Fig. 5).

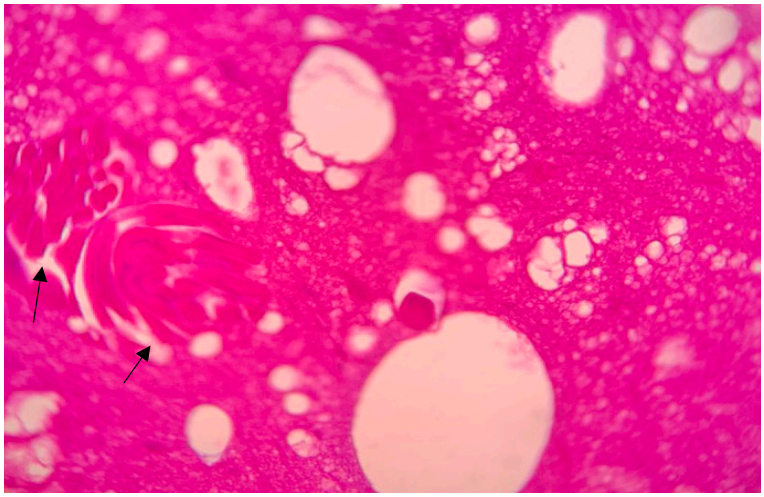

Figure 5. Fragments of muscle fibres (arrow) in the sausage of the control sample. Hematoxylin and eosin dyeing. Magnification ×100

In some vacuoles, eggs of rounded, oval, square, and diamond shapes are noticeable, which are intensely coloured dark red, and surrounded by fibrous structures of pink colour.

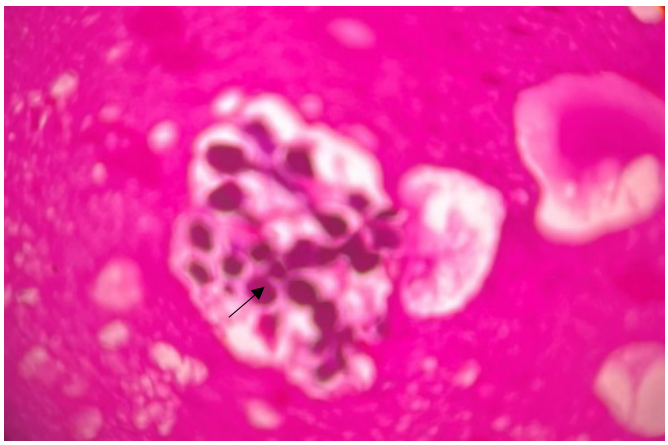

Figure 6. Group of eggs (arrow) in the sausage of the control sample. Hematoxylin and eosin dyeing. Magnification ×100

In some histology specimens of control samples, fragments of bundles of fibrous structures (bundles of collagen fibres) are detected, which, in the case of Van Gieson's staining of sections, turn red (Fig. 7). In the histology specimens of sausages of control samples, flavouring additives are detected.

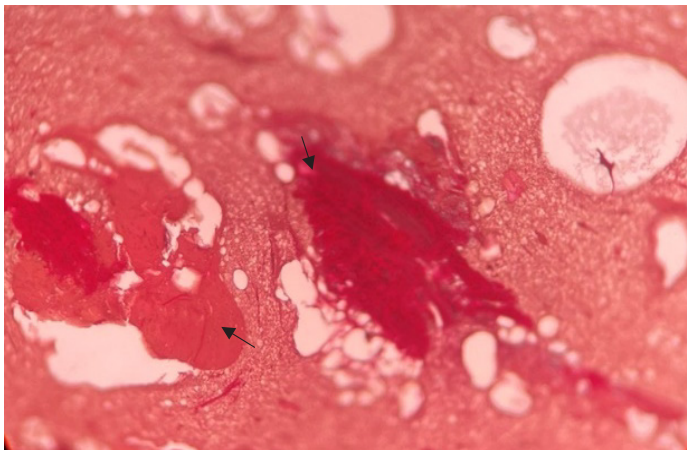

Figure 7. Bundles of fibrous structures (arrows) in the sausage of the control sample. Van Gieson's staining. Magnification ×100

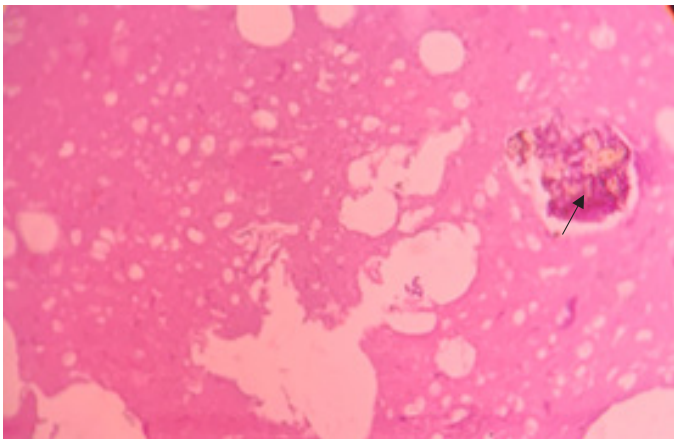

Figure 8. Pepper fragments (arrow) in the sausage of the control sample. Hematoxylin and eosin dyeing. Magnification ×100

The general plan of the microstructure of minced meat of experimental samples is similar to the same minced meat of control samples. In addition to the structures described above, it contains inclusions of spelt flour. They come in many shapes and sizes. Some of the inclusions

are located in vacuoles, and some – outside of them. In one field of view of the microscope, there can be 4-7 of them. On sections stained with hematoxylin and eosin, inclusions of spelt flour, which are located in vacuoles, are very similar to vacuoles with tissue fluid (Fig. 9), but unlike the latter, they have a fibrous structure. In the case of Van Gieson's staining of sections of experimental samples, the fibres of spelt flour inclusions acquire a specific colour. They have a gray-black colour (Fig. 10), which allows clearly differentiating them.

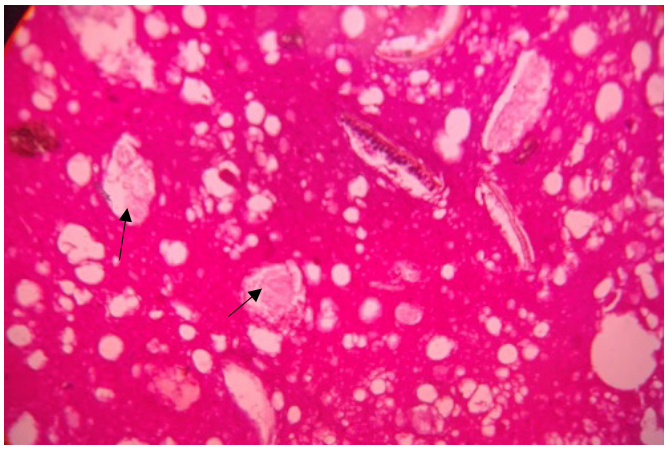

Figure 9. Inclusion of spelt flour (arrows) in the sausage of the experimental sample. Hematoxylin and eosin dyeing. Magnification ×100

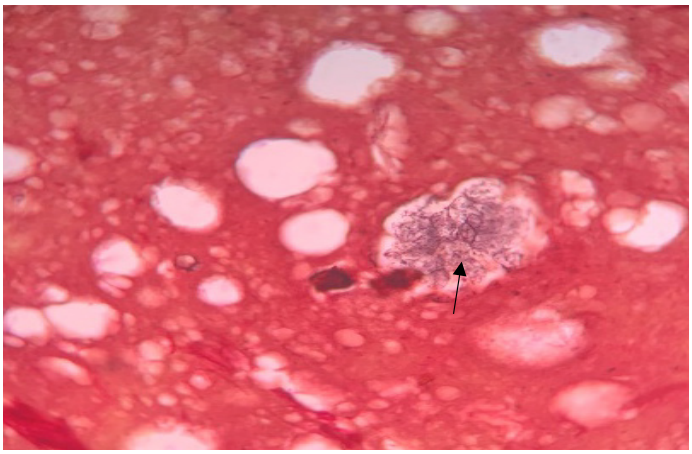

Figure 10. Inclusion of spelt flour (arrow) in the sausage of the experimental sample. Van Gieson's staining. Magnification ×100

Conclusions and Prospects

Histological studies, which form the basis of microstructural analysis, can clearly identify all the components of minced meat, from which sausages are made.

For more accurate identification of spelt flour in minced meat, which is used for making sausages, it is recommended to stain sections of histology specimens using Van Gieson's method.

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Мікроструктурний аналіз варених сосисок зі спельтовим борошном

Лариса Вацлавівна Баль-Прилипко, Володимир Тимофійович Хомич, Світлана Іванівна Усенко, Валентина Миколаївна Ісраелян, Марина Вікторівна Назаренко

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. В умовах ринкової економіки особливо важливим є випуск і забезпечення населення конкурентоспроможною, якісною та безпечною харчовою продукцією. Зважаючи на цінний хімічний склад, спельтове борошно є перспективною сировиною рослинного походження, призначеною для вдосконалення м'ясних продуктів. Тому метою роботи було з'ясування особливостей структуроутворення варених сосисок та мікроструктуру їхніх складових, що виникають під час технологічної переробки при додаванні до ковбасного фаршу спельтового борошна, методами гістологічних досліджень, якими обґрунтовано мікроструктурний аналіз контрольних та дослідних зразків. У статті висвітлено результати досліджень мікроструктурного аналізу сосисок із додаванням спельтового борошна, яке впливає на структуроутворення варених сосисок, під час технологічної переробки. У статті наведено рисунки зрізів контрольних та дослідних зразків під мікроскопом. Вивчено та проаналізовано основні складові кутерованого фаршу, в якому міститься спельтове борошно, яке додавали з метою впровадження нових високотехнологічних рішень, які будуть конкурентними не тільки на українському, але й на європейському ринку. Проведеними дослідженнями гістопрепаратів контрольних проб кутерованного фаршу і зафарбованих гематоксиліном та еозином встановлено, що фарш представлений неоднорідною масою рожево-червоного кольору з численними вакуолями різноманітних розмірів і форм. На зрізах дослідних зразків виявляються включення спельтового борошна, які розташовані у вакуолях дуже подібні до вакуолей із тканинною рідиною, але на відміну від останніх вони мають волокнисту структуру. Встановлено, що за допомогою гістологічних досліджень, які складають основу мікроструктурного аналізу, можна чітко виявити усі складові м'ясного фаршу з якого виготовлені сосиски. Отримані результати досліджень дають змогу розширити асортимент сосисок, а використання спельтового борошна дозволяє збагатити готовий продукт такими біологічно-активними речовинами, як харчові волокна, природніми антиоксидантами, мікро- та макроелементами

Ключові слова: сосиски, спельтове борошно, гістологічні дослідження, фарш, мікроструктурний аналіз

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Application of the papain enzyme in meat products technology

Valentyna Israelian*, Nataliia Holembovska, Nataliia Slobodianiuk

National University of Life and Environmental Sciences
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Abstract. The production of enzyme preparations occupies one of the leading places in modern biotechnology and belongs to industries whose production volume is constantly growing, and the scope of application is expanding. Therefore, it is advisable to use enzymes for various industrial processes from an economic and technological standpoint. The main purpose of the study is to examine the chemical composition and activity of the enzyme preparation papain with subsequent use in the technology of meat products production to increase the biological value and improve the functional and technological properties of the finished product. The following research methods were used to solve these problems: moisture content – by drying the sample to a constant mass; fat content – by the Soxhlet method; ash content – by the generally accepted weight method; protein content – by the Kjeldahl method; papain activity was determined by a method based on the spectrophotometric determination of the number of proteolysis products under the action of an enzyme. Based on the results of the analysis of literature sources and own studies, the prospects of the research and use of enzymes and enzyme preparations obtained on their basis in the food industry are demonstrated, since this contributes to improving the quality of finished products and the level of greening of production, more rational use of raw materials and material resources. As a result of a study of the chemical composition, it was determined that the enzyme papain has a high protein content of 87.44%, so it has a broader effect on meat proteins. During the studies, the dependence of papain activity on the pH of the medium, temperature, sodium chloride and enzyme concentrations was investigated. The results of the conducted studies demonstrated that papain shows the greatest activity in the pH range of 5.5-6.0. The enzyme has a maximum collagenase activity of PH 6.0 and at a temperature of 50-60°C. The obtained results allow expanding the range of meat products, increasing the nutritional and biological value of raw materials, and obtaining a finished product with high organoleptic parameters

Keywords: enzyme preparation, papain, enzyme, biotechnology, safety

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**Corresponding author*

Relevance

Rational use of meat raw materials and the development of new products of high nutritional value and quality that are safe for the consumer is an urgent task of the meat processing industry in Ukraine and the world [1].

In the modern food industry, the trend of finding and developing innovative technological solutions for the production of products characterised by a high level of quality, environmental friendliness, biological safety, and functional orientation prevails [2].

Resource-saving food technologies are a real source of strengthening the raw material base of processing industries. The growing need for meat products leads to the need to involve raw materials with a high content of connective tissue in technological processes and search for ways to improve its technological properties [3], [4].

Today, scientific discoveries in the field of enzymology have made enzyme preparations an indispensable participant in many food technologies. The creation and implementation of innovative technologies allowed for substantially expanding the scope of the application of enzyme preparations. Today, enzymes help to improve product quality, increase the safety and efficiency of technological processes, reduce production costs and anthropogenic impact on the environment [5].

In food technology, enzyme preparations with amylolytic, proteolytic, lipolytic, pectolytic, and oxidase activity are used.

Of particular importance is the use of proteolytic enzyme preparations, since they are characteristic of high catalytic activity, the possibility of implementation without the use of extreme temperatures and aggressive media, the specificity of the action of enzymes, and the ease of inactivation at conventional temperatures of heat treatment of meat products [6].

Analysis of recent studies and papers

Technologies of meat products using biotechnology techniques based on enzymatic proteolysis of meat raw materials are widely used in international practice.

Today, the use of biotechnological techniques is a common practice in the United States, Canada, England, France, Germany, etc. Enzymes of proteolytic and collagenase action, in meat and meat systems enable [7], [8]:

- the intensification of autolytic processes and acceleration of maturation;
- provision of a high level of juiciness and tenderness of meat;
- an increase in the production of high-quality natural meat products;
- obtainment of new sources of meat resources in the form of meat pastes, emulsions, hydrolysates for enriching various food products with protein, developing therapeutic nutrition;
- use of meat products as part of prescription and component solutions instead of the main raw materials;
- rational and maximum use of meat resources to increase the yield of useful products per unit of raw materials.

Enzyme preparations must meet the requirements imposed by specific technologies not only for the type of catalysed reaction but also for the conditions of their action: pH, temperature, stability, the presence of activators and inhibitors, that is, those factors that

determine the effectiveness of the preparation in this environment and allow correctly determining the technological modes of its application [9].

Depending on the purpose of the application, certain requirements are imposed on enzyme preparations not only for the composition of enzymes and optimal conditions of their action, but also for the degree of purification, fillers used, cost, and a number of other parameters [10], [11].

The purpose of the study. Study the chemical composition and activity of the enzyme preparation papain with subsequent use in the production technology of meat products to increase the biological value and improve the functional and technological properties of the finished product.

Methods

The research was conducted in the laboratory of the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine.

For the research, the enzyme papain was selected, which is the most commonly used proteolytic enzyme in production, it is produced from the latex of the melon tree fruit (Carica papaya).

The experimental studies were conducted according to the established relevant standard methods: moisture content – by drying according to DSTU ISO 1442:2005 Meat and meat products. Method for determining the moisture content [12]; the amount of protein was determined according to GOST 25011-2017 Meat and meat products. Methods for determining protein [13]; the amount of fat was determined by DSTU 8380: 2015 Meat and meat products. Method for measuring the mass fraction of fat [14]; the mass fraction of ash was determined by weight according to DSTU ISO 936:2008 Meat and meat products. Method for determining the mass fraction of total ash [15]; papain activity was determined by a method based on the spectrophotometric determination of the number of proteolysis products of tyrosine-containing substances under the action of an enzyme.

Results and Discussion

The practice of using enzyme preparations shows that not all drugs have the same effect on the muscle and connective tissue proteins of meat, including raw materials with abnormal autolysis. The same enzyme preparation, depending on the reaction of the meat medium, hydrolyses protein macromolecules in different ways. Technologists are largely interested in questions concerning the effect of enzyme preparations on the connective tissue proteins of meat. Therewith, an important point is to investigate the effect of enzyme preparations on the structural and mechanical properties of meat raw materials, which ultimately affect the quality of the resulting finished products.

Of particular interest are enzymes that contribute to the formation of the structure of meat products. In this case, the choice of the papain enzyme for softening meat is primarily due to the specificity of its effect on connective tissue proteins and the fact that it is now presented on the internal market and is offered for use in the meat industry.

Any technological processes are influenced by various factors. Therefore, to identify the field of practical use of biocatalysts, an important aspect is to investigate the behaviour and stability of biologically active systems and find optimal parameters for their operating mode.

Based on this, restructuring meat is the purpose of proteolytic enzymes. Softening of meat is effective under the action of endogenous proteases, especially neutral ones. The total chemical composition of the enzyme papain is presented in Table 1.

Table 1. *Chemical composition of the enzyme papain, (n=3, pJ0,95)*

Indicator	Content, %			
	Moisture	Protein	Fat	Ash
Enzyme Papain	10, 86 ± 0,85	87, 44 ± 2,76	0,61 ± 0,05	0,87 ± 0,02

According to Table 1, the enzyme papain has a high protein content of 87.44%, so it has a broader effect on meat proteins. The enzyme papain is a tested preparation that has proven itself to accelerate the maturation and tenderisation of meat with a high content of connective tissue.

The most important indicators that characterise the effectiveness of various enzyme preparations on meat raw materials are structural and mechanical properties, which, in the end, characterise the tenderness of the finished product.

The dependence of papain on the pH of the medium was investigated to clarify the activity of the enzyme used in the study. The results of the conducted studies showed (Fig. 1) that the greatest proteolytic activity of papain is manifested at pH 5.5-6.0, and at pH 6, the enzyme has the maximum collagenase activity.

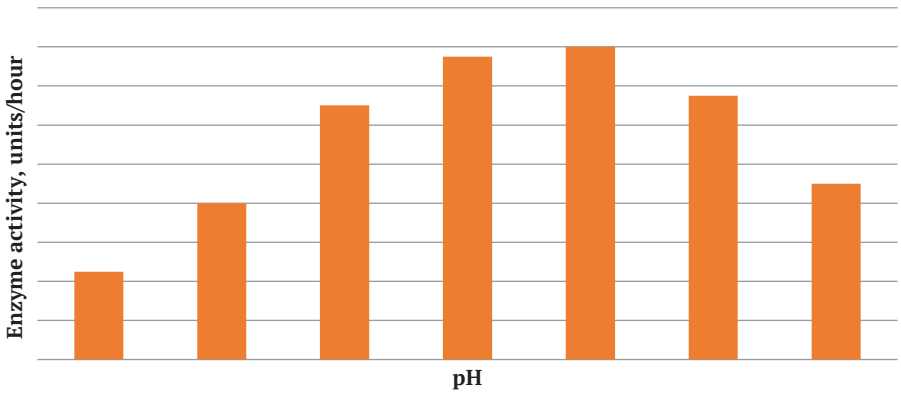

Figure 1. Effect of medium pH on papain enzyme activity

It is known that for the meat industry, the activity of the enzyme at temperatures of 2±2°C, recommended during salting, maturation of meat, and for storing finished products, is of practical interest. The effect of temperature on papain activity is displayed in Figure 2.

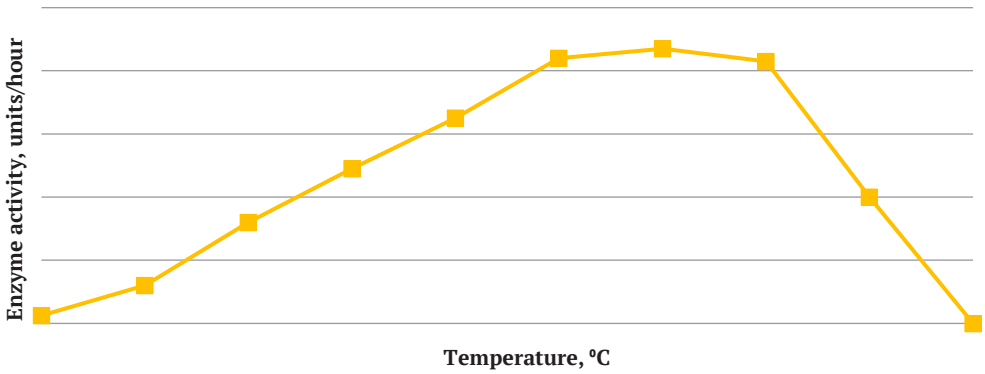

Figure 2. Effect of temperature on papain activity

Notably, the collagenase activity of papain in this experiment was recorded after 60 minutes of hydrolysis and therefore it is necessary to regard the "short-term activity", that is, the highest specific activity of papain at each specific temperature. The obtained data showed that papain shows maximum activity at temperatures of 50-60°C. At t=4°C, the activity of papain is 6.0% of the maximum value. According to the results of studies, complete inactivation of papain occurs at t=90°C. It is known from the literature sources that during the production of meat products, the maturation of raw materials occurs in the presence of sodium chloride, which increases or decreases the activity of proteolytic enzymes. In this regard, the effect of sodium chloride on papain activity was investigated. The dependence of the activity of the papain enzyme on the NaCl concentration is shown in Figure 3.

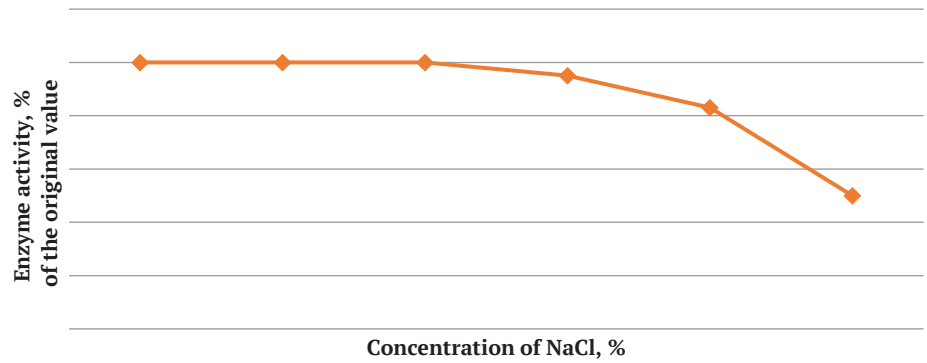

Figure 3. Dependence of papain enzyme activity on NaCl concentration

The results of research suggest that the plant enzyme papain can be used to tenderise meat. The greatest proteolytic activity of papain is manifested at pH 5.5-6.0, temperatures 60-80°C, and NaCl concentrations of approximately 2%, which are used for boiled meat products. The use of the enzyme papain for the fermentation of ostrich meat will increase the production of high-quality whole meat products.

Conclusions and Prospects

The obtained research results allow concluding that the use of the enzyme papain for the production of meat products is promising for the rational use of raw materials and the development of new types of meat products with high quality indicators.

During the studies, the dependence of papain activity on the pH of the medium, temperature, sodium chloride concentration, and enzyme concentration was investigated. The results of the conducted studies demonstrated that papain shows the greatest activity in the pH range of 5.5-6.0. The enzyme has a maximum collagenase activity at PH 6.0 and at a temperature of 50-60°C. Enzyme activity at 2±2°C.

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Застосування ферменту папаїну в технології м›ясних виробів

Валентина Миколаївна Ісраелян, Наталія Володимирівна Голембовська, Наталія Михайлівна Слободянюк

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Виробництво ферментних препаратів займає одне з провідних місць у сучасній біотехнології й належить до галузей, обсяг продукції яких постійно зростає, а сфера застосування розширюється. Тому ферменти доцільно використовувати для проведення різних промислових процесів, як з економічної, так і з технологічної точок зору. Основна мета роботи спрямована на дослідженні хімічного складу та активності ферментного препарату папаїн із подальшим використанням у технології виробництва м›ясних виробів для підвищення біологічної цінності та покращення функціонально-технологічних властивостей готового продукту. Для вирішення поставлених завдань використовували такі методи досліджень: вміст вологи – методом висушування зразка до постійної маси; вміст жиру – методом Сокслета; зольність – загальноприйнятим ваговим методом; визначення вмісту білка – методом К'єльдаля; активність папаїну визначали за методом, заснованим на спектрофотометричному визначенні кількості продуктів протеолізу під дією ферменту. За результатами аналізу літературних джерел та власних досліджень показано перспективність дослідження та використання ферментів і одержаних на їхній основі ферментних препаратів у галузі харчової промисловості, оскільки це сприяє підвищенню якості готової продукції та рівня екологізації виробництва, більш раціональному використанню сировинних та матеріальних ресурсів. У результаті дослідження хімічного складу встановлено, що фермент папаїн має високий вміст білку 87,44 %, завдяки чому володіє більш широким впливом на білки м'яса. Під час досліджень була вивчена залежність активності папаїну від pH середовища, температури, концентрації хлориду натрію і концентрації ферменту. Результати виконаних досліджень показали, що найбільшу активність папаїн проявляє в діапазоні за pH 5,5-6,0. Фермент має максимальну коллагеназну активність pH 6,0 та за температури 50-60 °C. Отримані результати досліджень дають змогу розширити асортимент м'ясних виробів, підвищити харчову і біологічну цінність сировини, отримати готовий продукт з високими органолептичними показниками

Ключові слова: ферментний препарат, папаїн, фермент, біотехнологія, безпечність

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Influence of marinade based on vegetable oil blends on the structural-mechanical parameters of natural marinated meat semi-finished products

Oksana Shtonda*, Kateryna Semeniuk, Viktoriia Kulyk

National University of Life and Environmental Sciences of Ukraine,
03040, Heroiv Oborony Str., 15, Kyiv, Ukraine

Abstract. Marinades based on vegetable oil blends for the production of natural marinated meat semi-finished products substantially affect the rheological and structural-mechanical parameters of the product. They determine the plasticity and consistency of semi-finished products made from raw materials of grades 1 and 2. Therefore, the purpose of the study was to develop recipes for marinades and establish the effect of marinade based on blends of vegetable oils enriched with the enzyme bromelain on the structural and mechanical parameters of natural marinated meat semi-finished products during storage. The research developed 8 samples of semi-finished products, namely: 4 samples using pork: 1 control sample without marinade and 3 samples with marinades based on vegetable oil blends; and 4 samples using beef: 1 control sample without marinade and 3 samples with marinades based on vegetable oil blends. In this regard, it was concluded that it is advisable to use blends of vegetable oils and enzymes in the marinade. An additional effect on natural marinated meat semi-finished products is the better organoleptic and structural-mechanical indicators in comparison with control samples. It was identified that the consistency of semi-finished beef products during the storage period becomes more tender compared to the control sample. It was proved that the plasticity of semi-finished pork products compared to the control sample decreased, which indicates an increase in meat hardness. The results of the study of the plasticity of marinated semi-finished products increased compared to the control sample, which indicates a decrease in meat hardness. The use of vegetable raw materials in the technology of natural marinated meat semi-finished products allows using meat raw materials of grades 1 and 2 and getting a tender, juicy, easily digestible product at the output

Keywords: meat, oil, blend, penetration stress, plasticity, enzyme, hardness of semi-finished products

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**Corresponding author*

Relevance

The structure of the consumer market is changing very quickly. All over the world, there is a tendency to offer consumers a product that requires minimal cooking time. In this regard, semi-finished products and fast food products are becoming more and more popular, simultaneously not losing the biological and nutritional value of the product (Cai *et al*., 2018).

Most of the vital processes of the human body depend on nutrition. Meat and meat products are the most complete food products because they are necessary as a material for building tissues, synthesis, metabolism, and energy (Doneva *et al*., 2018).

Scientists have long proven that nutrition is one of the main factors affecting human health. The nutritional value of meat depends on the amount and quality of proteins (amino acids) and the presence of fats in it. Fats, along with proteins and carbohydrates, form the basis of plastic material for building all cells and tissues of the body. It is important to expand the range of food products, especially meat, not only by replacing animal raw materials with vegetable ones, thereby worsening the nutritional and biological value of the product, but also to approach this issue in a comprehensive way. That is, in the case of improving the product technology, it is necessary to consider all possible options for the influence of all components not only on the product quality indicators but also on the human body (Semeniuk & Shtonda, 2021a).

The use of enzymes with specified properties leads to a substantial increase in the biological and technological functionality of collagen-containing raw materials, allowing for partially replacing the main raw materials, and improving the properties and yield of products due to the conversion of the structure of proteins and the transformation of the properties of complex biological systems in the production of meat products – a well-known source of high-grade protein in diets.

Studies analysis

The unforgettable aroma of fresh meat crackling on a hot grill awakens the appetite and promotes experiments. It remains only to endlessly experiment with the marinade.

The technology of natural marinated meat semi-finished products involves the use of various types of raw materials of animal and vegetable origin.

During the production of natural meat marinated semi-finished products, an important component is the development of marinade. An important place in the technology of marinated semi-finished products is occupied by marinades in liquid form, in particular, made based on blends of vegetable oils. Due to the use of vegetable oil during marinating meat, the effect of the acid used is softened, and the aromas of added spices are well dissolved. Seeping through the structure of the meat, the oil gently envelops the meat, sealing moisture, not allowing it to dry out during further cooking. (Borsolyuk *et al*., 2019; Jinap *et al*., 2018).

When developing a new food product, special attention is paid not only to its biological value but also to the formation of the necessary structural and mechanical indicators.

The use of marinades based on blends of refined vegetable oils gives the product the necessary consistency, ensures the formation of taste and aroma, the enrichment of blends of vegetable oils with the enzyme bromelain allows accelerating the maturation and softening

of meat by 2-2.5 times (Tyshchenko *et al.*, 2019; Semeniuk and Shtonda, 2021b; Semeniuk & Shtonda, 2018).

Verbytskyi S.B., Shevchenko V.V., Gotsyk T.P., Bandurenko G.M. identified that table salt with food acids is used to improve the preservative effect. The most used is acetic acid, but in the food industry it is also allowed to use malic, lactic, citric, and orthophosphate acids in marinades. (Ivankin *et al.*, 2020; Jung *et al.*, 2018).

Peshuk L.V. considered the degree of softening and detection of the maximum shift of marinated wild boar meat. Food acids, interacting with meat, give it a pleasant specific taste and aroma, and also break down proteins and fats, which gives softness to raw materials. Acids and their salts are used as technical food additives to regulate pH during the technological process. Thus, the use of food acids and their salts gives taste, aroma, colour; preserving effect and forming consistency (Ivankin *et al.*, 2020; Obajuluwa *et al.*, 2020; Wie *et al.*, 2020; Wang *et al.*, 2020).

The purpose of the study is the determination of structural-mechanical parameters, namely penetration stress and plasticity, of natural marinated meat semi-finished products, which show the feasibility of using the blends of vegetable oils and an enzyme of vegetable origin in the production of marinated meat semi-finished products.

Materials and Methods

For the study, the following was used: beef meat, pork meat, rapeseed oil, olive oil, sunflower oil, the enzyme bromelain, crushed and dried herbs and spices.

The degree of penetration was determined on an Ulab 3 – 31 M penetrometer, in accordance with (GOST R 50814-95, 2010).

The determination of the plasticity index was conducted using the pressing method (Keniiz *et al.*, 2019).

Results and Discussion

For the meat industry, the most interesting are enzymes that affect meat proteins at the appropriate pH of the medium (which is inherent in meat and meat products) and temperatures characteristic of refrigeration and heat treatment of meat, and information about the properties of their effect on the collagen of internal connective tissue. Marinade based on blended oils enriched with the enzyme bromelain has a substantial effect on the consistency of the product. Recipes for multifunctional marinades are shown in Table 1.

Table 1. *Options for multifunctional marinades*

Ingredient name	Sample No.1	Sample No.2	Sample No.3
Turmeric	+	+	+
Roman cumin	+	+	+
Paprika	+	+	+
Black pepper	+	+	+
Red pepper	+	+	+
Fennel	+	+	+
Coriander	+	+	+
Bay leaf	+	+	+
Onion	+	+	+
Cumin	+	+	+

Table 1. Continued

Ingredient name	Sample No.1	Sample No.2	Sample No.3
Ginger	+	+	+
Sodium Ascorbate	+	+	+
Salt	+	+	+
Sugar	+	+	+
Rapeseed oil	+	-	-
Blend No.1 (sunflower : rapeseed oil)	-	+	-
Blend No.2 (sunflower : olive oil)	-	-	+
The enzyme bromelain	+	+	+
Yeast extract	+	+	+

The degree of penetration (penetration stress) of all prototypes during the storage period was determined to confirm this fact, which is shown in Fig. 1 and 2. Samples No.1, No.2, No.3, No.4 – semi-finished pork products, samples No.5, No.6, No.7, No.8 – semi-finished beef products.

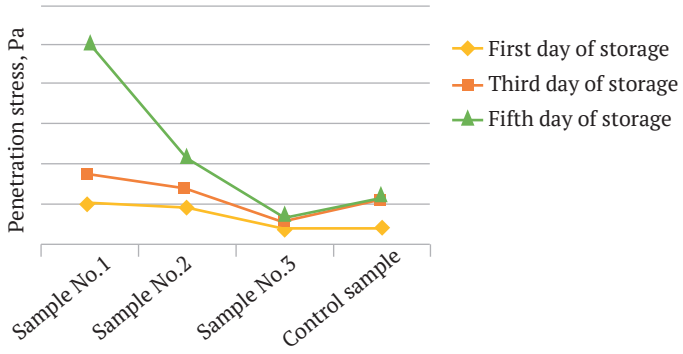

Figure 1. Change in the penetration stress of semi-finished pork products depending on the storage period

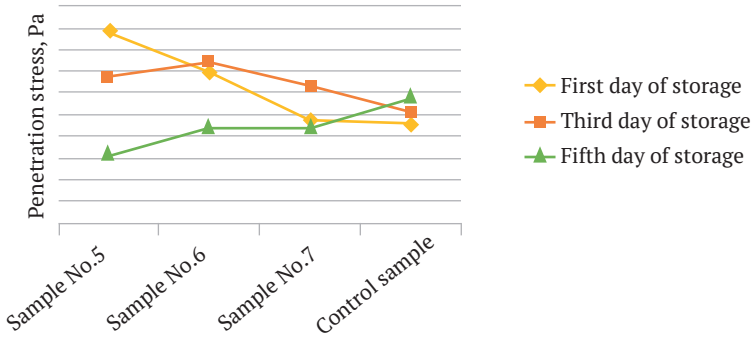

Figure 2. Change in the penetration stress of semi-finished beef products depending on the storage period

The results of determining the penetration stress show that the consistency of semi-finished beef products becomes more tender during the storage compared to the control sample.

An important indicator of a marinade based on vegetable oil blends enriched with the enzyme bromelain is a decrease in the hardness of semi-finished products, so the plasticity of the samples was determined on the first and third days of storage, as shown in Fig. 3 and 4. Plasticity is the ability of a product to undergo irreversible deformations (the original shape changes, and after the external action ceases, the new shape is preserved).

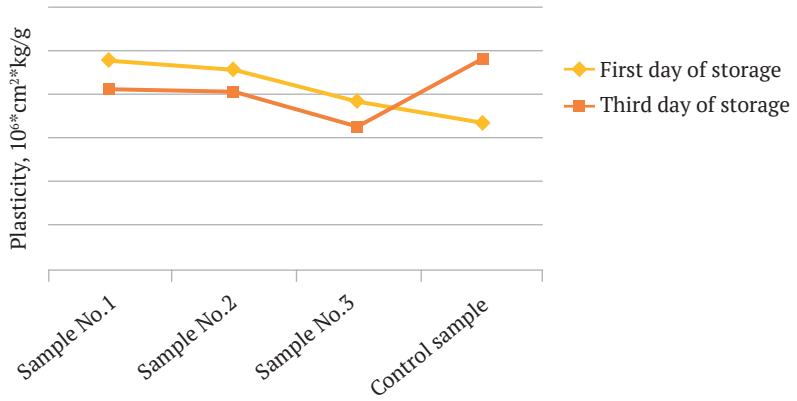

Figure 3. Changes in the plasticity of semi-finished pork products depending on the storage period

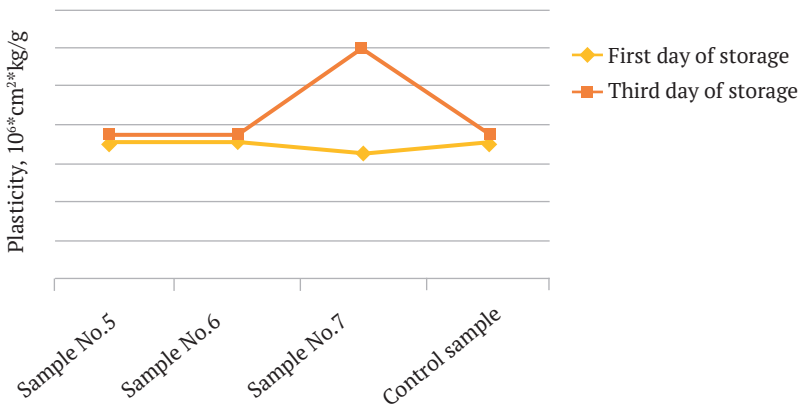

Figure 4. Change in the plasticity of semi-finished beef products depending on the storage period

The results of the studies shown in Figure 3 demonstrate that the plasticity of semi-finished pork products compared to the control sample decreased, which indicates an increase in meat hardness. The results shown in Fig. 4, demonstrate that the plasticity of marinated semi-finished products increased compared to the control sample, which indicates a decrease in meat hardness.

The use of enzyme preparations in the meat processing process allows for substantially accelerating a number of biochemical reactions and opens up interesting prospects for modifying and intensifying processing, accelerating softening, and increasing the tenderness of tissues.

Conclusions and Prospects

The results of the examination of structural-mechanical parameters of natural meat marinated semi-finished products showed that pork products have a tender, juicy consistency at the beginning of the storage period, this is due to the structure of muscle fibres and a large content of adipose tissue. Beef products are more tender and juicy in the middle and at the end of the storage period, because they have a rough structure of muscle fibres and a substantially lower fat content compared to pork. The use of bromelain in the technology of semi-finished meat products will increase the biological value of products, reduce the maturation time of meat, and will also contribute to better and faster fermentation of the product.

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Вплив маринаду на основі купажів рослинних олій на структурно-механічні показники натуральних м'ясних маринованих напівфабрикатів

Оксана Анатоліївна Штонда, Катерина Миколаївна Семенюк, Вікторія Костянтинівна Кулик

Національний університет біоресурсів і природокористування України, 03040, вул. Героїв оборони 15, м. Київ, Україна

Анотація. Маринади на основі купажів рослинних олій для виробництва натуральних м'ясних маринованих напівфабрикатів суттєво здійснюють вплив на реологічні та структурно-механічні показники продукту. Саме вони визначають пластичність та консистенцію напівфабрикатів, виготовлених із сировини 1 та 2 гатунків. Тому метою роботи була розробка рецептур для маринадів та встановлення впливу маринаду на основі купажів рослинних олій, збагачених ферментом бромелаїном на структурно-механічні показники натуральних м'ясних маринованих напівфабрикатів у процесі зберігання. Дослідженнями було розроблено 8 зразків напівфабрикатів, а саме: 4 зразки із використанням свинини: 1 контрольний зразок без застосування маринаду та 3 зразки із маринадами на основі купажів рослинних олій; та 4 зразки із використанням яловичини: 1 контрольний зразок без застосування маринаду та 3 зразки із маринадами на основі купажів рослинних олій. У зв'язку з цим прийшли до висновку про доцільність застосування в складі маринаду купажів рослинних олій та ферменту. Додатковим впливом на натуральні м'ясні мариновані напівфабрикати є кращі органолептичні та структурно-механічні показники в порівнянні із контрольними зразками. З'ясовано що консистенція напівфабрикатів зі яловичини впродовж терміну зберігання стає ніжніша у порівнянні з контрольним зразком. Доведено, що пластичність напівфабрикатів зі свинини проти контрольного зразка зменшилась, що свідчить про збільшення жорсткості м'яса. А результати дослідження пластичності маринованих напівфабрикатів збільшились порівняно з контрольним зразком, що свідчить про зменшення жорсткості м'яса. Застосування рослинної сировини в технології натуральних м'ясних маринованих напівфабрикатів дає можливість використовувати м'ясну сировину 1 та 2 гатунків та на виході отримати ніжний, соковитий, легкозасвоюваний продукт

Ключові слова: м'ясо, олія, купаж, пенетраційна напруга, пластичність, фермент, жорсткість напівфабрикатів

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Development of a propolis collecting device

Roman Dvykaliuk*, Leonora Adamchuk

National University of Life and Environmental Sciences of Ukraine
03040, Heroiv Oborony Str., 15, Kyiv, Ukraine

Abstract. Propolis is a sticky resinous substance collected from buds, leaves, stems of wild plants and processed by bees, which has bactericidal properties and which they use to seal cracks in the hive, polish the walls of wax cells, embalm the corpses of enemies. The analysis of research and publications gives grounds to conclude that Ukraine has not yet paid sufficient attention to the conditions of propolis production. No devices or equipment to improve the process of production of safe and high-quality propolis, which will meet the high requirements of regulatory acts on the quality and safety of food products and raw materials, are available today. Currently, apiaries use methods of collecting propolis, which require considerable human labor, are not economically efficient, and the resulting product does not meet the quality requirements of market operators. Therefore, there is a need to improve existing technologies for obtaining propolis, to ameliorate sanitary-hygienic conditions of production, to increase productivity and economic efficiency, mechanization, and automation of the production process. The goal of the present work was to develop a new propolis collecting device. The study was carried out as a part of the thesis research at the Department of Standardization and Certification of Agricultural Products of the National University of Life and Environmental Sciences of Ukraine during 2020-2021. A new propolis collecting device has been designed and manufactured. The design of the device shafts and the principle of mechanical cleaning of the grids from the propolis, laid down during its development, can be used to develop highly automated lines for cleaning the grids. The use of the device in industrial apiaries in countries with tropical and subtropical climates is possible by placing the device in honeycomb storage, if available, or in a manufacturing area equipped with air conditioning. For a good cleaning of the grids with propolis using the device, it is sufficient to cool the grids at a temperature of +5°C for 60-90 minutes, depending on the type of propolis. The device can be used at apiaries in Ukraine and in other countries where the production of propolis from bee colonies is carried out using elastic grids. The use of the device ensures the production of pure propolis without mechanical impurities, which meets the requirements of current legislation. The developed device is patented, a patent No. 139736 “Propolis collecting device”

Keywords: propolis, grid cleaning process, device, quality

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**Corresponding author*

Introduction

Production in the field of beekeeping is aimed at reducing human labor costs in the technological process and thus increasing profitability. At the same time, minimization of the presence of human labor and human contact with raw materials and products minimizes the risks associated with deterioration of sanitary-hygienic conditions of production. The number of bee colonies kept in the apiaries affects the number of employees involved, the time spent on servicing one bee colony, the time devoted to proper sanitary-hygienic conditions of production, the rate of return in production. Today, according to the Register of apiaries in Ukraine (https://dpss.gov.ua/diyalnist/reyestrividkritidani), 8% of apiaries keep up to 10 bee colonies, 39% – up to 30, 24% – up to 50, 20% – up to 100, 7% – up to 200, 2% more than 200. The apiaries with the number of bee colonies from 100 can be attributed to industrial apiaries, which is 29% of the total number of registered apiaries in Ukraine. Therefore, there is a need to develop, research, and implement in production of industrial and automated equipment for the production and obtaining of beekeeping products and propolis. The analysis of research and publications gives grounds to conclude that today, not enough attention has been paid to the conditions of propolis production in Ukraine. There are no devices and equipment to improve the process of production of safe and high-quality propolis, which will meet the high requirements of regulatory acts on the quality and safety of food products and raw materials.

Analysis of Recent Researches and Publications

Propolis is a sticky resinous substance collected from buds, leaves, stems of wild plants and processed by bees, which has bactericidal properties and which they use to seal cracks in the hive, polish the walls of wax cells, embalm the corpses of enemies (mice, reptiles, etc.) **(**DSTU 4662:2006). Propolis as a raw material is used in the food, pharmaceutical, and other industries (Karabaş *et al.*, 2020; Özer, 2020; Safaei & Azad, 2020; Sahlan *et al.*, 2020;). In the temperate climate zone in which Ukraine is located, honeybees collect plant resins mainly from *Populus nigra* L., *Populus tremula* L., *Betula pubescens* L., which determines their chemical and physical properties. Subsequently, bees transfer plant resins into the nest and use them for sealing cracks or as a building material (Denis *et al.*, 2011; de Groot, 2013; Isidorov *et al.*, 2016; El-Guendouz *et al.*, 2019). The chemical composition of propolis, specifically 344 chemicals are identified to date in samples collected by bees from *Populus* spp. and they determine its value as raw material and the use of this product by humans (de Groot *et al.*, 2014).

Obtaining propolis from bee colonies is carried out today in two known ways: a) by cleaning the elements of the hive (frames, bee entrance, and inner covers); b) the use of special tools (grids, gratings, and collectors) for the accumulation of propolis, considering the known biological instincts of bees (Osipitan *et al.*, 2012; Lima *et al.*, 2015, Okhale *et al.*, 2021). Cleaning the elements of the hive is carried out with a hive tool and may be inefficient and expensive way to collect propolis. Because during cleaning, propolis gets mechanical impurities: parts of bees' exoskeleton, wooden fragments of hive elements, wax.

In countries with tropical climate, the production of propolis is carried out using collectors of different designs (de Ayala *et al.*, 2019). The collectors are based on the instinct of bees to seal holes and cracks to prevent pests and enemies from entering the nest and restore the mi-

croclimate of the bee nest. Collectors Intelligent Collector of Propolis (CPI), Pirassununga, Marco Propolizador, Cuadro Propolizador are made in the form of a frame (cover) with openings of different sizes and a way to increase these openings as they are filled with propolis. The productivity of propolis collection using collectors depends on many factors and averages 600-1000 g of propolis per month (Jonathan, 2015; de Ayala *et al*., 2019). Cleaning of collectors from propolis is carried out manually with a knife, dismantling or without dismantling. From non-demountable collectors (frames), workers cut propolis in specially designated areas without automation and mechanization of the collector cleaning process (Breyer *et al*., 2016).

The Campechano (Mexico) method of propolis collection or the Sarrafo method (Brazil) involve the placement of bars measuring 2x3 cm and a length of 45 cm on both sides of the upper body of the hive. Propolis productivity is determined to be 960 g per year with the cleaning of collectors every week with a stainless-steel knife (Lima *et al*, 2015; de Ayala *et al*., 2019).

Ra'ed *et al*. (2008) proposed and investigated a modification of the hives of the Langstroth system placing in the side and rear wall metal sheets with slots of 4 mm with a distance between them of 10 mm. According to the results of the study, propolis productivity was highest in the sheets located in the side part of the hive and averaged from 91.92 to 96.60 g.

De Ayala *et al*. (2019) note several disadvantages in the use of collectors. Among the main obstacles to the adaptation of the collector use in temperate climate zone, there should be distinguished such factors as the formation of gaps with significant size, which cannot be used in countries with temperate climate due to cooling the honeybees' nest; the use of external collectors is accompanied by contamination of the product with mechanical impurities carried by wind gusts; the accumulation of propolis in the temperate climate zone by honey bees occurs in the second half of the beekeeping season, which coincides with the preparation of bee colonies for the winter and is accompanied by increased aggressiveness of bees; the formation of holes in the constructions of hives will intensify the attack of bees and may lead to the death of bee colonies.

The selection of propolis from bee colonies in Ukraine and many countries is also carried out using plastic gratings, grids, and canvases. These tools are placed above the nest of honeybees so that the bees have access to them to deposit propolis. Gratings and grids contain holes usually 1.6 mm wide. The grids and gratings are frozen for cleaning and subsequently, the propolis is knocked out or scraped (Tsagkarakis *et al*., 2017; Bankova *et al*., 2019; Mountford-McAuley *et al*., 2021). Water is used to purify propolis from wax and other mechanical impurities. Propolis is frozen and crushed and then mixed with water. Wax that has risen above the water's surface is removed, and propolis is dried on metal sieves (Bankovskiy *et al*., 2009). Solvent-based grid cleaning is not used because the water solubility of propolis at various temperatures ranges from 7% to 11% in ethyl alcohol from 50% to 70%, respectively, which affects the quality of the raw material and excludes certain uses (da Silva *et al*., 2011; Sukhanova *et al*., 2014).

Sadovnik (1982) proposed a line for obtaining propolis by cleaning canvases. The line consists of the SIP-55 brand machine, the SIP-up machine, the manual toothed roller, the Veterok-3 vacuum cleaner, the TsKL-1 centrifuge, the OKS-030 hydro-press. This equipment is not manufactured or sold on the market, and fabric canvases are not used in modern apiaries in Ukraine.

Polezhaikin *et al*. (2005) developed a propolis collecting device from propolized fabric

canvases. According to their technology, propolis canvases covered by bees are selected, sewn into a solid strip, wound on the reel of the device and in the process of cleaning cooled to -10°C using a liquid cooling agent. Tuktarov *et al*. (2017) proposed a device for cleaning linen canvases from propolis. The device is made in the form of a mouthpiece for household power tools, which involves cleaning the canvases with knives mounted in it.

The disadvantages of these devices are that the propolis contains mechanical impurities of the canvas particles. This affects the quality of the product and requires additional time to clean it.

Thus, now, the apiaries are using methods of collecting propolis, which require considerable human labor, are not economically efficient, and the resulting product does not meet the quality requirements of market operators. Therefore, there is a need to improve existing technologies for obtaining propolis, to improve sanitary-hygienic conditions of production, to increase productivity and economic efficiency, mechanization, and automation of the production process.

The goal of the present work was to develop a new propolis collecting device. In order to achieve the goal, the following tasks were set: a) to carry out research on scientific publications, to perform patent searches, to review catalogs of leading manufacturers of equipment, existing technologies and propolis collecting devices; b) to develop an experimental 3d model of the device; c) to make a prototype of the device for the preliminary laboratory test; d) according to the results of laboratory tests, if necessary, to refine the 3d model with the subsequent adjustment of the prototype of the device (re-production).

Materials and Methods

The work was carried out as part of thesis research on "Scientific and technical support of the process and equipment of propolis production" at the Department of Standardization and Certification of Agricultural Products of the National University of Life and Environmental Sciences of Ukraine during 2020-2021.

The analysis and synthesis of scientific information were performed using the Torraco (2005) method using the Springer scientific metric base and the Google Scholar search tool. The patent search was performed at our request by the patent-legal firm PRIMA VERITAS (https://prima-veritas.ua). Catalogs of beekeeping equipment manufacturers have been processed: Thomas Apiculture, Lyson, Melissa-93, ABB-100, PVIK Pavik, Civan, Park Plus, ICKO, Bienen-Voigt & Warnholz, Giordan Srl, Logar, Prestige Stainless, Boutelje Products, Dadant, Maxant.

The *focal object method* was used to develop an experimental device (version 1.1). The essence of the method is to transfer the features of randomly selected objects to the object being improved (Krupa & Lytvyn, 2016). The focal object in the development of the device was a machine for cleaning the painted canvases proposed by Sadovnikov (1982) – SIP-up.

The *device was modeled* using the COMPAS-3D v19.0.16 software by solid modeling method (Requicha, 1980; Requicha & Voelcker, 1982) with subsequent preservation of the device modeling results into files for 3d printing (format: *.stl) and laser cutting of metal (format: *.sdr).

Making an experimental model of the device. The framework of the device was made of profiled square metal pipe measuring 15x15x1.8 mm. The pipes were connected by manual arc welding using a Paton VDI-MINI 150 DC welding inverter. Subsequently, the framework was covered with metal sheets 0.45 mm thick and painted. The sheet metal was attached with aluminum rivets. A set of gear trains, a motor, and shafts were mounted

and installed on a preparatory frame. The moving machinery, shafts, and motor were covered with a metal casing made of sheet metal.

Making an experimental model of the device. The framework and other elements of the device (version 1.2) are made using additive technologies (3D printing) (Lazebnyi *et al*., 2020). A strong ABS pro polymer was applied to make the framework. The protective chamber that comes in contact with the product is made from environmentally safe PLA plastic. The elements of the built-up shafts of the device were made of stainless steel in accordance with the developed drawings with the use of laser cutting of metal. The metal framework of the device is made of steel with holes for mounting a set of gear trains, 2 electric motors, two pairs of built-up shafts, a protective chamber, and the device body and a handle.

The *device was tested* at the Department of Standardization and Certification of Agricultural Products of the National University of Life and Environmental Sciences of Ukraine. Grids covered with propolis and collected from the authors' apiary in Kyiv Oblast, Ukraine were used to test the device (version 1.1). Subsequently, 75 grids covered with different types of propolis from Ukrainian apiaries in a total of 24 oblasts of Ukraine were obtained for testing the device (version 1.2).

Results of the Research and Discussion

A review of the scientific literature concluded that no industrial equipment was produced for propolis production. The catalog 2021 of BIENEN-VOIGT & WARNHOLZ contains a proposal for the implementation of new development (device) for purifying plastic gratings from propolis. The device offered by the company is a plastic manual propolis stamp (Propolis Stamp) from the grating. The patent search conducted by the patent-legal firm "PRIMA VERITAS" testifies that there are no useful models and industrial prototypes of use in Ukraine that would allow receiving propolis.

The general form and principle of shaft operation of the machine were transferred to the selected focal object to produce a wave-shaped metal profile, the dimensions of which were adapted to the given tasks. The following criteria are met, which must have the experimental model of the device: a) will allow for the rapid cleaning of propolis from the grids without further preparation; b) it will not contain rapidly worn elements requiring additional financial costs for the maintenance of the device; c) be mobile with the possibility of usage in different production conditions; d) can be used at industrial and recreational apiaries; e) excludes manual work on the cleaning of propolis; f) is made of materials which do not affect the chemical, physical, and mechanical properties of propolis; g) enables reuse of the same grids in subsequent production cycles; h) maintainable.

The solvent-based cleaning of the grids was not considered because it affects the quality of the product. The base was a mechanical bend of elastic propolis grids with pre-cooling.

Device modeling. Propolis has increased adhesion (gluing), which depends on temperature, a contact area of propolis with the surface, pressure force and time. The average value of the adhesion of propolis in contact with steel is 2.29 J/m^2, while with glass – 2.96 J/m^2. The tests were carried out at room temperature of 24°C with a specified load of 5 mN and without delay between contact time and take-off time. The work of propolis adhesion on contact with glass (reference standard) and the increase of the contact time to 60 s at a temperature of 24°C and a specified load of 5 mN increases from 2.96 J/m^2 to 6.72 J/m^2. The radius of contact at maximum load was 36.06±17.14 μm (Saccardi *et al*., 2021). These physico-chemical

characteristics of propolis were considered in the design of shafts (Nekrashevich, 2005; Chursinov, 2006; Matin *et al.*, 2016). The contact time of propolis is directly proportional to the work of propolis adhesion, which was considered in the design of a set of gear trains that transmit torque from engines to the shafts.

An experimental model of the device (Fig. 1), consisting of a metal framing on which one pair of shafts was placed, has been developed. The shafts are made in such a way that the protrusions on one of them enter the gaps between the protrusions of the other shaft, and the grid passing between them is mechanically bent in a wave-like form. The torque from the electric motor is transmitted to the shafts through a set of gear trains. The shafts rotate opposite each other and intake the grid with propolis without the need for additional supply thereof. The intake of a grid by shafts is caused by a design of shafts sheets proposed. The motor, a set of gear trains, and shafts are mounted in the metal framing of the device and placed on a stand made of metal quadrilaterals. The tray for grids is inserted into the framing of the device by horizontal movement. As a result of modeling, an experimental model of the device was designed and subsequently manufactured (Fig. 1 (A)).

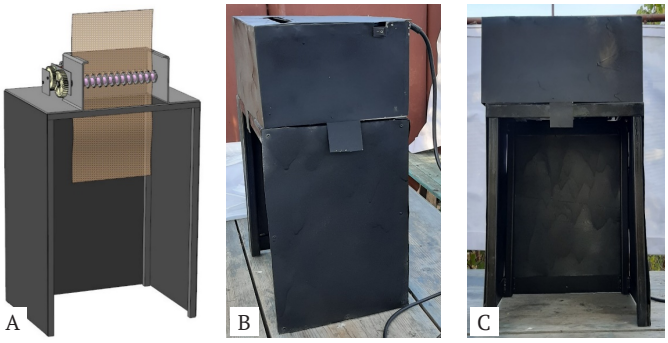

Figure 1. Experimental Model of Propolis Collecting Device (version 1.1): A – cut-away 3d Model of Propolis Collecting Device; B – lateral view of the manufactured device; C – profile view image of the device

The principle of device operation (Fig. 1). The device works as follows: propolized grids removed from the honeybee nest are cooled at +5°C for 60-90 min in a cooling chamber and are removed. The operator places the tray in the tray compartment and turns on the device. The cooled grids are alternately inserted by the operator into an opening located at the top of the device. The rotating shafts bend the grids in a wave-like form, so the propolis is separated from the grids and crumbled in the tray. The grids pass through the device and fall into the tray. The tray is in the lower part of the device.

Preliminary laboratory tests of the device (version 1.1) were performed by cleaning the elastic grids from propolis with pre-cooling. Several disadvantages of the experimental device (version 1.1) have been identified. When modeling and manufacturing the device, the need to provide a protective chamber of the shafts was not considered, which led to the ingress of propolis into the mechanisms of the device. The peculiarities of propolization of grids by honeybees are that the grid with propolis has a front and back side. The bending of the grid by a wave-shaped pair of the built-up

shafts of the device causes one side of the grid to bend outwards and, at a certain distance, the same side inwards. This wave-like bending results in incomplete purification of the grid from the propolis during a cycle of passing a grid through the set of device shafts. To completely purify the grid from propolis using the experimental device model (version 1.1), the grid should be passed through the device 2-3 times.

Based on the results of the laboratory tests of the experimental model (version 1.1), it was decided to improve the device (Fig. 1). It was determined that the device model (version 1.1) needed to be equipped with a protective shaft chamber to limit the propolis ingress into the mechanism of the device. Considering the results of laboratory tests of the device (version 1.1), it was established that it was necessary to design and manufacture a device with two pairs of shafts arranged one pair under the other. The elements of the second pair of built-up shafts are arranged in such a way towards the first one in order to ensure the reverse bending of the same section of the grid. Thus, the same part of the grid that passes through the upper pair of shafts and bends outwards and it bends inwards as it passes through the lower pair of shafts. In addition, the need to reduce the weight of the device was identified, so that it can be moved more easily within production if necessary.

The main technical characteristics of the device. Based on the modeling results, a device for further testing and evaluation of the effectiveness of design solutions was constructed (Fig. 3). The structural design of the built-up shafts of the device (Fig. 2 (2)) consists of a pair rotating oppositely to each other and retracting the grid independently, without the need to install additional mechanisms for its supplying. This approach in shaft design provides a simplified design of the device and minimizes elements that should be repaired and maintained in the future. The grid covered with propolis as it passes through the upper pair of the shafts bends in a wave-shaped form and the same section bends outwards and inwards when passing through the lower pair of the shafts. This solution provides improved cleaning of the grid, considering the bee ethology during the accumulation of propolis in the grids that we have observed. A set of gear trains and motors provide a speed of the grid of 2.5 m/min. To reduce propolis contact time with the shaft elements, rotation thereof with the aid of motors and a set of gear trains (Fig. 2 (1, 3)) is ensured at a speed of 60 m/min and this reduces the adhesion work.

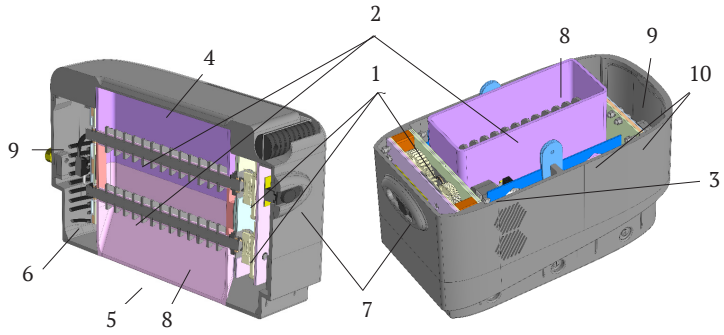

Figure 2. Experimental 3D Model of Propolis Collecting Device (version 1.2):
1 – a set of gear trains; 2 – lower and upper pair of shafts, the protrusions of which enter into each other; 3 – electric motor; 4 – propolis grid insert opening; 5 – outlet; 6 – electric cable; 7 – switch; 8 – protective chamber; 9 – power supply cable compartment; 10 – metal framing

To verify the effect of the shafts on the grid mechanical condition, a test with a passage of the grid through the device shafts in 100 cycles was conducted, and no visual mechanical damage was detected. To avoid the accumulation of propolis on shaft elements and the possibility of cleaning the grids at room temperatures (+20-25°C), the elements of the built-up shaft were designed so that the contact surface with propolis is 19.32% of the area of the elements in the ratio to the grid area in the shaft zone. The contact of one shaft element with the accumulated propolis in the grid is 40 mm². The inlet and outlet openings of the device (Fig. 2 (4, 5)) are designed in such a way that, if necessary, without disassembly thereof, it makes it possible to clean the device shafts from small amounts of propolis (>1 g cycle). The noise level of the device when it is idling is up to 72 dB. As a result of the replacement of some metal constructions of the device (Fig. 1) with plastic ones, the weight of the device was ensured without basket – 8 kg, which ensures its mobility. The device is powered by a domestic network of 220-240/50 V/Hz.

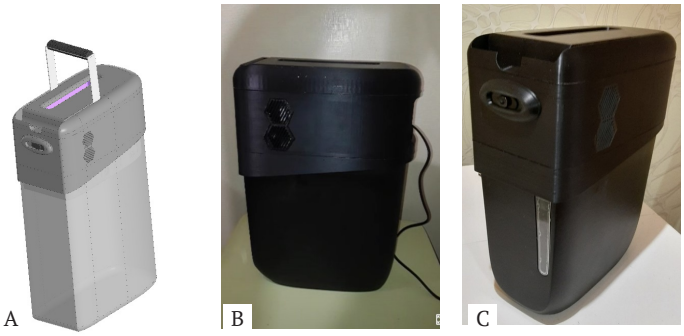

Figure 3. Experimental Model of Propolis Collecting Device (version 1.2): A – 3d Model of Propolis Collecting Device, general arrangement; B – profile view image of the device; C – lateral view of the manufactured device

The device is equipped with a protective shaft chamber to prevent the ingress of the propolis fractions which are cleaned from the grids into the mechanisms of the device (Fig. 2 (8)). Use of the device does not require additional consumables, special preparation, adjustment to start the operation. To minimize the consequences of mishandling of the device, it was possible to turn on the reverse rotation of the device shafts by turning the switch in the reverse position.

The main part of the device case is arranged on a plastic basket-stand in which propolis and cleaned grids accumulate after passing through the shafts of the device (Fig. 3). The stand-basket is disconnected from the main part of the device once it is filled or when transportation is necessary.

This approach ensures the compactness of the device as compared to the previous solution (Fig. 1), which had a solid body of the device. The device has a compartment for a power supply cable from the network, which can be closed for transportation purposes (Fig. 1 (9)). The device can be moved by means of a folding handle.

The operation principle of an improved Propolis Collecting Device (Fig. 2). For cleaning the grids, it is sufficient for the operator to place the device on a stable surface at a convenient level for laying the grids through an opening at the

top of the device. After the reliable placement of the device, the operator connects the device to the domestic network. Cooled propolized grids are inserted one by one into the device. A transparent window made of plastic is built in to evaluate the filled tray. After the tray is filled, the operator switches off the device and disconnects the upper part of the device from the basket with cleaned grids and propolis using a handle. Once the tray is cleaned, the cleaning operation is repeated. In the case of propolis adhesion on shaft structure, the shafts are cleaned with a metal brush in the reverse motion of the shafts.

Therefore, the design of the device shafts and the principle of mechanical cleaning of the grids from propolis, incorporated in its design, can serve to develop highly automated lines for cleaning grids. The use of the device in industrial apiaries in countries with tropical and subtropical climates is possible with the placement of the device in honeycomb storages if available or in manufacturing area equipped with air-conditioning. Minimizing the transfer time of propolis grids after cooling to +5°C from the cooling chamber to the device and cleaning contributes to the cleaning efficiency. For a high-quality cleaning of the propolis grid using the device, it is sufficient to cool the grids at +5°C for 60-90 minutes depending on the type of propolis.

The developed device is patented, a patent No. 139736 "Propolis Collection Device" and approved at 3 conferences (Dvykaliuk & Adamchuk, 2020[1], 2020[2]; Dvykaliuk & Adamchuk, 2021).

Conclusions

A new propolis collecting device has been designed and manufactured. The device can be used in Ukrainian apiaries and other countries where the propolis is obtained from bee colonies using elastic grids. The use of the device makes it possible to produce pure propolis without mechanical impurities that meet the requirements of the current legislation.

The prospects for further research are the production tests of the device and the assessment of the influence of different types (kinds) of propolis on the degree of cleaning of the grids, whether or not the shaft elements need to be periodically cleaned, wear resistance of the movable elements of the device (set of gear trains, motor), convenience of use of the device in different production conditions, and safety precautions rating of the operators when performing work with the device.

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Розробка пристрою для збору прополісу

Роман Мар'янович Двикалюк, Леонора Олександрівна Адамчук

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Аналіз досліджень та публікацій дає підстави зробити висновки, що в Україні до сьогодні не достатньо приділяли належної увагу умовам виробництву прополісу. Метою нашої роботи було розробити новий пристрій для збору прополісу котрий відповідатиме високим вимогам нормативно-правових актів з якості та безпечності харчових продуктів та сировини. Застосовуючи метод фокальних об'єктів та метод твердотілого моделювання нами було розроблено, спроектовано та виготовлено із застосуванням адативних технологій (3D-друк) дослідну модель пристрою для очищення сіток від прополісу. Робота проводилась в рамках виконання дисертаційного дослідження при кафедрі стандартизації та сертифікації сільськогосподарської продукції Національного університету біоресурсів і природокористування України» впродовж 2020-2021 рр. Сконструйовано та виготовлено новий пристрій для збору прополісу. Конструкція валів пристрою та принцип механічної очистки сіток від прополісу, що закладені при його розробці може слугувати для розробки високо автоматизованих ліній з очистки сіток. Використання пристрою на промислових пасіках у країнах з тропічним та субтропічним кліматом можливе з розміщенням пристрою у стільникосховищах за їх наявності або у виробничих приміщеннях, що забезпечені кондиціонером. Для якісної очистки сіток з прополісом з використанням пристрою сітки достатньо охолодити при температурі +5°С протягом 60-90 хв залежно від типу прополісу. Пристрій може бути використаний на пасічницьких господарствах України та інших країн де отримання прополісу від бджолиних сімей здійснюється з використанням еластичних сіток. Використання пристрою забезпечує отримання чистого без механічних домішок прополісу, що відповідає вимогам чинного законодавства. Розроблений пристрій запатентовано патент № 139736 «Пристрій для збору прополісу»

Ключові слова: прополіс, процес очищення сіток, пристрій, якість

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Analysis of the dangerous factors related to food products in a retail establishment

Artem Antoniv*, Tetiana Rozbytska

National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

Abstract. In accordance with the current legislation of Ukraine, retail establishments must develop, implement, and apply permanent procedures based on the principles of hazard analysis and control at critical points, and provide appropriate training on the application of permanent procedures based on the principles of HACCP; persons responsible for these procedures during the production and circulation of food products. The purpose of the study is to analyse food-related hazards in retail establishments. The study used methods of analysing internet resources, scientometric databases, in particular, Scopus and Web of Science, and regulatory documents on the food safety management system. Food safety hazards can occur at any stage of the food chain. Therefore, proper control throughout the entire food chain is essential. In the course of the study, adapted recommendations for network use were developed in the form of a HACCP book, which contains four volumes: Basic provisions, Basic programmes-prerequisites, HACCP Group, and HACCP plan (Production). Another method for determining the substantiality of hazardous factors is also proposed. In general, it is established that the implementation of HACCP principles ensures both the safety of culinary products and contributes to the development of trade enterprises. The process of production of culinary products becomes safe, the staff adheres to sanitary and hygienic standards; the confidence of visitors in the quality and safety of food consumed increases the rating of the institution; the detection of possible violations in case of inspections is practically excluded; the institution acquires a marketing advantage in the conditions of modern competition. Hazard analysis is important for an effective food safety management system because its implementation helps in streamlining the knowledge needed to establish an effective set of management measures and implement integrated quality systems

Keywords: quality, food safety management system, HACCP, risks, hazards

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**Corresponding author*

Relevance

In modern conditions, the problem of food quality and safety is becoming particularly relevant. The quality and safety of food products determine the life and health of people, including the food, economic, and national security of the state.

The issues of ensuring the stability of quality and safety of products of processing enterprises of the agro-industrial complex, in particular, agricultural and food, are becoming increasingly important, which is achieved through the introduction of quality management systems at enterprises in accordance with the requirements of international standards, the development of products considering consumer preferences and the needs of the modern market.

According to the requirements of the Laws of Ukraine "On food safety and quality", "On baby food", all enterprises that are engaged in the cultivation and production of agricultural and food products must implement food safety management systems based on the principles of HACCP.

Today, food consumers demand that market operators have an effective food safety management system, in accordance with the requirements of voluntary standards and certification schemes recognised by the Global Food Safety Initiative.

In the context of European integration, it is important for Ukrainian producers to meet not only the EU requirements for food safety but also apply knowledge of quality management. This will help to correct gaps in certain phases of development of Ukrainian enterprises and, accordingly, the competence of personnel, which will contribute to the process of integration of Ukrainian producers into the European community, developing a production culture, and applying best practices of quality management.

All participants in the chain: from the farmer – carrier, food producer and retail chain – understand that today the condition for their existence is precisely the safety of products. Therefore, the market and consumer understanding have led to new requirements for food products, and therefore for the quality management systems of all participants in the food chain. Retail trade and purchasing unions were the first to put forward their demands. They were supported by major shopping centres in Europe, which began to compile their own lists, determine criteria for evaluating food producers, and conduct internal audits. Manufacturers had to adhere to the formulated requirements to be able to sell their products in certain retail chains.

Implementation of food safety management system (FSMS) is a strategic decision for an organisation that can help improve overall productivity in food safety.

In this regard, the identification and control of hazardous factors will allow for predicting the quality and safety of products according to the criteria of efficiency of technological processes, so this subject is an urgent problem and has practical importance. In addition, the analysis of food-related hazards in retail establishments deserves special attention.

Analysis of Recent Studies and Papers

In the course of research (Agnieszka Jackowska-Tracz, Michał Tracz, and Krzysztof Anusz, 2018) determined that the introduction of only the HACCP concept at the enterprise for product safety control is not enough. In addition to the concept of risk analysis, it is also necessary to introduce programmes of prerequisites and various integrated approaches. Marić Radenko and Goran Vukmirović (2018)

determined the dependence on the introduction of sustainable technologies in retail on customer satisfaction. Thus, the results of the study prove the importance of sustainable development with the introduction of international quality and safety management systems in the retail sector. These principles also serve as guidelines among buyers.

A considerable number of retail enterprises have internal capacities for the production of culinary products and semi-finished products. The study (Mrdovic *et al*., 2019) identified that out of 297 samples of semi-finished meat products from nine retail outlets, 5% (16/297) of semi-finished meat products contained Escherichia coli, and Salmonella spp. was detected in 1.6% of semi-finished meat products. Such results confirm the need for corrective actions, hazard analysis and revision of the current HACCP concept.

Availability of a record-keeping system for documentation, hazard analysis, sanitation compliance, and other necessary programmes – support the successful development and implementation of the HACCP concept (Gehring K.B. and Kirkpatrick R., 2020). Product quality in the study (Stoyanova, 2020) is considered as a socio-economic category and is perceived as a set of properties and features that must meet the constantly growing needs of consumers and consumption requirements. Identifying opportunities for a unified approach to integrated management, which is implemented through risk-based thinking at all levels of management, is essential to ensure food safety.

Justification of the need to implement a food safety management system was also covered by the following researchers: M.T. Bilukha, F.F. Butynets, N.I. Lavrenchenko, L.A. Maiurnykova, T. Maies, S. Mortymer, V.M. Parkhomenko, Sh.A. Sfiev, I.Yu. Tymrienko, and many others. Despite the presence of a substantial number of scientific papers on this subject, problematic issues related to the implementation of the system in retail establishments remain insufficiently investigated.

Purpose of the study. The purpose of the study is to analyse food-related hazards in retail establishments.

Materials and Methods

The study uses methods of analysis, synthesis, information-search investigation, Internet resources, and regulatory-methodological documents of Ukraine.

Research Results

Food market operator (market operator):

- legal entity, individual entrepreneur, individual, agri-food market;
- activities with or without the purpose of making a profit;
- primary production, production, sale and/or turnover of food products and/or other objects of sanitary measures (except for contacting with food materials);
- responsible for meeting the requirements of the law and legislation on safety and certain indicators of food quality.

Food safety is associated with the presence of hazardous factors in the food at the time of consumption. Since the food hazard factor can appear at any link in the food chain, adequate management throughout the food chain is essential.

Information throughout the food chain is essential to ensure that all relevant food hazards are identified and adequately managed at each link in the food chain (DSTU ISO 22000:2019; Bal-Prylypko *et al*., 2020).

The tasks in the field of ensuring the quality system and food safety for a trading enterprise are continuous improvement of the food production process, ensuring the stability of

product quality at all stages of its life cycle, improving the efficiency of resource use, providing customers and regulatory authorities with confirmation of product compliance with established requirements. In accordance with the main tasks, solutions are developed, which can be expressed in the following: personal responsibility of the manager and employees, constant work with suppliers of food raw materials to improve the quality and safety of delivered products, improving the forms and methods of production organisation, the level of knowledge in the field of food safety, preventive actions and their management, regular internal audit and monitoring of the effectiveness of the system, systematic analysis of audit results, monitoring and satisfaction of customers of retail establishments, continuous improvement of the food safety management system (Nikolaenko *et al*., 2017; Silonova, 2018).

HACCP groups are responsible for compliance with and implementation of elements of the food quality and safety management system in accordance with legal requirements and proper functioning of the implemented HACCP concept in a retail establishment.

In accordance with the above, adapted recommendations in accordance with the requirements of national legislation and international practices for network use in the form of a HACCP book were developed. The HACCP book of the retail chain has an extensive structure and is generally divided into 4 books:

*The HACCP book. Main provisions – describes the architecture of the HACCP book, its main provisions, terms, principles, and defines responsibility.

*The HACCP book. Volume 1. Basic programmes-prerequisites – the basic conditions for ensuring the safety of products of a network of retail establishments are described.

*The HACCP book. Volume 2. HACCP Group – the provisions on HACCP groups and their responsibility are included, the methodology for analysing hazards (risks), determining critical control points (CCP), and key information on managing the HACCP concept are presented.

*The HACCP book. Volume 3. HACCP Plan (Production) – the application of HACCP principles on each type of production is described, which includes: conducting a risk analysis, determining the critical control points (CCP), determining critical limits for each CCP, monitoring system, corrective actions, procedures for confirming the functioning of the system, its documentation.

The HACCP plan contains information about all critical control points identified in the network's production facilities, namely: general information about the CCP (page number and CCP, stage of the technological process, intended monitoring method); object of control (name of the CCP, substantial hazard factor, critical limits for this CCP); monitoring of the CCP (subject of monitoring, monitoring methods, frequency of monitoring, ones responsible for monitoring); corrective actions (corrective actions, protocol of performing corrective actions, method of checking the effectiveness of monitoring).

According to HACCP, hazards are classified into three types: biological (B), chemical (C), and physical (P). When further identifying hazards, it is important to understand that hazards include only those that can cause health disorders, diseases, or injuries to a person. Many other conditions are also highly undesirable and must be controlled, but as long as these conditions do not directly affect food products, they are not included in the HACCP plan.

Biological hazard factors – microbiological: pathogenic and conditionally pathogenic bacteria, viruses, parasites, and single-celled

organisms, mould, etc. As a rule, there is at least one factor that can affect the degree of risk. The determination of risk may be influenced by the processing conditions to which the food product is subject. A food product that is subjected to heat treatment reduces the risk of disease (Bocharova, 2019; Bal-Prylypko *et al*., 2018).

Chemical hazard factors — detergents, migration of plasticisers from packaging, pesticides, heavy metals, nitrates, nitrites, nitro compounds, mycotoxins, food additives, veterinary drugs (antibiotics, hormones), etc. Chemical hazards can also cause foodborne illnesses, although they tend to affect fewer people. Chemical contamination can occur at any stage of production and processing. The potential risk to consumers increases when the chemical content is not controlled, or when recommended standards are exceeded (Bocharova, 2019).

Physical hazard factors – foreign objects: glass, metal, stones, wood, plastic, etc. As a rule, physical hazards create problems only for individual consumers or a small number of them. It is because of physical factors that injury occurs immediately or shortly after eating and the source of danger is easy to identify (Petrovskaya *et al*., 2020; Bal-Prylypko *et al*., 2017). In a retail establishment, the method of determining the degree of dangerous factors is used, which is presented in the table. The substantiality of hazardous factors is calculated using the following formula:

Substantiality = probability of occurrence multiplied by the severity of the consequences.

Table 1. *Method for determining the substantiality of hazardous factors*

Probability of occurrence of a dangerous factor in humans	**Severity of the consequences of exposure to a dangerous factor on humans**		
	Mild lesion Short-term malaise for a time up to 1 day – 1 point	Average lesion Temporary loss of ability to work up to 1 week - 2 points	Severe damage Temporary loss of ability to work up to 1 month – 3 points
Almost impossible 1 time per 5 years 1 point	1 Can be neglected	2 Acceptable	3 Moderate
Unlikely 1 time per 3 years 2 points	2 Acceptable	4 Moderate	6 Substantial
Probable 1 time per year 3 points	3 Moderate	6 Substantial	9 Unacceptable

All hazards the substantiality of which was 3 or higher were further analysed to rank the management measures that will be applied to manage the relevant hazards.

Hazard analysis is conducted sequentially, entering data in a special form. If at any stage there is a dangerous factor that is not controlled during the production process, it is marked as a potential critical control point. This form includes: localisation of danger: technological stage of the production process; description of the danger: a type of dangerous factor, its possible source; hazard assessment: evaluated by the method of determining the substantiality of dangerous factors; explanation of the presence or absence of danger. Management and recording measures for insubstantial hazards (Slyva, 2021; Pivets *et al*., 2018).

Conclusions and Prospects

The introduction of a food safety management system and Ukrainian legislation based

on HACCP principles is particularly useful for organisations seeking to have a more focused, consistent and integrated food safety management system.

Hazard analysis is key to an effective food safety management system, as it helps to streamline the knowledge needed to establish an effective set of management measures.

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Аналіз небезпечних чинників, пов'язаних із харчовими продуктами в закладі роздрібної торгівлі

Артем Дмитрович Антонів, Тетяна Вікторівна Розбицька

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Анотація. Відповідно до чинного законодавства України заклади роздрібної торгівлі мають розробляти, вводити в дію та застосовувати постійно діючі процедури, що ґрунтуються на принципах аналізу небезпечних чинників та контролю в критичних точках, а також забезпечувати належну підготовку з питань застосування постійно діючих процедур, що базуються на принципах НАССР; осіб, які є відповідальними за ці процедури, під час виробництва та обігу харчових продуктів. Метою дослідження є проведення аналізу небезпечних чинників пов'язаних з харчовими продуктами в закладі роздрібної торгівлі. Під час дослідження використовували методи аналізу Інтернет-ресурсів, наукометричних баз даних, зокрема Scopus та Web of Science та нормативно-правові документи щодо системи управління безпечністю харчових продуктів. Поява небезпечних чинників для безпечності харчової продукції може статися на будь-якому етапі харчового ланцюга. Тому необхідним є належний контроль упродовж усього харчового ланцюга. В ході дослідження було розроблено адаптовані рекомендації для мережевого використання у вигляді «Книга НАССР», яка містить чотири томи: Основні положення, Базові програми-передумови, Група НАССР, План НАССР (Виробництво). Також запропоновано ще один метод визначення значущості небезпечних чинників. Загалом встановлено, що впровадження принципів НАССР забезпечує, як безпеку продукції і кулінарних виробів, так і сприяє розвитку підприємств торгівлі. Процес виробництва кулінарної продукції стає безпечним, персонал дотримується санітарно-гігієнічних норм; впевненість відвідувачів в якості та безпечності їжі, яку споживають, підвищується рейтинг закладу; практично виключається виявлення можливих порушень у разі перевірок; заклад набуває маркетингову перевагу в умовах сучасної конкуренції. Аналіз небезпечних чинників, має важливе значення для ефективної системи управління безпечністю харчових продуктів, адже його проведення допомагає в упорядкуванні знань, необхідних для встановлення ефективного комплексу заходів керування та впровадження інтегрованих систем якості

Ключові слова: якість, система управління безпечністю харчових продуктів, НАССР, ризики, небезпечні чинники

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The impact of storage on the sensory, viscosity and chemical characteristics of yogurt fortified with oat β-glucan

Xiaoqing Qu[1,2]

[1]Sumy National Agrarian University
40021, Herasima Kondratieva St. 160, Sumy, Ukraine

[2]Henan Institute of Science and Technology
453003, HuaLan Avenue, Xinxiang, China

Abstract. Oat β-glucan has the potential of a functional additive to yogurt, however, texture analysis and chemical characteristics during storage of yogurt with the addition of this additive require more systematic research, which determines the relevance of the study. The aim of the research work was to analyze the feasibility of enriching yogurt with 0.3% oat β-glucan. A number of methods for obtaining new knowledge in the direction of developing healthy food products were used. It was found that yogurt with the addition of 0.3% oat β-glucan had water-holding capacity. All pH values ranged from 4.18 to 4.28, which are within the normal ranges for set-type yogurts. A higher viscosity of the experimental sample of yogurt compared to the control was established, and the highest values were 58560±2120 cp at 21 days for yogurt with the addition of 0.3% oat β-glucan. The viability of probiotic bacteria in yogurts was examined. During the whole storage period, the content of probiotics decreased, but yogurt with the addition of 0.3% oat β-glucan contained significantly more live probiotic bacteria compared to the control. The viability of probiotic bacteria of 0.3% oat β-glucan yogurt at 14 d (3.18±0.2×107 CFU/mL) was only slightly lower than that of control yogurt at 1 d (3.45±0.3×107 CFU/mL). This fully demonstrates that the addition of 0.3% oat β-glucan has a protective effect on probiotics in yogurt, which will be beneficial for human health. It was found that the addition of 0.3% oat β-glucan led to a decrease in adhesiveness, but an increase in hardness and stickiness during storage. The results of the sensory evaluation showed the highest acceptability values of 86.49 for 21 days of storage of yogurt with the addition of 0.3% oat β-glucan. The practical value of the research work lies in the developed yogurt containing 0.3% oat β-glucan being possibly to use as an innovative healthy dairy product

Keywords: yogurt, oat β-glucan, sensory, viscosity, chemical characteristics

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*Corresponding author

Introduction

The demand for healthy foods has caused the development of products containing functional components. In the dairy industry, prebiotic substances or probiotic bacteria have sparked interest due to scientific evidence related to their positive health benefits [1].

Dietary fibers, usually polysaccharides, can be insoluble or soluble in water. Soluble fibers are usually found in fruits, vegetables, oat bran, and barley, etc. Oat β-glucan (OG), a soluble dietary fiber from oat, has received tremendous attention during the previous decades. It is a non-starchy polysaccharide that comprises mainly glucose molecules linked by (1-3), (1-4) mixed linkage with glycosidic bonds [2]. More importantly, it has diverse and great effects on the maintenance and improvement of human health. For example, consumption of OG can help in reducing the occurrence of some chronic diseases such as high blood pressure, insulin responses, obesity, and colon cancer [3]. In addition, it can modify the rheological and mouthfeel attributes, and physical stability of beverages, and be used as a prebiotic in yogurt formulations [4]. Nowadays, consumption of OG is encouraged and it is added to various food products as a functional ingredient.

Analysis of Recent Researches and Publications

Yogurt, a traditional fermented dairy product containing probiotics and prebiotics, has gained widespread consumer acceptance for being considered as a healthy product [5, 6]. It has shown a substantial consumption increase in recent years due to its nutritional and health interest. During the fermentation action, some toxic or antinutritional factors, such as lactose and galactose, can be removed from fermented milk, thus preventing lactose intolerance and accumulation of galactose [7]. In this sense, yogurt can be used as an excellent matrix for developing innovative health-promoting products and functional foods.

The addition of soluble fibers can change the structural-mechanical properties [8] and functional characteristics of fermented dairy products. For example, used hydrolyzed guar gum can be used to enhance the functional and sensory properties of yogurt [9]. In recent years, there is growing interest to launch health-promoting foodstuffs with OG.

Because OG is a kind of dietary fiber, it can be used as a prebiotic of probiotics, and it has a positive influence on the physicochemical properties and vitality of probiotics in yogurt. This feature is conducive to OG as a functional component of yogurt [10, 11].

From the analysis data of literature sources, it can be said that OG has the potential as a functional additive for yogurt; however, the texture analysis and chemical characteristics of the storage period after adding OG to yogurt still need to be more systematically studied.

The addition of 0.3% OG decreased the fermentation time of set-type yogurt, making the highest score of sensory evaluation [12]. As a functional food ingredient, 0.3% OG is important in enhancing the nutraceutical quality and physical characteristics of yogurt. Moreover, 0.3% OG shows its effect on starter culture growth. However, the impact of 0.3% OG on the quality of yogurt, such as sensory evaluation and physical characteristics, during storage, has not been evaluated. Therefore, in this work, the quality characteristics of set-type yogurt, i.e., control yogurt and 0.3% OG yogurt, were studied. The water-holding capacity (WHC), acidity value, pH, viscosity, textural parameters, viability of probiotic bacteria, and sensory properties, during 21 d of storage, were evaluated and compared.

The aim and objectives of the study. The aim of the study is to analyze the effect of the

feasibility of set-type yogurt fortification with 0.3% OG.

To achieve the aim of the study, it was necessary to solve the following problems:

– to analyze the effects of yogurt with or without 0.3% OG on sensory during storage;

– to examine the impact of yogurt with or without 0.3% OG on viscosity and chemical properties during storage;

– to investigate the effect on probiotics in yogurt with or without 0.3% OG during storage.

Materials and Methods

Pure milk was purchased from Yili Industrial Group Co. Ltd (Neimenggu, China). Oat β-glucan (95% purity) was provided by Zhongkang Food Co., (Guangzhou, China). Starters: *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (*Lactobacillus dechellii Bulgarian subspecies*) (viable bacteria count was about 1×10^9 CFU/g) were provided by Danisco (China) Co., Ltd, (Shanghai, China). MRS medium was purchased from Shanghai Mingrui Biotechnology Co., Ltd, (Shanghai, China). Agar was purchased from Xi'an Huibang Bioengineering Co., Ltd, (Xi'an, China). All other chemicals were used of analytical grade.

The preparation of yogurt samples refers to the previous experimental methods [12].

Take a certain quality (M_1) of yogurt in a centrifuge tube; centrifuge at 4 000 r/min for 25 min at 4°C, discard the supernatant and weigh the remaining mass (M_2). It is not easy to separate whey from yogurt with good water-holding capacity during storage [13].

The calculation formula is as follows:

$$WHC\ (\%) = M_2 \div M_1 \times 100\% \qquad (1)$$

Determination of acidity by an acidimeter (PB-10, Seidolis instruments, Germany): set-type yogurt samples were taken every 1 h during the fermentation process and the yogurt samples were determined after being stored 24 h. Then, 10 g yogurt samples were put into a 250 mL triangle bottle and 20 mL distilled water was added to dilute and mixed, 0.5% phenolphthalein was added as an indicator and titrated with 0.1mol/L NaOH standard solution until it was slightly red. Not fading within 30 s marked the end of determination. Consuming 0.1 M of NaOH is equal to 1 °T.

All pH values were monitored after adding starter bacterial cultures using a digital pH meter (Thermol Scientific Inc., USA).

The viscosity of yogurt was measured at 4°C with a spindle (No. 3) rotation of 1500 rpm using the digital display rotating viscometer (NDJ-8S, Shanghai Yueping Scientific Instrument Co., Ltd., Shanghai, China). The readings were recorded at the 20th s of the measurement. The measurements were made in triplicate.

The experiments were performed by a texture analyzer (TA-XT.plus Texture Analyzer; Stable Micro Systems, Godalming, UK). Refer to Bedani *et al*., Ciron *et al*. (2010) and other methods, slightly improved. The yogurt samples were placed in 25 mL beakers and the Texture Profile Analysis (TPA) test mode and P/0.5 probe were used to determine the gel structure of the fermented milk. The parameters are as follows: the speed is divided into 2.0 mm/s before measurement, 1.0 mm/s during measurement, and 2.0 mm/s after measurement. Test samples shall be made in triplicate.

Microbial Analyses. The 1 g of yogurt with 9 mL of 0.9% (w/v) NaCl was mixed and diluted to a concentration of 10^4, 10^5, and 10^6, and then 1 mL of each dilution was inoculated on plates containing the MRS agar. Bacteria were counted by the pour plate technique. The plates in duplicates were incubated anaerobically at 37°C for 72 h, and then colonies were counted [4, 14, 15].

According to the relevant sensory evaluation methods of the national standard, 10 volunteers (5 men and 5 women) with sensory

evaluation experience of fermented milk were selected to conduct the sensory evaluation of fermented milk added with OG from the aspects of color, structural state, texture, and flavor. The full score was 100 and the sensory score was the average score of 10 people.

Unless otherwise stated, all tests were performed in triplicate, and data were averaged. Standard deviation was also calculated. SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical evaluations, and OriginPro 8.6.0 (Originlab, Northampton, Massachusetts, USA) was used for the construction of the graphs. The sensory evaluation and yogurt WHC with different storage times of OG were analyzed by independent sample t-test of SPSS 17.0 software. The significance (*P* values) of the microbiological parameters were calculated by the general linear model. One-way ANOVA was used to analyze the titration acidity of yogurt for different storage time, LSD and Dunnett's T3 test were applied for multiple comparisons and differences were considered to be statistically significant at $P<0.05$.

Results of the Research and Discussion

For water-holding capacity values, a significant decrease was observed in the control yogurt, while a slight decrease was observed in 0.3% OG yogurt (Fig. 1 (a)). This can be attributed to the hydration properties of OG, which have an impact on the shelf life of food products by preventing texture loss and avoiding syneresis problems.

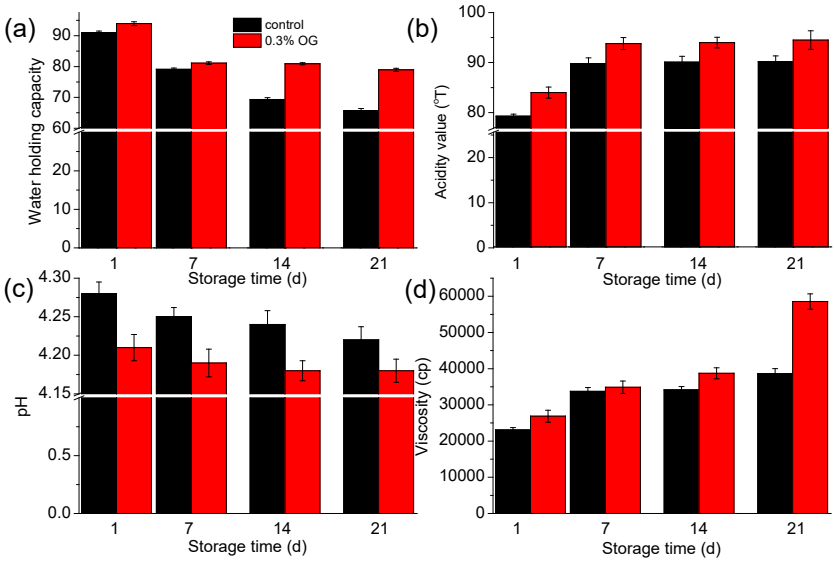

Figure 1. The WHC (a), acidity value (b), pH (c), and viscosity (d) of yogurt

As can be seen from Figure 1(b), the acidity of both control yogurt and 0.3% OG yogurt significantly increased to 93.8±1.2 during 7 d of storage. And then (7-21 d of storage), no significant ($P\leq0.05$) changes were observed in acidity values. An opposite trend was observed for pH values and reached the minimum (about 4.21 in control yogurt and about 4.18 in 0.3% OG yogurt) (Fig. 1(c)). The decrease in pH values during the storage period might be mainly due to the utilization of OG by viable probiotic bacteria and the production of lactic acid. In addition, small amounts of CO_2 and formic acid from lactose may also lead to a decrease in pH [16, 17].

All pH values ranged from 4.18 to 4.28, which are within the normal ranges for set-type yogurts.

Figure 1(d) shows the changes in viscosity values over 21 d of storage. Significant differences were noted between control yogurt and 0.3% OG yogurt. In general, the viscosity values increased throughout storage in concentrated and non-fat plain yogurt throughout storage [18, 19]. The increasing viscosity during storage could be due to the protein rearrangement and protein-protein contact. The 0.3% OG yogurt had a higher viscosity than the control yogurt, and the highest values were 58560±2120 cp at 21 d for 0.3% OG yogurt. This change could be attributed to the fact that OG has the ability to entrap water within the product. On the other hand, the addition of 0.3% OG could improve the protein rearrangement and protein-protein contact.

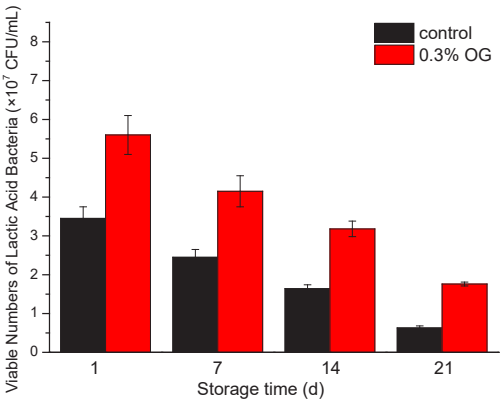

Figure 2. The viability of probiotic bacteria in yogurts during the storage

Live and active probiotic bacteria are considered to be beneficial for human health [20, 21]. OG is considered to be prebiotic and may contribute to the activity of probiotic bacteria. So, the viability of probiotic bacteria in yogurts was checked. As shown in Figure 2, during the whole storage period, the content of probiotics decreased, which was only $0.63\pm0.05\times10^7$ CFU/mL at 21 d. However, 0.3% OG yogurt contained significantly more live probiotic bacteria compared to the control one ($P\leq0.05$) throughout the whole cold storage period. The viability of probiotic bacteria of 0.3% OG yogurt at 14 d ($3.18\pm0.2\times10^7$ CFU/mL) was only slightly lower than that of the control yogurt at 1 d ($3.45\pm0.3\times10^7$ CFU/mL). Similar results have also been reported [15]. This fully demonstrates that the addition of OG has a protective effect on probiotics in yogurt. The survival of yogurt microbiota in 0.3% OG yogurt will be beneficial for human health.

The textural parameters of yogurt are important for yogurt products, as they can simulate their breakdown occurring in the mouth. Results of texture profile analysis (TPA) of yogurts, including hardness (N), consistency, cohesiveness, and springiness (%) are summarized in Table 1. For both control yogurt and 0.3% OG yogurt, the hardness of yogurts was improved, while the adhesiveness and gumminess values declined during the storage. The textural characteristics of yogurts are affected by the addition of 0.3% OG.

Table 1. *Results of TPA test in the control yogurt and 0.3% OG yogurt*

Test	Days	Yogurt samples	
		control yogurt	0.3% OG yogurt
Hardness	1	21.14	22.85
	7	24.77	28.36
	14	28.76	35.99
	21	40.99	50.45
Adhesiveness	1	-8.23	-9.15
	7	-9.18	-10.21

Table 1. Continued

Test	Days	Yogurt samples	
		control yogurt	0.3% OG yogurt
	14	-9.25	-11.37
	21	-10.39	-11.85
Gumminess	1	9.26	13.78
	7	12.79	13.81
	14	14.71	19.82
	21	21.54	13.78
Cohesiveness	1	0.43	0.43
	7	0.41	0.44
	14	0.51	0.57
	21	0.53	0.59
Chewiness	1	8.75	9.46
	7	11.39	12.87
	14	14.06	13.77
	21	20.72	18.99
Springiness	1	0.94	0.92
	7	0.95	0.93
	14	0.95	0.95
	21	0.96	0.97

The evaluation index of yogurt is mainly the hardness. The hardness of 0.3% OG yogurt was higher than that of control yogurt, especially after 21 days of storage (50.45 in 0.3% OG yogurt and 40.99 in the control yogurt). The higher hardness values could be attributed to the ability of the OG to entrap water, and maintain structure within the product [19, 22].

In contrast, the adhesiveness of 0.3% OG yogurt was lower than that of the control yogurt, especially after 21 d of storage (-11.85 in 0.3% OG yogurt and -10.39 in the control yogurt). The decrease in adhesiveness may be due to the fact that OG can reduce adherence of the yogurt with teeth during chewing.

The 0.3% OG yogurt had a slight increase in gumminess as compared to the control yogurt. And, during storage, an increase in gumminess was observed, which might be due to the increased hardness of yogurts. Similar behavior was found for cohesiveness, which can be attributed to the fact that OG has the ability to form new gel structures with casein, effectively intercepting and entrapping water within the yogurt. No significant differences were obtained for springiness values between the control yogurt and 0.3% OG yogurt.

In short, results of textural profile tests showed appropriate hardness, less gumminess, less adhesiveness, and less destruction in 0.3% OG yogurt, giving a firm and creamy texture that was near to creamy mouthfeel of full-fat yogurt, improving the mouthfeel characteristics thereby enhanced sensory appeal for the product in which incorporated. The sensory properties of the yogurts are shown in Table 2. All yogurts had average sensory scores of above 80, indicating a preference both for the control yogurt and 0.3% OG yogurt throughout storage.

The sensory results indicated that there was a statistically significant ($P \leq 0.05$) difference in sensory characteristics between the control yogurt and 0.3% OG yogurt. The control yogurt had the highest acceptability value of 83.26 at 21 d of storage, while 0.3% OG yogurt had the highest acceptability value

of 86.49 at 21 d of storage. Clearly, the addition of 0.3% OG has a positive effect on the acceptability of the yogurt, independently of the storage time.

Table 2. *Sensory properties of the control yogurt and 0.3% OG yogurt during storage*

Variables	Days	Yogurt samples	
		control yogurt	0.3% OG yogurt
Color	1	8.12 ± 0.24	8.71 ± 0.46*
	7	8.13 ± 0.34*	8.68 ± 0.32**
	14	8.18 ± 0.28*	8.51 ± 0.48**
	21	8.20 ± 0.14*	8.50 ± 0.28*
Structural state	1	26.05 ± 0.47	26.78 ± 0.63**
	7	27.05 ± 0.12*	27.32 ± 0.76*
	14	27.02 ± 0.32*	28.08 ± 0.92**
	21	27.08 ± 0.28*	27.98 ± 0.88*
Texture	1	24.28 ± 0.39	24.97 ± 0.79**
	7	24.92 ± 0.22*	25.12 ± 0.82*
	14	25.04 ± 0.28*	25.98 ± 0.70**
	21	24.88 ± 0.40**	25.88 ± 0.70**
Flavor	1	23.7 ± 0.90	24.67 ± 0.47**
	7	23.1 ± 0.70*	24.02 ± 0.32**
	14	23.0 ± 1.20**	24.12 ± 0.22*
	21	23.1 ± 1.20**	23.88 ± 0.28*

Conclusions

The results of the present work showed that 0.3% oat β-glucan yogurt had good sensory and mouthfeel characteristics by improving viscosity and texture as compared to the control. Due to the lack of dietary fiber in milk and yogurt, β-glucan is a suitable choice for dairy systems. The 0.3% oat β-glucan yogurt also has high nutritional values as oat β-glucan can act as a prebiotic in probiotic yogurt. Therefore, yogurt containing 0.3% oat β-glucan could be an innovative healthy dairy product for enhancing oat β-glucan consumption.

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Вплив зберігання на сенсорні показники, в'язкість та хімічні характеристики йогурту, збагаченого вівсяним β-глюканом

Сяодзинь Цю[1,2]

[1]Сумський національний аграрний університет
4002, вул. Герасима Кондратьєва, 160, м. Суми, Україна
[2]Хенанський інститут науки і технологій
453003, пр-т. Хуалан, м. Сіньсян, Китай

Анотація. Вівсяний β-глюкан має потенціал функціональної добавки до йогурту, однак аналіз сенсорних показників, текстури та хімічні характеристики впродовж зберігання йогурту з додавання цієї добавки потребують більш систематичного вивчення, що зумовлює актуальність дослідження. Метою наукової роботи було проаналізувати доцільність збагачення йогурту 0,3 % вівсяним β-глюканом. Використані методи для отримання нових знань в напрямку розроблення корисних для здоров'я продуктів харчування. З'ясовано, що йогурт із додаванням 0,3 % вівсяного β-глюкану володіє водоутримуючою здатністю. Усі значення pH, під час зберігання, становили від 4,18 до 4,28, що є в межах норми для йогуртів. Встановлено вищу в'язкість експериментального зразка йогурту порівняно з контрольним, а найвищі значення були 58560 ± 2120 ср на 21 добу для йогурту з додаванням 0,3 % вівсяного β-глюкану. Перевірено життєздатність пробіотичних бактерій у йогуртах. За весь період зберігання вміст пробіотиків знижувався, проте йогурт із додаванням 0,3 % вівсяного β-глюкану містив значно більше живих пробіотичних бактерій, порівняно з контролем. Життєздатність пробіотичних бактерій йогурту з додаванням 0,3 % вівсяного β-глюкану на 14 добу (3,18 ± 0,2 ×10^7 КУО/мл) була лише незначно нижчою, ніж у контрольного йогурту на 1 добу (3,45 ± 0,3 ×10^7 КУО/мл). Це повністю демонструє, що додавання 0,3 % вівсяного β-глюкану чинить захисну дію на пробіотики в йогурті, що буде корисно для здоров'я людини. Встановлено, що додавання 0,3 % вівсяного β-глюкану, призвело до зниження адгезивності, але посилення твердості та клейкості під час зберігання. Результати сенсорної оцінки показали найвищі значення прийнятності 86,49 на 21 добу зберігання йогурту із додаванням 0,3 % вівсяного β-глюкану. Практична цінність наукової роботи полягає в тому, що розроблений йогурт, який містить 0,3 % вівсяного β-глюкану, може бути інноваційним молочним продуктом для здорового харчування

Ключові слова: йогурт, вівсяний β-глюкан, сенсорні показники, в'язкість, хімічні характеристики

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вул. Героїв Оборони, 15, м. Київ, 03041, Україна
E-mail: info@animalscience.com.ua
https://animalscience.com.ua/uk

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