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CONTENTS

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Quality indicators of extracted sunflower and rapeseed oil obtained with hexane and ethyl alcohol solvents

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Abstract. The relevance of the conducted research is conditioned by the increase in demand for oilseeds with improved and environmentally friendly qualities, namely, the replacement of a dangerous solvent in the extraction process of processing oilseeds. In this regard, this paper is aimed at investigating the use of an organic solvent, such as ethanol, in extraction technology that is safer for human health. The leading approach to studying this problem is Soxhlet extraction and microwave extraction using hexane and ethanol solvents. The fatty acid composition of the resulting product was analysed by gas chromatography. In the proposed microwave method of oil extraction with a "green" solvent, which is ethyl alcohol, physical and chemical parameters were studied and compared with those obtained by the Soxhlet method. The efficiency of microwave processing is related to the heating process, which significantly increases the internal pressure of cells, which causes their destruction. A barodiffusion flow is created, which contributes to a significant increase in the yield of the extraction oil concentration by 1.4-1.8 times over the same time period and a decrease in the extraction process time by almost 3 times. The oil obtained by extraction of raw materials in a microwave

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field with a solvent ethyl alcohol is more resistant to oxidation, as evidenced by a decrease in the numbers: peroxide from 4.8 to 3.8, and anisidine from 0.25 to 0.2. The acid number, which characterises the degree of freshness of the resulting oil, also decreased from 2.5 to 2.1. The research results show that the use of microwave extraction with a polar solvent, which is ethyl alcohol, was effective in improving the quality properties of the extracted oil. The use of a "green" solvent does not degrade the quality of the finished product, unlike hexane, which is harmful to human health. The materials of the study are of practical value for the fat and oil industry, namely, in the technology of extraction of oilseeds

Keywords: solvents; extraction; hexane; ethyl alcohol; microwave energy; fatty acid composition

Introduction

The energy crisis and the growing demand for products with ecological and harmless properties for human health are priorities for the development of the latest technologies in the extractive production of materials (in particular, oilseeds).

The volume of oilseeds, namely sunflower seeds, is one of the oilseeds that are mass-produced in Ukraine. According to the State Statistics Service, in the 2021/22 season, Ukrainian farmers collected a record harvest of oilseeds: sunflower – 16.4 million tonnes, soybeans – 3.4 million tonnes, and rapeseed – 2.96 million tonnes. Of these, processors produced 6.87 million tonnes of vegetable oil: sunflower – 6.45 million tonnes, rapeseed – 265 thousand tonnes and soy – 163 thousand tonnes (Latifundist Media..., 2022). The strategy for the development of food industry exports and ensuring the quality of food products for the population, as well as the ecology of living systems, indicates the regularity of manufacturing and implementing energy-saving, resource-efficient, and harmless ("green") technologies (On the approval of the Strategy ..., 2020).

Improving the technology of oil production in order to increase the yield of finished products while maintaining their good quality is one of the main tasks of developing scientific and technical progress in the industry and intensifying mass transfer processes. When determining innovative methods of conducting the extraction process, it is worth considering the practice of using conventional solvents such as hexane and exploring non-traditional methods of "green technologies" for extracting substances from oilseeds with ethanol solvent.

Ukraine occupies a leading position in terms of gross sunflower harvest in the world (Agro Polit..., 2020). At the same time, the bulk of sunflower seeds are processed into oil, feed cake, and meal. The oilseed market of Ukraine is one of the main ones in the agricultural sector. The Ukrainian fat and oil industry has held a leading position in the world over the past five years. However, in the context of a full-scale invasion of the Russian Federation, it operates in conditions of a shortage of raw materials and energy resources. This determines the areas of finding solutions to improve existing technologies and develop new ones that allow obtaining high-quality products with high technical and economic indicators. According to statistics, since the beginning of the full-scale invasion (March-June 2022), Ukraine has exported more than 700 thousand tonnes of sunflower oil, which is almost 50% lower than the data for the current period of the past season (APK-Inform ..., 2022).

According to the results of the 2021/22 marketing year (ended August 31, 2022), Ukraine exported a significant amount of sunflower – 1.63 million tonnes (APK-Inform …, 2022). The increase in sunflower exports was conditioned by the suspension of sunflower oil exports and a significant decrease in domestic processing. Even in the state of a full-scale invasion of the Russian Federation on the territory of Ukraine, the country has a leading position in the rating for the production and export of sunflower seeds and its processed products on the world market. Therefore, the development and implementation of the latest technologies for oil production, in particular from sunflower seeds, remains relevant.

Analysis of literature data shows that extraction processes for substances in solid and liquid systems form the basis of a number of important enterprises of the chemical, petrochemical, food, microbiological, and other branches of the industrial industry (Puertolas *et al.*, 2016; Tan *et al.,* 2016; Mwaurah *et al.*, 2020), and require modern approaches, one of which is the use of microwave energy in the process of extracting oilseeds and switching to safe solvents.

The development of new methods is because traditional methods have various disadvantages, such as more energy, more time, low yield, and less environmental friendliness. Physical methods of oil extraction can only extract about 80% of the oil present in the oil material; therefore, a different technology must be used to extract the remaining 20% (Puertolas *et al.*, 2016).

Solvent extraction is widely used due to the simplicity and cost-effectiveness of the process (Mwaurah *et al.*, 2020). Typically, the solvents are hexane and n-hexane, as they provide the highest yield (95%) (Tan *et al.*, 2016). In particular, n-hexane is preferred because of its properties such as easy extraction, low latent heat of evaporation (330 KJ/kg), narrow boiling point range (63 to 69°C), high solubility, and nonpolarity. The disadvantages of using these solvents are their harm to human health, safety, and the environment, and therefore, despite their high extraction efficiency, their use is not only harmful and toxic, but also leads to air pollution (Konopka *et al.*, 2016; Kumar *et al.*, 2017). In addition, although hexane is approved for the food industry by the European Commission and the Food and Drug Administration (FDA) (Commission Implementation Regulation (EU)…, 2022), it is still considered and classified as dangerous and not the best for some international organisations (Castejon *et al.*, 2018). However, the extraction of vegetable oil consumes large amounts of hexane, and therefore, there is a need to investigate environmentally friendly technologies.

The purpose of the study is to determine the quality indicators of extracted oil with "green solvent" ethanol under the influence of an electromagnetic field in comparison with conventional technologies.

Literature Review

One of the methods of oil extraction in industrial conditions is mechanical pressing. The resulting product after pressing is characterised by high quality. Screw presses are mainly used to ensure this process. However, between 8% and 14% of the oil remains in the cake (Ionescu *et al.*, 2013). The advantage of solvent extraction is a more complete extraction (up to 95% of the oil contained in the raw material) (Topare *et al.*, 2011) and can be used for seeds with low oil content, as well as for complete extraction of oil from cake after pressing.

The research paper by S. Hussain *et al.* (2018) presents the results of using both pure solvents and mixtures. The researchers investigated the potential of less dangerous binary mixtures of ethyl acetate (EA) and dichloromethane (DCM) for rice from bran oil extraction. Nine solvent

mixtures with different volume EA/DCM ratios in the range from 0.11 to 9 were used. A mixture of solvents with a volume factor of 4 (S8) provided a maximum oil recovery of 88.04%. The oil yield increases from 76.41% to 89.7% by increasing the preheating temperature from 40°C to 65°C. Other optimised parameters for increasing oil extraction: bran particle size < 125 microns (obtained by Sieve), solvent-to-bran ratio 5 ml/g, and mixing time 15 min. The minimum mixing speed to prevent agglomeration in the mixture and optimise oil extraction is 80 rpm.

Oil extraction takes place by mass transfer. Mass transfer is the process of mass transfer on the surface of particles and diffusion inside (Bandura *et al*, 2021). Recent studies on the improvement of extraction processes that can reduce the amount of energy consumed, use harmless alternative solvents, and ensure the production of a safe, benign extract product and the feasibility of using microwave technology are reported by the authors (Grasso *et al.*, 2012). Microwave extraction is a new method that can reduce extraction time and solvent consumption (Burdo *et al.*, 2017; Bandura *et al.*, 2018).

Replacing toxic organic solvents from fossil sources with non-toxic ones from bio-renewable sources in large-scale processes has been an object of research by M.C. Ferreira *et al.* (2022). Although ethanol is being investigated as a hexane substitute for vegetable oil extraction, most studies are conducted on a laboratory scale. The initial parameters of the continuous and countercurrent extractor, which indicates the technical feasibility of a large-scale operation, are still scarce. Here, a continuous-action extractor consisting of columns with a fixed layer connected in series (resembling the so-called simulated movable layer extractor) for the extraction of soybean oil with anhydrous ethanol was experimentally reproduced using a multi-section solid-liquid extraction system. After 5-step extraction, the residual oil in the solid phase was 0.17% with an extraction yield of 99.2%, confirming that ethanol was able to exhaust the solid matrix with the maximum extraction yield. Food safety technologies and less environmental impact confirm that ethanol is a safe and promising solvent for the extraction of vegetable oils in continuous equipment (Ferreira *et al.*, 2022).

By Baümler *et al*. (2016) investigated the ethanol extraction of sunflower oil and compared it with previous data, where hexane was used as the extraction solvent. Soxhlet first determined the extractive power of ethanol. This gave a higher yield of the extracted material, the content of soluble components of hexane (oil phase) was similar to that obtained with n-hexane. When ethanol was used as a solvent, 70% less crystallising waxes and at least 38% more tocopherols and phospholipids were extracted. The kinetics of ethanol extraction at 50 and 60°C in a periodic reactor were then investigated. Under equilibrium conditions, it was observed that extraction can be limited by the solubility of the extracted material. From the standpoint of the quality of the resulting products, this study demonstrated the feasibility of using ethanol as a solvent, an alternative to hexane, in the extraction of oil from sunflower cake.

O. Burdo *et al*. (2018) emphasised that the most important problems of human development (energy, ecology, food) are typical for the food industry, and their solution is associated with the search for new approaches to thermal processing of raw materials. The prospects of electrical technologies for targeted energy supply for individual elements of food raw materials using microwave processing are substantiated. Hypotheses of energy-efficient processes of dehydration, extraction and inactivation of microorganisms are formulated.

Microwave extraction is a popular extraction method that has high extraction performance and efficiency compared to other conventional methods. Microwave radiation interacts with the dipoles present in the sample matrix, causing them to oscillate in response to changing electromagnetic fields. Vibrations or rotation of dipoles during movement lead to the friction of molecules, which turns into heat and is transferred inside the material due to thermal conductivity. In addition to the dipoles from the solvent used in the extraction process, this heat leads to the formation of water vapour and electroporation effects that destroy the cell wall of oilseeds and enhance the effective extraction of intracellular metabolites (Mwaurah *et al.*, 2020).

Nonpolar solvents, when used by microwave extraction, show poor synergy between the solvent and microwave radiation due to their low permittivity. In addition, the microwave heating mechanism is based on the rotation of molecules or dipoles in combination with ionic conductivity. For these reasons, polar solvents are best suited for microwave extraction because they have a high dielectric constant, absorb more microwave radiation, and promote conductivity. Moreover, polar solvents showed better results than nonpolar solvents in most cases (Khan & Rathod, 2018). Ethanol has excellent microwave absorption properties, while the commonly used hexane is inert to microwave radiation.

Materials and Methods

The research presented in the paper was conducted from 2020 to 2022. Sunflower seeds from the batch of seeds received by the Vinnytsia fat and oil plant were used. The moisture content of sunflower seeds was determined in accordance with the DSTU ISO 10565-2003 standard "Oilseeds. Simultaneous determination of oil and moisture content. Spectrometry method using pulsed nuclear magnetic resonance" (2005). Sunflower seeds were processed by the press in accordance with the technology of sunflower oil production approved at the enterprise. Samples of cake that remained after pressing were taken for further studies of the extraction process. Rapeseed of the "Champion" variety of the 2021 harvest was used. Seed moisture was determined according to the current standard DSTU 8175:2015 "Rapeseed oil. Technical specifications" (2017).

Solvents. Hexane, as an extractive solvent, was obtained from Antekom LLC (Ukraine). Ethyl alcohol – from the manufacturer of the state enterprise SpirtLux (Ukraine).

Materials. Laboratory equipment: laboratory sieve, thermostat TS-80 M2, thermometer TL-2K, electronic scales PS 750/c/1 RADWAG®, desiccators, containers, flasks, weighing cups, drying cabinet SPT-200, drying cabinet 2B-151, analytical scales of the AS 310x series, experimental stand of microwave action (developed by Odesa National Technological University), gas chromatograph Agilent 8890 (manufacturer – Alsi Chrome (USA)).

Soxhlet extraction methods. Soxhlet extraction was carried out in accordance with DSTU 4492:2017 "Sunflower oil. Technical specifications" (2019). When using this method, 40 g of crushed sunflower cake (or crushed rapeseed) was weighed and transferred to the Soxhlet extractor. Extraction was completed in 22-24 hours at a maximum temperature of 50….68.7°C (boiling point of n-hexane). After the extraction process, the solvent residue was removed at 50°C and reduced pressure using a rotary evapourator (Heidolf, Germany). To further reduce the amount of solvent, the extracted oil was transferred to a TS-80 M2 thermostat (Ukraine) at a temperature of 50°C until a constant mass was reached. The resulting oil was weighed and the oil yield was calculated.

The same experiments were conducted with the ethyl alcohol solvent. Extraction was completed in 22-24 hours at a maximum temperature of 50....78.3°C (boiling point of ethyl alcohol). Determination was carried out in triplicate for individual solvents. Investigation of physical and chemical parameters of sunflower extraction oil obtained by Soxhlet extraction and oil extraction under the influence of a microwave field, were carried out by generally accepted methods of analysis, which are set out in the relevant standards and reference books on techno-chemical control of production, and by methods described in the state standards of Ukraine (Table 1). Testing of rapeseed oil was carried out in accordance with the standard DSTU 8175:2015 "Rapeseed oil. Technical specifications" (2017). Table 1 shows methods of sunflower oil testing.

Table 1. *Metodics of sunflower oil testing*

Indicator	Principle of the research method
Oil sampling and preparation for analysis	According to DSTU 4349:2004 (2005)
Mass fraction of moisture and volatile substances, %	According to DSTU ISO 662:2004 (2006)
Mass fraction of insoluble impurities, %	According to DSTU EN ISO 663:2019 (EN ISO 663:2017, IDT; ISO 663:2017, IDT)
Acid number, mgKOH/g	According to DSTU EN ISO 660:2019 (EN ISO 660:2009, IDT; ISO 660:2009, IDT)
Peroxide number, mol ½O/kg	According to DSTU EN ISO 3960:2019 (EN ISO 3960:2017, IDT; ISO 3960:2017, IDT)
Flash point, °C	According to DSTU 4455:2005 (2006)
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin, %	According to DSTU 7082:2009 (2011)
Anisidine number	According to DSTU EN ISO 6885:2019 (EN ISO 6885:2016, IDT)
Fatty acid composition of the oil	According to DSTU ISO 5508-2001 (2003)

Microwave extraction. A Samsung microwave oven (Korea, 425 W output power with a frequency of 2450 MHz) and a refrigerator connected to it were used (Fig. 1). For each cycle of the experiment, 40 g of sunflower cake (or crushed rapeseed) was weighed, a solvent (n-hexane, or ethyl alcohol) was added in the ratio of cake and solvent 1:3 in each cycle of experiments. Crushed sunflower cake or rapeseed was poured into a flask, filled with a solvent and exposed to an electromagnetic field for 10-20 minutes. Next, the kinetics of the process was studied.

The main elements of the experimental microwave stand were a chamber in which, due to the magnetron, a microwave field was created, and a container in which the actual process of extracting the objects of research took place: sunflower seed cake and winter rapeseed of the "Champion" variety.

The principle of operation of the experimental stand is as follows: in the container with the product, the extraction process takes place under the action of a microwave field in chamber 1. The extractant vapours enter the return refrigerator 2, condense, and flow back into the reaction tank with the test sample and solvent. A syringe is used to collect the seed for further study of the oil concentration.

Extraction was completed in 10-20 minutes. To further reduce the amount of solvent,

the extracted oil was transferred to a TS-80 M2 thermostat (Ukraine) at a temperature of 50°C until a constant mass was reached. The resulting oil was weighed and the oil yield was calculated.

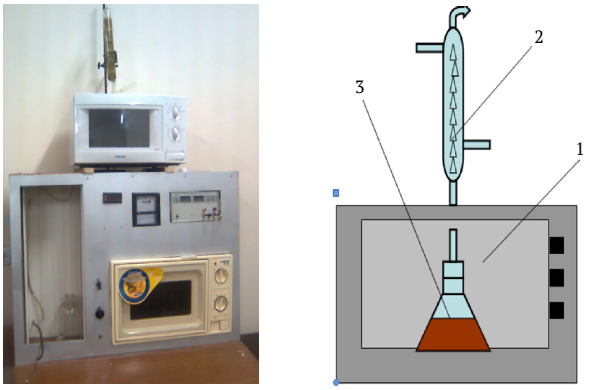

Figure 1. Photo and diagram of an experimental installation for extracting oil raw materials in a microwave field: 1 –microwave oven, 2 – return refrigerator, 3 – flask with raw material and solvent

Source: developed by the author

To obtain a control sample (sunflower and rapeseed oils), the authors used oils obtained at the Vinnytsia fat and oil plant using the current technology (extraction in a carousel extractor, hexane is used as a solvent.

To determine the fatty acid composition of the oil, an Agilent 8890 gas chromatograph (manufacturer – Alsi Chromium (USA)) was used. The fatty acid composition of the oil was analysed by gas chromatography using an HP-88 100 m*0.25 mm*0.2 mkm column. Experimental laboratory studies of extracted oils were conducted. The prospect of using the oil for food purposes was approved by conducting trial laboratory experiments to study and determine changes in physicochemical data for the storage period of 3 months.

Statistical analysis. The study was repeated three times and mathematically processed using Microsoft Excel 2007 to ensure the accuracy of the results obtained. The statistical error did not exceed 5% (with a 95% confidence level).

Results and Discussion

In the proposed extraction method, a thermal effect occurs on the processed product through the penetration of microwave energy into the material molecule, where radiation interacts with opposite molecules with the assistance of ionic conductivity and dipole rotation, accompanied by the release of heat. The degree of heating of raw materials depends on the dielectric constant of the material. The efficiency of microwave processing is related to the heating process, which significantly increases the internal pressure of cells, which causes their destruction. Extractives are mixed with a solvent after the destruction of the cell membrane.

In the conducted studies of the extraction process without the use of microwave energy, only under the influence of temperature, the solvent hexane is more effective than ethyl alcohol (Fig. 2).

Conducting studies using microwave energy allows increasing the yield of the extraction oil concentration over the same period of time

by 1.4-1.8 times while reducing the process time by almost 3 times. A study with the solvent polar ethyl alcohol proves that the intensity of oil extraction under the influence of ultrahigh-frequency action increased to the efficiency of hexane (Fig. 3). This is probably conditioned by the rupture of the cell structure of the material under the influence of microwave heating, which leads to an increase in the degree of solvent penetration into the internal structure of the material.

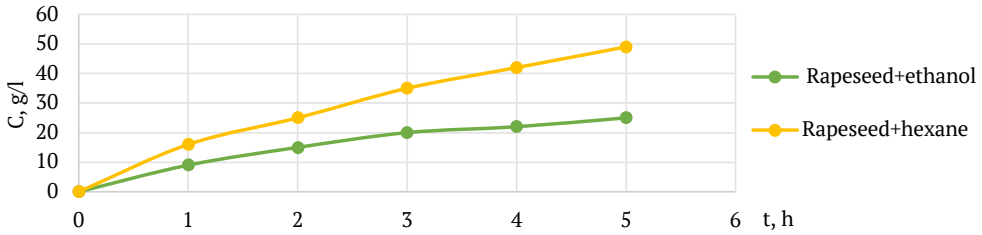

Figure 2. Change in oil concentration over time during oil extraction with solvents hexane and ethyl alcohol at a temperature of 50°C

Source: developed by the author

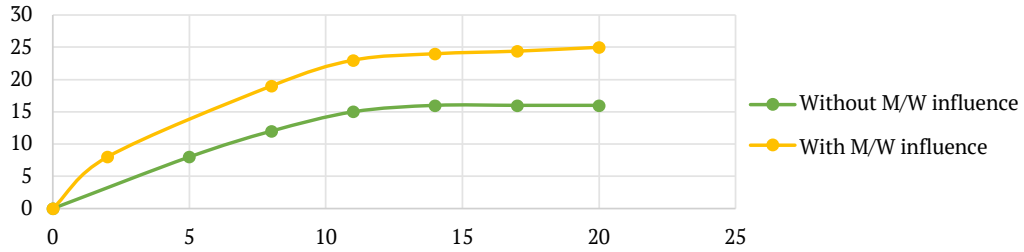

Figure 3. Change in the oil concentration from time during extraction of crushed rapeseed with ethanol at the boiling point of 78.3°C

Source: developed by the author

The results of the study of sunflower extraction oil obtained by Soxhlet extraction and under the influence of a microwave field are shown in Table 2.

Table 2. *Physical and chemical parameters of sunflower extraction oil were obtained after extraction with solvents: hexane samples No. 1, No. 3, and alcohol samples No. 2, No. 4*

Indicator	Soxhlet Method		Under the influence of a microwave field	
	Solvent hexane	Solvent ethyl alcohol	Solvent hexane	Solvent ethyl alcohol
Test sample	No. 1	No. 2	No. 3	No. 4
Mass fraction of moisture and volatile substances, %	0.18	0.17	0.19	0.16
Mass fraction of non-fat impurities, %	0.05	0.04	0.05	0.03
Acid number, mgKOH/g	3.1	2.5	2.8	2.1

Table 2. Continued

Indicator	Soxhlet Method		Under the influence of a microwave field	
	Solvent hexane	Solvent ethyl alcohol	Solvent hexane	Solvent ethyl alcohol
Peroxide number, mol ½O/kg	5.0	4.8	4.3	3.8
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin, %	0.45	0.41	0.43	0.38
Anisidine number, c.u.	0.3	0.25	0.28	0.2
Flash point, °C	226	227	226	225

Source: developed by the author

The obtained data from studies of the peroxide and anisidine numbers confirm the best indicators of the oil obtained by extraction of raw materials in a microwave field (solvent – ethyl alcohol). The oil obtained by extraction of raw materials in a microwave field with a solvent ethyl alcohol is more resistant to oxidation, as evidenced by a decrease in the numbers: peroxide from 4.8 to 3.8, and anisidine from 0.25 to 0.2. The acid number, which characterises the degree of freshness of the resulting oil, also decreased from 2.5 to 2.1.

Notably, the main guarantee of the nutritional value of oil is the fatty acid composition (Ivanov *et al.*, 2013). Together with the generally accepted oil parameters, the fatty acid composition of sunflower extraction oil was studied. The results are shown in Tables 3-6.

Table 3. *Fatty acid composition of sunflower extraction oil (sample No. 1)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{6:0}$	Caproic	0.07
$C_{14:0}$	Miristic	0.07
$C_{16:0}$	Palmitinic	6.49
$C_{16:1}$	Palmitooleic	0.09
$C_{18:0}$	Stearic	3.69
$C_{18:1}$	Oleic	28.37
$C_{18:2}$	Linoleic	59.23
$C_{20:0}$	Arachic	0.21
$C_{20:1}$	Eikosanoic	0.11
$C_{18:3}$	Linolenoic	0.16
$C_{21:0}$	Heneicosanic	0.18
$C_{22:0}$	Begenic	0.69
$C_{24:0}$	Lignoceric	0.17

Source: developed by the author

Table 4. *Fatty acid composition of sunflower extraction oil (sample No. 2)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{16:0}$	Palmitinic	6.87
$C_{16:1}$	Palmitooleic	0.09
$C_{17:0}$	Margaric	0.06
$C_{18:0}$	Stearic	3.67
$C_{18:1}$	Oleic	25.84
$C_{18:2}$	Linoleic	59.54
$C_{20:0}$	Arachic	0.68
$C_{20:1}$	Eikosanoic	0.30
$C_{18:3}$	Linolenoic	0.22
$C_{21:0}$	Heneicosanic	0.15
$C_{22:0}$	Begenic	0.82

Source: developed by the author

Table 5. *Fatty acid composition of sunflower extraction oil (sample No. 3)*

Conditional sign \acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{14:0}$	Miristic	0.08
$C_{16:0}$	Palmitinic	6.88
$C_{16:1}$	Palmitooleic	0.11
$C_{18:0}$	Stearic	3.27
$C_{18:1}$	Oleic	30.09
$C_{18:2}$	Linoleic	57.42
$C_{18:3}$	Linolenoic	0.25
$C_{20:1}$	Gondoinic	0.10
$C_{24:0}$	Lignoceric	0.21

Source: developed by the author

Table 6. *Fatty acid composition of sunflower extraction oil (sample No. 4)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{6:0}$	Caproic	0.19
$C_{8:0}$	Caprylic	0.05
$C_{14:0}$	Miristic	0.08
$C_{16:0}$	Palmitinic	7.18
$C_{16:1}$	Palmitooleic	0.17
$C_{17:0}$	Margarine-oleic	0.41
$C_{17:1}$	Margaric	0.19
$C_{18:0}$	Stearic	3.53

Table 6. Continued

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{18:1}$	Oleic	26.44
$C_{18:2}$	Linoleic	57.12
$C_{20:0}$	Arachic	0.19
$C_{20:3}$	Eicosatrienoic	0.67

Source: developed by the author

The composition of fatty acids of sunflower oil, in general, should include the following fatty acids: miristic (up to 0.2%), palmitinic (up to 5.0 to 7.6%), palmitooleic (up to 0.3%), stearic (from 2.7 to 6.5%), oleic (from 14.0 to 39.4%), linoleic (from 48.3 to 74.0%), linolenoic (up to 0.3%), arachic (from 0.1 to 0.5%), gondoinic (up to 0.3%), begenic (from 0.3 to 1.5%), lignoceric (up to 0.5%).

Thus, after conducting laboratory tests, it can be argued that sunflower oil extraction, obtained by the method of extraction of raw materials in a microwave field, meets the requirements of DSTU 4492-2017 (2017). A study of the fatty acid composition of rapeseed oil was also conducted (Tables 7 and 8) obtained by extraction in a microwave field with solvents hexane and ethyl alcohol of rapeseed meal.

Table 7. *Fatty acid composition of rapeseed oil (sample No. 1, hexane solvent)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{16:0}$	Palmitinic	7.53
$C_{16:1}$	Palmitooleic	0.14
$C_{18:0}$	Stearic	3.15
$C_{18:1}$	Oleic	27.66
$C_{18:2}$	Linoleic	60.08
$C_{18:3}$	Linolenoic	0.16
$C_{20:0}$	Arachic	0.22
$C_{20:1}$	Gondoinic	0.12
$C_{22:0}$	Begenic	0.46
$C_{22:1}$	Erucic	0.48

Source: developed by the author

Table 8. *Fatty acid composition of rapeseed oil (sample No. 2, ethyl alcohol solvent)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{14:0}$	Miristic	0.1
$C_{16:0}$	Palmitinic	7.3
$C_{16:1}$	Palmitooleic	0.16
$C_{18:0}$	Stearic	2.98
$C_{18:1}$	Oleic	28.79

Table 8. Continued

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{18:2}$	Linoleic	58.56
$C_{18:3}$	Linolenoic	0.23
$C_{20:0}$	Arachic	0.19
$C_{20:1}$	Gondoinic	0.16
$C_{22:0}$	Begenic	0.48
$C_{22:1}$	Erucic	0.5

Source: developed by the author

The findings show that microwave technologies are a powerful tool for implementing food nanoenergy technologies. They will, in comparison with conventional technologies, significantly increase the concentration for the same time period by 1.4 -1.8 times, as well as reduce the time of the process by almost 3 times, to create technologies for processing food raw materials that fully meet modern requirements of resource and energy efficiency, environmental safety, and market economy requirements. Since ethanol is non-toxic and safe, but extracts extractives more slowly than n-hexane, it is advisable to perform extraction in a microwave field.

Ethanol is one of the alternative solvents because it is cheap and can be produced by fermentation from a wide variety of biological materials using a simple technology, and is therefore designated as "natural" or "bio-renewable". The discrepancy for some target components is conditioned by the fact that they are insoluble in ethyl alcohol, which is a polar solvent. The choice of polar solvents is justified for microwave devices by the dipole shift effect. Therefore, if the main target component in extraction is those fatty acids that are insoluble in alcohol, a combined or other extraction method should be considered.

In the studies by Baümler *et al*. (2016) ethanol was used as the solvent, with 70% less crystallising waxes and at least 38% more tocopherols and phospholipids extracted. From the standpoint of the quality of the resulting products, this study demonstrated the feasibility of using ethanol as a solvent, an alternative to hexane, in the extraction of oil from sunflower cake. These studies confirm the relevance and results are presented.

Ying Li *et al.* (2014) evaluated the effectiveness of five alternative solvents (alcohols: ethanol, isopropanol, and terpenes: d-limonene, α-pinene, and n-cymol) compared to n-hexane in rapeseed oil extraction. The extracted oils were quantitatively and qualitatively analysed to compare solvent characteristics in terms of kinetics, fatty acid composition, lipid yield, and grades. In addition, the trace elements in the extracted oils were also quantified by high-performance liquid chromatography and gas chromatography, respectively. In addition, the interaction between alternative solvents and rapeseed oil was theoretically studied using the Hansen solubility methodology to better understand the dissolution mechanisms. The results showed that n-cymol may be the most promising solvent for replacing n-hexane with a higher lipid yield and good selectivity, despite the relatively low content of trace elements. But the authors did not specify that n-cymol is an organic compound, belongs to aromatic hydrocarbons and is highly toxic, which is dangerous for use in food technologies.

Candidate and doctoral theses have been published based on the results of studies on the efficiency of using the microwave field in extraction processes. According to the topic of the dissertation work (Levtrynska, 2017), coffee extraction was performed under the influence of a microwave field in a rarefaction chamber. During production tests of the device, coffee extract concentrate was obtained. According to the tasting reports, the resulting product has high quality, flavouring properties that are superior to ordinary instant coffee. No more than 0.65% of extractives remain in the spent solid phase, which confirms the effectiveness of the microwave field.

In the dissertation (Bandura, 2021), the results of oil extraction under the influence of a microwave field increase by 30%, and electricity costs decrease significantly. The recommended solvent for extraction in MX is poly-ethyl alcohol, as polar, safe, non-toxic and 1.5 times more intense than hexane in a microwave field environment. This is confirmed by the authors' research on the energy-efficient use of microwave technologies in ethyl alcohol extraction processes.

A. Binello *et al*. (2014) conducted a comparative study of classical hydrodistillation (HD), microwave hydrodistillation (MGH), and microwave hydrodiffusion and gravity (MHG) used in the extraction of four plant species cultivated in Piedmont (Italy): lavender, oregano, basil, and sage. Both microwave treatments yielded excellent results; in particular, the essential oils obtained with MHG were very similar to those obtained with HD. In MGH, the polarity and physicochemical properties of the extracted compounds caused large differences in the composition of the essential oil. The authors confirmed the effective effect of microwave energy in the hydrodistillation process.

Using basic research in the field of studying the action of the microwave field, an innovative technique is created (Burdo *et al*., 2018). To intensify and increase the energy efficiency of extraction processes, the principles of directed energy action and microwave action at the capillary level of the product are used. The main difference in this study is a more in-depth examination of the use of different solvents for oil extraction.

The research deepens the understanding of the feasibility of using a microwave field for various solid-liquid systems, the use of a green solvent improves the quality characteristics of the finished product and environmental safety, and is recommended for further implementation of these technologies in production.

Conclusions

The results of the conducted studies have shown that the use of microwave technologies increases the efficiency of the oil extraction process, oil density, oxidative stability, and oil colour index. Based on the results obtained, it can be argued that the use of microwave extraction with a polar solvent, which is ethyl alcohol, was effective in improving the quality properties of the extracted oil.

Since the obtained data from studies of peroxide (3.8), anisidine (0.2), and acid numbers (2.1) are lower in the oil values obtained by microwave extraction methods, they indicate a greater resistance of the oil to oxidation.

The use of a microwave field in the process of extracting oil raw materials with a polar solvent (ethyl alcohol) leads to a gradient-free wave supply of electromagnetic energy to polar molecules. It is due to this effect that a powerful diffusion flow of extract is obtained from the raw material, which is supplemented by the flow of a whole complex of components and does not degrade the quality of oils.

The results obtained confirm the improvement of the extraction process of oil materials using microwave energy, which increases the yield of the final product and speeds up the extraction process, ensuring high quality of the product, through the use of "green technologies" and environmentally friendly solvents.

Accordingly, the results obtained allow the recommendation of the microwave method for introducing vegetable oils with ethyl solvents into production. Promising areas of research are patenting this method and developing technological conditions for the production of vegetable oils. Since a more detailed investigation of the effect of the microwave field on the product is required and microbiological and technological studies of the finished product obtained using the new technology are necessary.

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Conflict of Interest

None.

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Показники якості екстрагованої соняшникової та ріпакової олії отриманої розчинниками гексаном та етиловим спиртом

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Анотація. Актуальність проведених досліджень зумовлена збільшенням попиту на олійну продукцію з покращеними та екологічно безпечними якостями, а саме заміною небезпечного розчинника в екстракційному процесі переробки олійного насіння. У зв'язку з цим дана стаття спрямована на застосування в технології екстрагування більш безпечного для здоров'я людини органічного розчинника, яким є етанол. Провідним підходом до дослідження цієї проблеми є екстракція за методом Сокслета та мікрохвильового екстрагування із застосуванням розчинників гексан та етанол. Дослідження жирно-кислотного складу отриманого продукту проводили методом газової хроматографії. У запропонованому мікрохвильовому методі екстракції олії «зеленим» розчинником, яким є етиловий спирт, досліджували фізико-хімічні показники та порівнювали їх із показниками отриманими за методом Сокслета. Ефективність мікрохвильового оброблення пов'язана з процесом нагрівання, що значно підвищує внутрішній тиск клітин, який викликає їх руйнування. Створюється бародифузійний потік, який сприяє вагомому, за однаковий період часу, у 1,4-1,8 рази збільшенню виходу концентрації екстракційної олії та зменшенню часу процесу екстрагування майже в 3 рази. Олія, отримана методом екстракції сировини в мікрохвильовому полі розчинником етиловим спиртом більш стійка до окислення про це свідчать зменшення чисел: пероксидного з 4,8 до 3,8, анізидинового з 0,25 до 0,2. Кислотне число, яке характеризує ступінь свіжості отриманої олії, також зменшилось з 2,5 до 2,1. Результати досліджень свідчать, що застосування мікрохвильового екстрагування полярним розчинником, яким є етиловий спирт, було ефективним для покращення якісних властивостей екстрагованої олії. Застосування «зеленого» розчинника не погіршує якості готового продукту на відміну гексану, який є шкідливим для здоров'я людини. Матеріали статті становлять практичну цінність для олієжирової промисловості, а саме в технології екстрагування олійної сировини

Ключові слова: розчинники; екстракція; гексан; етиловий спирт; мікрохвильова енергія; жирно-кислотний склад

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Development of safety and quality of propolis as a food raw material

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Abstract. It is promising to use propolis as a unique food ingredient with an awareness of the importance of each technological stage and the formation of its quality. Therefore, the purpose of the study was to conduct a systematic review of scientific information on the use of propolis as a food ingredient, with an emphasis on the stages of its formation in terms of quality. The study used

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the Torraco method to analyse and synthesise scientific information, the Springer scientific metric database, and the Google Scholar and Researchgate search tool. It was found that the safety and quality of propolis are formed at each of the stages. Propolis sources and their availability, collection, storage, and processing technologies play an important role. The search and investigation of new ways of processing and applying propolis allows widely using it as a food ingredient. Today, propolis can be used directly as a raw material for a significant number of food products, both directly and indirectly, as a component of new food packaging, and as a substitute for preservatives. Based on a systematic review of scientific information, it is proved that at each stage of the formation of propolis as a safe and high-quality raw material of food products, there are factors that can irreversibly affect the quality of propolis. Plant sources of propolis form types of propolis with appropriate chemical and physical properties, depending on the geography of origin. The geographical marker is an important indicator in the fight against the falsification of bee products. The availability of propolis sources in environmentally friendly beekeeping areas has a significant impact on quality. The use of advanced propolis collecting technologies adapted to the local climate ensures a proper economic effect and a reduction in the cost of raw materials. Proper compliance with sanitary and hygienic requirements during the collection, transportation, and storage of propolis improves its quality

Keywords: quality control; natural preservative; product; vegetable resin; balsam

Introduction

The traceability system as a tool for protecting businesses and consumers is largely implemented in the legislation of the EU and leading countries of the world. Food producers in Ukraine are also following the path of implementing best practices in consumer protection. Development and promotion of a healthy lifestyle also concerns food products as an important component of such approaches. The search for valuable food raw materials of natural origin that can improve food products by several factors is growing. Propolis can be a natural substitute for preservatives by its properties, as well as increase the value of food products due to its significant chemical composition and promote the use of natural ingredients in the food industry. Propolis is a product of plant and animal origin that goes through several stages of formation from vegetable resin to the prepared ingredient of food products. Minimising the factors that affect the quality and safety of propolis as a raw material at each stage will provide a product that does not require additional costs for cleaning, or complex processing with subsequent direct impact on the cost of food products.

Y. Irigoiti *et al*. (2021) note that propolis is a promising natural product for the food industry. Based on the results of a study conducted by Y. Tumbarski *et al*. (2022) propolis is used in the bio-preservation of meat, fish, eggs, milk and dairy products, perishable fruits, vegetables, fruit juices and other beverages. Propolis can be added directly to the food matrix as an extract, applied to the surface of the product as a bioactive film or edible coating, or included in food bio-packages. The use of propolis in the food industry, due to its specific organoleptic characteristics, requires its processing. Extraction is a key step in the use of bioactive components of propolis. V. Bankova *et al*., (2021) concluded that ethanol remains the best solvent today, while natural deep-extracting solvents (NADES)

are promising. H. Yıldırım *et al*. (2018) based on the results of the study, concluded that if it is necessary to overcome the factors that cause propolis allergy, biotransformation can be used. Biotransformation of propolis L. plantarum can be used to optimise propolis extract based on the required phenolic profile. At the same time, propolis, as a product of plant and animal origin, can also pose a threat to human health due to its natural and technogenic contamination, which is consistent with the results of studies by M.E. Conti *et al*. (2022). Although pesticides that have been banned for a long time and are not used in agriculture should not be ignored as potential contaminants. Mititelu, *et al*. (2022) accounted for the presence of the agrochemical (insecticide) DDT in the propolis samples they studied. According to A. Sharma *et al*. (2022), excessive use of veterinary drugs in violation of regulations also causes additional contamination of bee products. C. Arruda *et al*. (2020) found that failure to follow good beekeeping practices in the transportation and storage of propolis as a raw material can affect its quality. H. Hu *et al*. (2022) concluded that substance markers should be considered as a tool in detecting adulterated propolis. Therefore, the purpose of this study was to analyse and synthesise scientific information on the use of propolis as a food ingredient, with an emphasis on the stages of its formation in terms of quality and safety.

The authors used the Torraco method to conduct research and create new scientific information. The Springer scientific metric database, Google Scholar and ResearchGate search tools were used to collect the data.

Plant resins and balsams as sources of propolis production

Propolis is a sticky resinous substance collected by bees from the buds, leaves, and stems of wild plants and processed, which has bactericidal properties and is used for sealing cracks in the hive, polishing the walls of wax cells, embalming the corpses of stung enemies (mice, reptiles, etc.) (DSTU 4662:2006). The quality of propolis is influenced by factors at different stages of its formation as a separate product or raw material for use in food technologies. At the stage of formation of plant resin as a source of propolis, these are plant biodiversity, soil quality, technogenic pollution of the territory, and intensive agriculture. At the stage of transportation by bees to the nest – air pollution. At the harvesting stage – outdated collecting methods (manual scraping), lack of advanced technologies, lack of professionalism of beekeepers, and violation of hygiene conditions. At the stage of processing – lack of modern technologies and relevant knowledge, expensive equipment.

It is proved that propolis is of botanical origin and, depending on the climatic zone, honeybees collect propolis from various plants (Bankova *et al*., 2000). In the temperate climate zone to which Ukraine also belongs, the following sources of propolis were identified: *Betula pendula* Roth, *Populus tremula* L, Populus nigra L., (*Populus nigra* L. X *Populus x euramericana* buds) P. x canadensis (a hybrid of black poplar) (Anđelković *et al*., 2017; Bankova *et al*., 2018; Ristivojević *et al*., 2022). A study of propolis samples obtained in Ukraine (Crimea and Poltava oblast) by sources of origin found that the main dominant component is resins *Populus nigra* L. (black poplar) while, for example, samples obtained from Belarus contain a mixture of resin *Populus nigra* L., *Populus tremula* L. and *Betula pubescens* L. Propolis samples from Poland had a more pronounced content of *Betula pubescens* L. resin compared to samples from Belarus. Propolis from the north-eastern region of Russia has the main component of resins of *Betula pendula* L. *Pinus pinea* L. (Italian pine), *Pinus ni-*

gra L. (European black pine), *Pinus halepensis* L. (Aleppo pine), as well as *Pinus brutia* L. (Turkish pine), serve as a characteristic source of propolis resin on the islands of the east Aegean Sea, Cyprus, Greece (Milojković Opsenica *et al*., 2016). *Populus tremuloides* Michx.(Aspen-like poplar), *Populus deltoids* Marsh.(triangular-leaved poplar, Canadian poplar), *Populus fremontii* Wats., *Populus maximoviczi* Henry (topol maksimovich), *Populus trichocarpa* Torr. (California poplar) are common source of propolis in Canada (Christov *et al*., 2006; Al Naggar *et al*., 2016).

The study was conducted in 2018 by scientists from the Institute of Apicultural Research, Chinese Academy of Agricultural Sciences (Beijing, China) (Xue Wanga *et al*., 2018) proved that the main component of propolis from China is hybrid resin *Populus nigra* L. and *Populus deltoides* L. This is *Populus canadensis* Moench. (Wang *et al*., 2018). There is an opinion that the likely source of propolis in Greece is the island of Samothraki *Quercus pubescens* Willd (Italian oak), *Prunus dulcis* Mill (Almond), *Prunus amygdaliformis* Vill, *Paliurus spina-christi* Mill (Jerusalem thorn) (Papachristoforou *et al*., 2019;). It is proven that *Populus balsamifera* L. (balsam poplar) is the main source of propolis in Oregon, California, and Minnesota (Aliboni, 2014). *Mangifera indica* L. (Mango) has been identified as the main source of propolis resin in the following countries: Oman, Indonesia, Thailand, Cameroon, Fiji (Sanpa *et al*., 2017; Bankova *et al*., 2018). In Oman, scientists have identified, in addition to the above-mentioned plant, such sources of plant resins for the production of propolis by honey bees: *Azadirachta indica* A.Juss, *Acacia nilotica* L. Del (genus Acacia spp.) (Popova *et al*., 2013).

Researchers have found that the juice of *Rhus javanica var. chinensis* (Mill.) (Sumac Chinese) is also a source of propolis in Japan (Murase *et al*., 2008). A common source of propolis in northwestern Argentina is the shrub *Zuccagnia punctata* Cav. (Solorzano *et al*., 2017). A *Larrea nitida* Cav. plant has also been identified in Argentina as a source of propolis resin (Miguel & Figueiredo, 2017). The source of the famous red propolis in Brazil (de Pontes *et al*., 2018) and Cuba are *Dalbergia ecastaphyllum* L. Studies have established that the seasonality of collecting red propolis collected by honey bees with *Dalbergia ecastaphyllum* (L.) Taubert. influences its effectiveness. When comparing resin collected directly from *Dalbergia ecastaphyllum* (L.) Taube and propolis collected by bees from *Dalbergia ecastaphyllum* (L.) Taube, propolis extract was found to have greater cytotoxicity compared to the resin extract itself. This result gave researchers reason to put forward a hypothesis about the modification of the resin. *Dalbergia ecastaphyllum* (L.) Taube during the production of propolis by bees from the resins of the specified plant (da Silveira Regueira-Neto *et al*., 2018). *Mimosa tenuiflora* L. has been identified as a source of propolis in Brazil (Ferreira *et al*., 2017). Plant genus *Dalbergia* spp. serves as a source of propolis for honeybees in countries such as Nigeria and Mexico (Omar *et al*., 2016).

S. Kumazawa found that the source of plant resins for propolis production by honeybees in Korea (Jeju Island) is the plant Angelica keiskei (Miq.) Koidz. Macaranga tanarius L. is one of the proven sources of propolis resin in countries such as Japan (Okinawa), Indonesia, Taiwan, the United States (Hawai), and the Solomon Islands, which is commonly referred to as "Pacific propolis" (Kumazawa, 2018).

Currently, the only known plants whose resin is collected directly from flowers are *Clusia minor* L. and *Clusia major* L. (Guttiferae). This plant serves as a source of propolis in countries such as Venezuela, Cuba, and Brazil (Spulber *et al*., 2017). One of the most scientifically studied plants in the context of the

plant-bee today is *Baccharis dracunculifolia* DC, which serves as a source of green propolis produced mainly in Brazil, despite the fact that this plant is common in tropical regions (Rodriguez *et al*., 2019; Hodel *et al*., 2020).Teixeira *et al*. (2005) found that honeybees during the collection of resinous secretions from plant *B. dracunculifolia* DC fragment the vegetative upper parts of the plant by moving them to the back pair of legs. In the future, the plant regenerates the vegetative parts by releasing side shoots. This symbiosis of honeybees and this plant contributes to an increase in the number of vegetative processes and the source of propolis, respectively. At the same time scientists Rodriguez *et al*. (2019) found that bees tend to visit female plants *B. dracunculifolia* DC and, accordingly, the authors recommend planting them to increase the productivity of propolis collection. In addition, the researchers recommend transporting an apiary focused on collecting propolis to the place of the greatest accumulation of plants, which is its source (Rodriguez *et al*., 2019; Teixeira *et al*., 2005).

Honeybees collect exudates for the production of red propolis *Dalbergia ecastaphyllum* L. To increase the access of honey bees to the resinous secretions of this plant, beekeepers resort to incisions in the bark. Thus, they contribute to increasing the productivity of bee colonies in collecting valuable red propolis. Regueira, *et al*. (2017) studied seasonal changes in resin composition of *D. ecastaphyllum* L. and the best periods for collecting propolis were determined, during which propolis has increased activity (de Pontes *et al*., 2018; Regueira *et al*., 2017; Daugsch *et al*., 2018).

Research on the aetiology of honey bee collection of propolis from *Macaranga tanarius* L. fruits helps determine optimal propolis collecting periods. Studies show that the basis of propolis when collected from this plant is the coating of young unripe fruits, which honey bees remove and form into lumps on their hind legs for further transfer to the nest (Murase *et al*., 2008; Salatino A. & Salatino MLF, 2017).

Paying considerable attention to scientific research on propolis sources contributes to knowledge and practical actions to improve them, which affects the productivity of bee colonies and the production of valuable types of this raw material. In general, plants as sources of propolis can be divided into wild and cultivated (Salatino *et al*., 2021).

Planting cultivated propolis sources in technogenically contaminated areas (roadsides, forest protection strips of agricultural land, buffer zones) causes contamination of propolis as a product.

The lack of an available plant base for the accumulation of propolis by honey bees in the nest, in case of such needs, can lead to the search for substitutes (bitumen, industrial paints, gardening putties), which will lead to contamination of bee products that should be avoided (Breyer *et al*., 2016; Özenirler *et al*., 2018).

Propolis productivity of honeybees

Morphometric parameters of the honey bee are one of the factors that affect propolis productivity. Research conducted by Kekeçoğlu *et al.* (2020), on the productivity of such bee races *Apis mellifera caucasica*, *Apis m. carnica*, *Apis me. syriaca* and ecotype *Apis m.anatoliaca* consisted in investigating the interdependence of performance and exoskeleton parameters such as wing width and length, leg length (shin length, hip length, heel length and width), and mandible parameters. Based on the results of the study, there was a significant correlation between bee body size and propolis productivity (Kekeçoğlu *et al*., 2020).

Salatino *et al*. (2017) suggested that the spectrum of plants that serve as a source of

propolis is conditioned by the anatomical structure of the honey bee's mouth apparatus and the inability to manipulate certain types of plant resins based on the efforts that the bee can tear off a piece of resin (too weak mandibles) (Salatino & Salatino MLF., 2017).

The influence of the bee race on the choice of plant species serving as a source of propolis was investigated by Eroglu *et al*. (2021). The experiment conducted by researchers in Turkey involved honey bees of races *Apis m. caucasica*, *Apis m. carnica*, *Apis m. syriaca* and ecotype *Apis m. anatoliaca*. Propolis collection in all experimental groups was carried out using plastic grids. The obtained samples were examined for the presence of pollen grains in terms of chemical and botanical composition. Based on the findings, researchers came to the conclusion that each breed of bee in the same conditions preferred different plant sources of propolis (Eroğlu *et al*., 2021).

The authors' observations on the propolis productivity of honey bees in the Kyiv oblast indicate that each bee colony has an individual predisposition to propolis productivity. These conclusions are also confirmed by the results published by Lima *et al*. (2015). A review and study of 415 bee colonies in terms of propolis productivity within 15 days showed that 15% of bee colonies collect too little propolis, 20% of bee colonies collect more than 100 grams, and only one – 320 grams (Lima *et al*., 2015). With this in mind, the genetic predisposition to propolis is another factor affecting propolis productivity.

Therefore, the issue of proper breeding is no less important, considering the above. The results of breeding show that after the first generation, propolis productivity increases by 27.92%, and in the third generation – by 71% compared to the original one (Manrique, 2001).

Collection of propolis from bee colonies, its contamination, identification and falsification

The creation of unfavourable conditions, such as a violation of the microclimate of the bee nest, is the basis for activating the instincts of honeybees to increase the delivery of propolis to the nest. Today, the most efficient collectors and collection methods based on disturbing the microclimate of a bee's nest are known, including the following:

- the "Sarrafo" method, which involves placing two slats measuring 2×3 cm and 45 cm long on both sides between the nursery and feeding part of the honey bee nest. Propolis productivity is determined to be 960 g per year. (de Ayala *et al*., 2019);
- collection of propolis using the EGPP (Elias Green Plate Propolis) method using CPI (Intelligent Collector of Propolis) collectors. Collectors are made in the form of frames that are inserted into the body of the hive and form a gap of 30×430 mm. The capacity of the specified collector is from 600-1,000 g per month (de Ayala *et al*., 2019);
- the collector in the form of a canopy frame "Marco Colector de Propóleo" (Spanish) made of wood. The holes in the collector are made of the middle and rear walls and in various versions can be 1 or 2 cm high. The collector capacity is 900 grams from one bee colony per year. Cleaning the Collector involves cooling it for 24 hours (Breyer *et al*., 2016);
- "Colector de Propóleo Pirassununga" was developed by Brazilian Carlos Eduardo Conceiçao in 2000. Sliding plates are mounted in the grooves on one side and the other in the body of the beehive. The initial gap between the plates is 2 cm as propolis is deposited by honey bees, the gap is increased by moving the plates apart. Propolis productivity depends on climatic conditions, the availability of propolis sources and averages 1,200 g per year.

By the time these collecting methods were created and tested, propolis was collected by cleaning the nest elements with a beekeeper's chisel. Productivity was 100-300 grams per season (Lima *et al*., 2015). These methods of collecting propolis from the standpoint of the quality of the collected propolis have both positive and negative aspects. Rapid logging of collectors allows collecting frequently and this has a positive effect on quality. At the same time, due to significant holes, additional protective measures should be taken to prevent dust and leaves from entering the product, theft and attacks by enemies and pests of honeybees. Results of a study by Lima *et al*. (2015) show that using a honeybee instinct such as protecting nest feed stocks significantly affects propolis productivity. Among the four study groups, bee colonies that did not take honey and had sufficient amounts in the nest along with additional feeding with sugar syrup had higher propolis productivity than the groups without feeding, respectively (Lima *et al*., 2015).

The next and important factor affecting the quality of the resulting propolis is proper sanitary and hygienic production conditions and the sanitary and veterinary condition of beekeeping farms and industrial premises. Researchers (Matin *et al*., 2016) from Izmir (Republic of Turkey) conducted a study on the content of heavy metals (Pb, As, Cd and Hg) in samples of honeybees, propolis, and pine needles, which were the source of resins for propolis. The results of the study showed an excessive content of heavy metals in propolis samples. At the same time, no Hg (mercury) content was detected in any sample (Matin *et al*., 2016). Studies of products produced using propolis were conducted by González-Martín *et al*., (2018). In total, according to the reports, 31 products from 7 countries (Spain, Portugal, Belgium, the United Kingdom, the United States, and Chile) were analysed. Seven acaricides, fungicides, and herbicides were found in the studied product samples. Triadimephone systemic fungicide was present in 65% of the samples of the studied products. The heavy metal content of Cr, Cu, Ni, Pb, and Zn was analysed and found that 42% of the samples had a Pb content above 0.1 ppm. The content of Cr (chromium) in the study samples was at the level that if 10 grams of the product were consumed, the daily permissible volume of consumption of this element would be fulfilled (González-Martín *et al*., 2018).

De Oliveira Orsi *et al*., (2018) conducted a study of the content of heavy metals in propolis from Brazil and the rate of their entry from the resulting raw propolis into the ethanol extract of propolis. A total of 106 propolis samples were examined for Ni, Cr, Hg, Cd, Pb, and Sn content. The analysis revealed the presence of all these elements in propolis. The authors note that when propolis was extracted with ethanol, the movement of the detected metals was low, which allows the use of the resulting extract as safe for consumption (de Oliveira Orsi *et al*., 2018).

H. Akkaya *et al*. (2020) examined the collected 100 propolis samples to investigate the contamination of propolis with bacteria *Escherichia coli*, *Staphylococcus aureus, Clostridium botulinum* and *Nosema* spp. In the study samples, 14 (14%) were found to be infected with bacteria belonging to the group of coliform bacteria, 5 (5%) Escherichia coli, 38 (38%) Staphylococcus aureus, 11 (11%) *Clostridium botulinum*, and 8 (8%) Nosema spp. Researchers came to the conclusion that propolis contamination could have occurred both during its production and during primary processing (Akkaya *et al*., 2020). Long-term use of the veterinary drug thymol may lead to the presence of its residues in propolis (Miguel *et al*., 2013).

Falsification of poplar-type propolis is mainly carried out by replacing it with poplar

bud extracts (*Populus* spp.). Huang *et al*. (2014) conducted a comparative study of propolis samples collected in China and poplar bud extracts for the identity of chemical composition. Based on the results of the study, it was found that Catechol is present in all the studied samples of poplar bud extract. No Catechol was detected in the tested propolis samples. Researchers have concluded that Catechol is probably oxidised by polyphenol oxidase during the processing of plant resins by honeybees and therefore is absent in propolis. Thus, Catechol can serve as a marker substance in the study of propolis for falsification by poplar bud extracts (Huang *et al*., 2014).

H. Hu *et al*., (2022) based on results obtained, proposed two substances 9-oxo-ODE and 9-oxo-ODA as markers that distinguish the type of poplar propolis from poplar bud extracts. During the studies, it was found that in 57 propolis samples, the ratio of 9-oxo-Ode and 9-oxo-ODA to pinobankin was less than 0.7, while in poplar bud extracts the value was higher. This approach, according to the researchers, opens up new opportunities in identifying the authenticity of propolis (Hu *et al*., 2022).

The search for marker substances is important, since the export of raw propolis due to possible infection with various parasites is prohibited in many countries. Accordingly, the export of extracts or microencapsulated propolis should be verified for authenticity due to the presence of marker substances.

Despite the fact that such agrochemical (insecticide) as DDT (Dichlorodiphenyltrichloromethylmethane) is not used in agriculture in most countries of the world, Mititelu *et al*., (2022) examined 144 samples of honey, propolis and soil collected from different regions of Romania. According to the results of the study, the concentration of heavy metals in propolis from industrial areas was: 0.080 ± 0.006 mg/kg Cd, 3.203 ± 0.052 mg/kg Cu, 4.195 ± 0.067 mg/kg Zn, 2.344 ± 0.006 mg/kg.kg Cr, 0.651 ± 0.063 mg/kg Pb, 1.146 ± 0.061 mg/kg Zn and 2.184 ± 0.067 mg/kg Mn. The pesticide content of propolis from the industrial zone was the concentration in the total DDT (0.0867 mg/kg), which is 1.7 times higher than the maximum permissible for food products in accordance with Commission Regulation (EU) No. 396/2005 (Mititelu, *et al*., 2022).

W. Chmielewski (2002) examined 70 samples of propolis collected in Poland. The following Entomological objects were identified and identified in the prototypes: *Acarus siro* L., *Acarus immobilis* Griffiths, *Tyrophagus longior* Gerv., *Tyrophagus putrescentiae* Schr., *Carpoglyphus lactis* L., *Glycyphagus domesticus*, *Lepidoglyphus destructor*, *Melichares tarsalis* Berl., *Cheyletus eruditus* Schr., *Tarsonemus fusarii* Cooreman, *Varroa jacobsoni* Oud., *Stegobium paniceum* L., *Anthrenus museorum* L., *Anthrenus verbasci* L., *Dermestes lardarius* L., *Dermestes maculatus* De Geer, *Trogoderma granaria* Everts, *Ptinus fur* L., *Tenebrio molitor* L., *Tribolium madens* Charpentier, *Apis mellifera* L., *Paravespula germanica* F., *Achroia grisella* F., *Cadra cautella* Walker, *Ephestia elutella* Hubner, *Galleria mellonella* L., *Plodia interpunctella* Hubner, *Tineola biseliella* Hummel, *Lepinotus inquilinus* Heyden, *Liposcelis divinatorius* Muller, *Lachesilla pedicularia* L., *Forficula auricularia* L., *Lepisma saccharina* L., *Chelifer canroides* L. It is noted that the most contaminated samples were collected by the classic method of cleaning various elements of the honey bee nest. Samples of the collected propolis contained honey, wax, bee bread, and particles of the bee exoskeleton, which can cause the presence of various pests that feed on these objects at different stages of their development. In addition, the storage of propolis in open containers and in various utility rooms contributes to its contamination with various entomological objects. Propolis,

which was collected in an experimental apiary using plastic gratings and stored in closed containers at low temperatures, was the cleanest compared to propolis from commercial apiaries (Chmielewski, 2002).

Storage and transportation of raw propolis

L. Saccardi *et al*. (2021) investigated weight loss with propolis. Three samples were weighed at 10-second intervals for 7 hours at 24°C and 45% relative humidity (RH). According to the results, it is noted that the propolis samples that were examined formed a hardened outer layer, although the inner part of the propolis samples remained softer. To characterise the evaporation process of volatile components, the weight of propolis samples was measured over time. On average, the samples lost 0.9 ± 0.3% (N = 3) by weight for seven hours at room temperature of 24°C.

To assess food quality, the values of α-dicarbonyl compounds (α-DC) are regularly measured. Storage stability is an important aspect of food safety. During propolis storage (Song *et al*., 2021) monitored 10 α-DC in BGPE (Brazilian green propolis extract) and CPPE (common poplar propolis extract) every three months for one year. The levels of most α-DC species remained relatively unchanged during storage, while 3-DG (3-deoxyglucosulose), MGO (methylglyoxal), and GS (glucosone) fluctuated. 3-DG was the only α-DC that was constantly crumpled during storage. Thus, 3-DG may be a potential compound that characterises propolis ageing. In both types of propolis, GS decreased during the first half of the year and then levelled off. With long-term storage, MGO levels decreased for the first nine months, and then slowly increased. Degradation of 3-DG in MGO due to the reverse aldol condensation reaction may explain this phenomenon (Song *et al*. 2021).

Propolis processing and use in the food industry

The use of propolis as a raw material in the food industry is primarily related to its antimicrobial properties. According to many authors, propolis counteracts pathogenic bacteria, fungi, yeast and viruses (including coronaviruses) (Ali *et al*., 2021). S. Sallemi *et al*. (2022) conducted a study of a column of fungi cultured from Tunisian propolis and evaluated their antibacterial properties against pathogenic bacteria. A total of 80 fungal strains were isolated from propolis samples obtained from seven different locations in Tunisia. Most of the isolated fungi were attributed to *Ascomycota* spp. (97.5%), and only 2.5% referred to *Basidiomycota* spp. The resulting list of fungi contained 15 genera, including *Coniochaeta* spp.(36,25%), *Aspergillus* spp. (15%), *Penicillium* spp. (13,75%), *Cladosporium* spp. (10%), *Fusarium* spp. (7,5%), *Didymella* spp. (5%) and *Alternaria* spp. (3,75%) were the most common. Evaluation of antibacterial activity showed that 25.6% of all fungal colonies showed a wide range of antibacterial activity. In particular, the strain *Penicillium griseofulvum* CC8 showed the strongest inhibitory effects against all bacteria. Researchers have suggested that the antimicrobial activity of propolis may be conditioned by antibacterial compounds produced by propolis-related microorganisms, especially fungal colonies, which may contribute to the internal protective role of propolis against parasites and pathogens.

Researchers see the point in further study of the methods and technologies of foodomics (Table 1). Fudomics is a new area of research in food science that applies advanced omics technologies to assess relevant aspects related to food and nutrition, with the ultimate goal of improving human health and well-being. Fudomics combines the approaches of food chemistry, biological sciences, and bioinformatics and

introduces four main types of high-performance technologies, such as genomics, transcriptomics, proteomics, and metabolomics. Chemically, propolis is made up of more than 300 different compounds, including polyphenols, phenolic aldehydes, and ketones (Kafantaris *et al.*, 2021).

Table 1. *Omics technologies used in propolis research*

Propolis	Omics technology	Application	Advantages/disadvantages
Transcriptomics	microarrays	bioactivity, differential analysis of gene expression	microarrays (low cost, well-defined hybridisation protocols/limited dynamic range)
Proteomics	2D-PAGE and LC-MS, HPLC-PDA-ESI-MS, LC-ESI-QTOF-MS, HPLC - GC-MS, HPLC-DAD-MS, 1-D SDS-PAGE and NMR	protein identification and quantification, chemical profile, geographical and botanical origin, quality control, bioactivity	NMR (reproducibility, accuracy/ significant equipment cost) MS (high sensitivity, quality features/ cost) 2D-PAGE (more information/ time-consuming, not automated, expensive)
Metabolomics	HPLC-DAD-MS/MS, LC-MS, NMR	geographical and botanical origin, bioactivity	MS (high sensitivity, quality features/cost) NMR (reproducibility, small sample volumes, accurate/expensive instrument)
Metagenomics	Illumina Miseq NGS platform	identification, quantification, and diversity of microbial colonies	Illumina Miseq NGS (simple, scalable, high-performance/ expensive hardware)

Notes: 2D-PAGE – two-dimensional polyacrylamide gel electrophoresis; LC – MS-liquid chromatography-mass spectrometry; HPLC-PDA-ESI-MS – high performance liquid chromatography-photodiode matrix-electroplating ionisation mass spectrometry; LC-ESI-QTOF-MS – liquid chromatography – electroplating ionisation-quadrupole flight time-mass spectrometry; HPLC-GC-MS – high-performance liquid chromatography – gas chromatography-mass spectrometry; HPLC-DAD-MS – high-performance liquid chromatography – diode matrix detection-mass spectrometry; 1-D SDS-PAGE – one-dimensional sodium electrophoresis in dodecyl sulphate-polyacrylamide gel; NMR – nuclear magnetic resonance; NGS – next generation sequencing
Source: Kafantaris *et al.*, 2021

Preservatives play an important role in extending the shelf life of food products. As noted by Gomes *et al*. (2021), the demand for natural antimicrobials as food preservatives has increased due to the growing public interest in a healthy lifestyle. They evaluated the minimum inhibitory concentrations of three natural antimicrobial compounds – chitosan, ethanol extract of propolis and nisin, against 37 microorganisms (various pathogens and microorganisms that cause food spoilage) by agar dilution and drip diffusion on agar. Nutrient media with different pH values were used for both methods of simulating different foods. Most microorganisms were inhibited by chitosan (0.5% wt./ob.) and propolis (10 mg/mL), and most gram-positive bacteria – nisin (25 mcg/ml). Petruzzi *et al*. (2020) investigated the activity of propolis, relative to strains *Pseudomonas* spp., Enterobacteriaceae, *Lactobacillus plantarum*, yeast *Saccharomyces cerevisiae* and *Debaryomyces hansenii*) and *Fusarium oxysporum*. The researchers used two approaches (a modified micro-dilution protocol and counting viable microorganisms). Microorganisms were seeded at two levels (low or high inoculate).

It is noted that the antimicrobial effect of propolis depends on several factors, such as: the type of microorganisms (for example, *S. cerevisiae* was more stable than *D. hansenii*, whereas *Lactobacillus plantarum* was not affected); cell concentration (with high inoculation, more propolis was required for antimicrobial action); mode of action (growth retardation, not complete inhibition).

Packaging is an important part of the food industry. Food packaging is directly related to quality and safety, including expiration dates and marketing communications. The current trend of consumers towards eco-friendly packaging is growing. Origin, type of production, and packaging are the three most important indicators that assess the environmental impact of food products. The intelligent packaging system indicates and monitors the physical and chemical conditions of the product (for example, the degree of freshness) and environmental influences (for example, temperature, pH level, gas) during transportation and storage.

Edible films and coatings are bound to natural antimicrobial agents and biologically active polymers found in carbohydrates or food proteins (Yan *et al.*, 2022). Due to the presence of a large number of polyphenolic compounds, propolis extract (especially alcohol-based propolis extract) is widely used in the development of active packaging films (Yong & Liu, 2021). State-of-the-art biopolymer-based packaging technologies, such as active packaging, are creative solutions to improve the safety and quality of packaged food products.

L.M. Júnior *et al.*, (2022) conducted a study in which pectin (P) powder from citrus fruits was mixed with green propolis (PE) extract (i.e., P/PE films), which were obtained by casting. The effect of various PE concentrations (1-3% by weight) on the physical and chemical properties of films was studied. Regardless of the added PE concentration, scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FT-IR) did not reveal significant morphological and structural changes in pectin-based films. The addition of polyethylene improved the barrier properties of P-films for UV light. In addition, the antioxidant activity of P films (12.6%) significantly increased to 54.8% (P/PE 3% film), which indicates the potential for using P/PE film as active food packaging (Júnior *et al.*, 2022). Ardjoum *et al.*, (2023) according to the results of the study, it is noted that the addition of alcohol extract of propolis and essential oil *Thymus vulgaris* in films with corn starch showed a synergistic effect against *Escherichia coli* and *Listeria monocytogenes*. The antimicrobial composite films developed by the researchers can be used in food packaging.

Marcinkowska-Lesiak *et al.*, (2021) evaluated the effect of a gelatin coating enriched with ethanol propolis extract (PE) at a concentration of 1%, 2% or 3% (wt./ob.) on the quality parameters of pork during storage at 2°C. The results of the study showed that a high level of prevention of physicochemical changes and maximum inhibition of microorganisms were obtained for meat samples stored in gelatin coatings containing 2% and 3% PE. In addition, despite a slight deterioration in odour on Day 4 in the PE group, no negative changes were observed compared to uncoated samples. The results show a significant role of introducing propolis extract into gelatin packaging to extend the shelf life of pork during storage.

El Sheikha *et al.*, (2022) examined their developed carboxymethylcellulose (CMC) coatings containing various concentrations (0, 1, 2, 3, and 4%) of propolis ethanol extract (PEE) to extend the shelf life of chicken meat (pectoral muscles) stored at 2°C for 16 days. Significantly lower weight loss and pH ($p \leqslant 0.05$) during the storage period were observed in

coated samples compared to uncoated samples (control). MetMb content was significantly reduced ($p \leqslant 0.05$) in coated samples compared to the control. In addition, the addition of PEE to CMC was more effective in inhibiting microbial growth, preventing lipid oxidation, and maintaining the overall acceptability of coated chicken breast meat compared to the control. In the study, scientists present CMC and EPP as alternative preservatives for the production of active packaging coatings for chicken meat.

J.F. Mafra *et al.*, (2022) evaluated the oxidative, microbiological, and sensory stability of fish salami containing red propolis hydroalcoholic extract (RPHE) instead of the antioxidant butylhydroxytoluene (BHT). Initially, RPHE was characterised chemically and biologically. Then, during maturation, the antimicrobial and physicochemical activity of the most acceptable salami composition was evaluated in organoleptic analysis (F3 = 0.4% RPHE) and control compositions (F1 = 0.01% BHT and F5 = no antioxidant). RPHE has shown promising biological activity. 16 chemical compounds were identified in RPHE, including the chemical marker formononetin. Salami with 0.4% RPHE demonstrated high sensory acceptability and effectively delayed spoilage (19.67 mg TVB-n 100/g) and lipid oxidation of salami (0.7 mg MDA-eq/kg). The use of RPHE as a natural preservative is promising for the production of fish salami.

Ucar, (2022) investigated co-microcapsulation of a cell-free extract (CFE) obtained from *Lactobacillus reuteri*, with aqueous and ethanal propolis extracts (1% CFE), to study their enhanced antibacterial activity against four fish spoilage-causing bacteria (*Pseudomonas luteola, Enterobacter cloacae, Photobacterium damselae* and *Proteus mirabilis*). The results of the analysis showed that microencapsulated CFE with *L. reuteri* in combination with propolis extracts (aqueous and ethanal), contained organic acids, hydrocarbons, phenolic acids/flavonoids, and benzene derivatives. *P. mirabilis* fish spoilage bacteria were found to be the most sensitive to CFE from L. reuteri. The results of the study showed that the combined use of propolis extracts, especially alcohol extract with CFE, obtained from *L. reuteri* in microencapsulated form, generally showed a higher antimicrobial effect on all tested bacteria.

E. Olewnik-Kruszkowska *et al*. (2022) produced polymeric films based on polylactide (PLA) with the addition of polyethylene glycol (PEG) and propolis chloroform extract. According to the results of the study, propolis significantly affects the properties of moulded materials, extending the shelf life of blueberries packed in new films.

A.A. Areff *et al*. (2022) note that propolis is one of the methods of preventing post-harvest losses in the food industry. Scientists tested the prepared coating based on an ethanol extract of propolis for antifungal activity against *Colletotrichum gloeosporioides*, a fungal pathogen that causes anthracnose on a banana (*Musa acuminata*). All samples were artificially inoculated *C. gloeosporioides* and the disease severity index (DSI) was measured. Other post-harvest qualities of bananas tested were weight loss, total soluble dry matter (TSS), colour, and titrated acidity (TA). The results showed that control banana samples were more affected by fungi (necrosis 60%) compared to treated ones. Propolis coating successfully suppressed fungal activity *C. gloeosporioides* on a banana during storage. Control samples showed greater weight loss (6.92%) and total soluble solids ($p < 0.05$) compared to bananas in the shell during storage. It was found that bananas treated with a coating with 11% propolis concentration are promising for improving colour, total soluble solids and titrated acidity, and are also able to inhibit artificial anthracnose disease caused

by *C. gloeosporioides*. Soares *et al*., (2022) investigated the quality of eggs subjected to various processing methods. 144 fresh red eggs were distributed according to a scheme of 4 treatments (without washing, washing and immersion in chlorine, washing and immersion in peracetic acid, washing and spraying with propolis extract) and stored for 5 storage periods (7, 14, 21, 28, and 35 days) at a temperature of 25°C. 6 eggs were analysed for each period. Treatment with propolis extract was the only effective way to maintain high quality of HU eggs up to 21 days of storage at 25°C and was effective against microbiological contamination by all bacterial groups. According to the researchers, the presented results showed great effectiveness of propolis extract in maintaining the internal and microbiological quality of eggs, it can be an alternative to chemical disinfectants.

Propolis as a food ingredient

The use of propolis as a functional food ingredient in the food industry is still very limited due to its specific bitter and slightly pungent taste, strong smell, low water solubility, and low thermal and oxidative stability. In order to use a product such as propolis, microencapsulation is used (Maroof *et al*., 2022). The preparation of vacuum-dried encapsulated propolis powder involved the following process variables: propolis ethanol extract (PEE) (40-70%), temperature (30-50°C), and pressure (15-25 inches of mercury) to assess their effect on the physical characteristics and total phenol content (TPC) of the prepared powder. The results of the study showed a higher TPC (20.98-30.91 mg of GAEg-1) with an increase in propolis extract concentration and blood pressure. The optimal conditions for encapsulating propolis powder were a PEE concentration of 52.3%, a temperature of 39.2°C, and a pressure of 21.7 HG.art. In addition, encapsulation efficiency, antioxidant activity, FTIR spectroscopy, morphological analysis of the optimised powder sample showed the existence of polyphenolic compounds with effective encapsulation (Pant *et al*., 2022). Konuk *et al*. (2022) note that among proteins, sodium caseinate was less effective in encapsulating bioactive propolis compounds, while maltodextrin was the most suitable carbohydrate-based carrier. Propolis powders encapsulated with maltodextrin and whey protein had the highest content of phenolic compounds and antioxidant activity.

A. Gunes-Bayir *et al*. (2022) a fermented milk product (yoghurt) containing probiotics, propolis, and cinnamon was developed, and the interaction of all ingredients was characterised. Yoghurts were prepared using starter cultures with propolis (0.03%) and cinnamon in various concentrations (0.3%, 1%, and 2.5%). *Bifidobacterium animalis* subsp. *lactis*, *Lactobacillus acidophilus, Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* were used as micro-organisms for the production of yoghurt and probiotics. According to researchers, propolis has a statistically significant predominant effect on *Bifidobacterium animalis* subsp. *lactis*, as well as on *Lactobacillus delbrueckii* subsp. *bulgaricus* ($p < 0.05$). At the same time, these effects decreased with increasing cinnamon concentrations. For *Lactobacillus acidophilu*, a statistically significant decrease in the number of colonies was observed in all the products studied. However, all samples met the recommended standard level of ⩾ 106 viable cells/g of the product. Propolis has the opposite effect on *Streptococcus thermophilus*, increasing the number of its colonies in yoghurts. Probiotic yoghurt samples containing propolis (0.03%) and cinnamon (2.5%) scored higher on organoleptic assessment compared to the control.

J.B. Seibert *et al*., (2019) a nanoemulsion with Brazilian propolis extracts has been proposed for use as a natural food preservative. The antimicrobial, antioxidant activity and chemical composition of the extracts were studied. The latter were obtained by sequential extraction using various solvents (hexane, ethyl acetate, and ethanol). Antimicrobial activity was evaluated by Agar diffusion and micro-dilution methods, and antioxidant activity by DPPH and ABTS methods. The extracts showed antibacterial and antioxidant activity by isolating ethanol containing artepillin-C, kaempferide, drupanin, and p-coumaric acid as the main compounds from the LC-MS assay. The nanoemulsion obtained by phase inversion was characterised and stable under thermal stress and centrifugation conditions.

Zinc oxide (ZnO) is used in the food industry to coat surfaces and absorb UV rays. Zinc oxide (ZnO-NP) nanoparticles are generally recognised as safe (GRAS) and, due to their antimicrobial properties at the nanoscale, can be a promising chemical for decontamination. T.O. Kevenk, & Z. Aras, (2022) investigated the antimicrobial activity of rosemary acid and propolis prepared in various concentrations together with ZnO-NP. Six leading food pathogens and sourdough were selected for this purpose. According to their results, propolis and ZnO-NP showed good results when combined with each other. In addition, lower concentrations of rosemary acid were also found to cause the deactivation effect of ZnO-NP. Although the antimicrobial effect of ZnO-NP when used alone was less than when used in combination, it was still considered sufficient (Kevenk & Aras, 2022).

The search for new solvents, including for propolis, can contribute to the development of new food formulations. Petkov *et al*. (2022) note that natural deep eutectic solvents (NADES) were developed to replace traditional volatile and toxic organic solvents to extract biologically active substances from natural sources. Scientists have evaluated the antioxidant activity of extracts of two medicinal plants, *Plantago major* and *Sideritis scardica*, and propolis with 10 different NADES. The results confirm that extracts of medicinal plants and propolis NADES have a good antioxidant potential, which allows obtaining natural antioxidants without the use of organic solvents. Due to the biocompatibility and low toxicity of NADES, the possibility of using these extracts directly in food additives is promising.

H. Yıldırım *et al*. (2018) note that propolis is a useful ingredient in food, but it can cause allergies. The main allergic molecules in propolis are caffeic acid esters (especially caffeic acid phenyl ether, 1,1-dimethylallyl caffeic acid), cinnamic acid and its aromatic esters (benzylcinnamate, benzylferulate, benzylisoferulate or cinamyl)) containing the cinnamoyl ester bond. During their research, propolis samples were treated with various solvents (10% ethanol and polyethylene glycol, PEG 40%). Biotransformation was performed at 30°C for 48 hours under constant conditions. Fermentation was carried out using different strains of *Lactobacillus plantarum* with an inoculation rate of 1.5%. Propolis 1 g (solid state) and 1 ml (liquid state) were used as a nutrient medium. The findings show that the types and percentage of solvents used for extraction and the strains used *L. plantarum* have an important effect on the phenolic profile of propolis composition, including allergic molecules. Given the specific influence of these parameters, propolis biotransformation *L. plantarum* can be used to optimise propolis extract based on the required phenolic profile. The conducted study demonstrated the possibility of using propolis biotransformation by strains *L. plantarum*.

Conclusions

Each stage of the formation of propolis as a safe and high-quality raw material for food products is exposed to various factors that can have irreversible consequences for the quality of propolis. Plant sources of propolis vary in their chemical and physical properties depending on their geographical origin. Geographical location is an important indicator in the fight against counterfeiting of bee products. The availability of available propolis sources in ecologically clean areas for beekeepers has a significant impact on quality. The use of advanced propolis collecting technologies adapted to the climatic conditions of the area contributes to achieving the proper economic effect and reducing the cost of raw materials. Compliance with sanitary and hygienic requirements during the collection, transportation, and storage of propolis helps to improve its quality. Research and implementation of propolis processing technologies expands the range of its application and consumption, in particular, contribute to its use in the food industry. Propolis is a promising and valuable raw material for the food industry and can be used directly as an ingredient, and indirectly as a component of packaging. Despite the fact that propolis is a valuable natural product, it can also carry risks to human health. At each stage of propolis formation in Ukraine, attention should be paid to the sources (causes) that degrade the quality of propolis in order to develop effective recommendations for minimising them. Consumer awareness of the quality of products, risks, and benefits associated with the consumption of products containing propolis is one of the safeguards for consumer safety. In the future, it is advisable to focus on three key areas: implementation of good beekeeping practices; compliance with good agricultural practices; and proper control of raw materials and finished products on the market. The development of technologies for producing propolis and processing should be aimed at reducing the cost of raw materials and the economic benefits of its use, which will lead to the availability of products for consumers. In addition, recommendations should be developed for the daily consumption of propolis or propolis-containing products for the consumer.

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Conflict of Interest

None.

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Формування безпечності та якості прополісу як харчової сировини

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Анотація. Перспективним є використання прополісу як унікального харчового інгредієнту з усвідомленням важливості кожного технологічного етапу та формування його якості. Тому метою роботи було проведення систематичного огляду наукової інформації, щодо використання прополісу як харчового інгредієнту з акцентом на етапи його формування у розрізі якості. Використовували метод Торрако для аналізу та синтезу наукової інформації; користувалися науково-метричною базою Springer та пошуковим інструментом Google Scholar, Researchgate. З'ясували, що безпечність та якість прополісу формується на кожному із етапів. Важливу роль відіграють джерела прополісу та їх доступність, технології збору, зберігання та переробки. Пошук та дослідження нових способів переробки та застосування прополісу уможливлює його широке використання як харчового інгредієнту. На сьогодні прополіс можливо застосовувати безпосередньо як сировину значної кількості харчових продуктів як безпосередньо так і опосередковано, складник нових харчових упаковок, замінник консервантів. На підґрунті систематичного огляду наукової інформації, доведено, що на кожному з етапів формування прополісу як безпечної та якісної сировини харчових продуктів існують чинники, котрі можуть незворотно впливати на якість прополісу. Рослинні джерела прополісу формують типи прополісу з відповідними хімічними та фізичними

властивостями в залежності від географії походження. Географічний маркер є важливим індикатором у боротьбі з фальсифікацією продуктів бджолиного походження. Наявність доступних джерел прополісу у екологічно чистих зонах пасічникування має вагомий вплив на якість. Застосування передових та адаптованих до клімату місцевості технологій збору прополісу забезпечує належний економічний ефект та зниження собівартості сировини. Належне дотримання санітарно-гігієнічних вимог при зборі, транспортуванні та зберіганні прополісу покращує його якість

Ключові слова: контроль якості; природний консервант; продукт; рослинна смола; бальзам

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Application of modern technologies to improve the quality of sausage products

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Abstract. The production of sausages without the use of phosphates and sodium nitrite improves the quality and safety of the product, meeting the demand of consumers for natural and healthy food products. The purpose of the study was to investigate various technological aspects of sausage products that would improve their quality indicators, be attractive to the consumer, and have a positive impact on human health. Organoleptic qualities were evaluated by the appearance, consistency, type of minced meat on the cut, smell, taste; protein content – by Kjeldahl method; moisture content – by drying the suspension in a drying cabinet at a temperature of 103 ± 2°C to a constant mass; fat content – by extraction and weight Soxhlet method; moisture retention capacity – by centrifugation; penetration stress – by recalculation of penetration using a needle indenter; output of the finished product – by weighing before and after heat treatment. The

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replacement of sodium nitrite with organic nitrite based on chard powder was studied together with a bacterial culture that, as a result of interaction, produces nitrate reductase and reduces nitrate to nitrite (samples 1, 2), in samples 3 and 4, chard powder was replaced with beet juice. All samples were pink in colour. Replacing phosphates with amylopectin starch gave the developed sausages an elastic and juicy consistency, increased the moisture retention capacity by 4.6%-6% compared to the control sample, and penetration stress by 31%-53%. The use of sous-vide technology provided the developed sausage samples with a more pronounced good taste of each recipe ingredient separately, a delicate, elastic consistency, a uniform colour on the cut, and a higher yield by 1.8%-3.3%. Replacing fatty raw materials with dietary ones, and cooking sausages in heat-resistant bags with vacuuming provided an increase in protein by 8.7%-16.7% and a reduction in fat by almost two times. The practical value of the study was to obtain a dietary product that meets the needs of modern people in a healthy diet

Keywords: sous-vide technology, amylopectin starch, phosphates, sodium nitrite, bacterial culture

Introduction

The population of Ukraine considers sausage products to be traditional food products for their taste properties and cooking speed. However, nutritionists in recent decades do not refer to this group of products as a healthy diet. The reason for this can be both the raw materials used, namely meat with signs of PSE and DFD, which has a low or high pH value, loose or hard consistency, and food additives that are used for various purposes in recipes and technologies. Therefore, such requirements of modern life encourage researchers and specialists in the meat processing industry to develop new products that would minimise the negative impact on human health, and vice versa, enrich the body with valuable substances that are components of ingredients selected according to the recipe.

The Ukrainian consumer pays attention, first of all, to the attractive appearance of the product and only after that is interested in the recipe composition (Vlasenko & Kryzhak, 2014). One of the ingredients that provide the usual pink colour to sausage products is sodium nitrite, which has both bactericidal properties and is involved in colour formation. When salting meat raw materials, meat myoglobin is quickly oxidised by nitrite to metmyoglobin, which has a characteristic brownish-grey colour. At the intermediate stage, due to reactions, nitrosometmyoglobin is formed, which has a red colour. Nitrosometmioglobin is reduced to a not very stable nitrosomyoglobin, which is further decomposed into globin and nitrosomyochromogen. It is this pigment, nitrosomyochromogen, that is a stable pink pigment that determines the colour of salty products. During the heat treatment of sausage products, namely, roasting boiled sausages, and frankfurters, starting from a temperature of 25-30°C, sodium nitrite breaks down, metmyoglobin is reduced to nitrosomyoglobin, providing colour formation. However, sodium nitrite has toxic properties and can participate in the synthesis of carcinogenic nitrosamines, so its amount is strictly limited (Crowe *et al.*, 2022).

The use of sodium nitrite in the meat industry has always been controversial due to the likely carcinogenic effects on health and the search for an alternative to nitrites, reducing their amount to provide antimicrobial action

and improve sensory characteristics remains a topical issue (Mynul Hasan Shakil *et al*., 2022, Keuleyan *et.al*., 2022,). Therefore, researchers have long been engaged in the issue of replacing sodium nitrite in food production with various natural components of plant or animal origin (Vlasenko & Kryzhak, 2014, Govari & Pexara, 2015, Vlasenko and Vlasenko, 2016). This issue was part of the research work that was being done.

Literature sources have published works on the use of blended vegetable juices with different ratios based on beetroot instead of sodium nitrite, thanks to which boiled sausages had a characteristic colour for this group of sausages, as well as the use of beet syrup (Kryzhova & Deyak, 2021).

Xu Yuning & Zhu Yinglian (2021) investigated the complete replacement of nitrite by a strain *Lactobacillus fermentum* and its positive impact on the quality and safety of Chinese fermented sausages. Results were obtained in which the strain reduced the pH and risk of food pathogens, and its ability to produce a pink colour similar to 50 mg/kg of nitrite was established, which significantly reduced the residual nitrite in sausages. It was concluded that the strain has the potential to replace nitrites for the production of sausages that will not have a negative impact on health.

M.M. Polumbrik *et al*. (2019) investigated the partial replacement of sodium nitrite in the formulation of pasteurised sausages with food blood from pig slaughter. Organoleptic parameters of sausages were not reduced.

Heat treatment of sausage products leads to the loss of meat juice, as a result of which the tissues are dehydrated, and the juiciness of products, consistency and taste decrease. As a result of cooling, freezing, and storage of steamed meat, its moisture retention capacity decreases. Therefore, in the production of meat products, various substances are used to increase the moisture retention capacity to a level corresponding to fresh meat. Table salt cannot fully restore this ability of meat; for this purpose, phosphates are used in sausage production, which have a specific effect on muscle proteins and other components of minced meat. They also shift the pH to the alkaline side. The content of soluble proteins in meat, together with the addition of phosphates, increases the moisture retention capacity of meat, which provides a denser consistency of sausage products.

However, the presence of food phosphates in most meat products leads to an increase in the intake of phosphorus in the body, and this has a negative impact on human health. Therefore, for partial, and in some products even complete replacement of food phosphates, amylopectin starch based on waxy potatoes was used – Perfectabind C, which has a pure taste. Some studies (Kryzhova & Duzenko, 2020, Kryzhova *et al*., 2020) prove the expediency of replacing food phosphates with amylopectin starch in order to limit the intake of phosphorus in the body and reduce the negative impact on human health.

V.S. Trokhimenko *et al*. (2018) analysed the use of food additives in the production of sausages and their effect on the human body. Researchers have noted the negative effect of phosphorus compounds, which have a carcinogenic effect, cause diarrhoea, inflammatory processes of the mucous membrane of the digestive tract, and impair the absorption of calcium, and this, in turn, leads to the deposition of calcium and phosphorus in the kidneys.

L.V. Bal'-Prylypko *et al*. (2019) studied the use of edible orange fibre instead of phosphates and other food additives in order to increase the yield of finished products and maintain high organoleptic parameters.

Sous-vide technology was used in modern establishments of the restaurant industry to

reduce the time of order fulfilment, obtaining dietary meals, simultaneous preparation of various dishes in vacuum bags in one water bath with a temperature of 85°C or using other modern equipment. Some meat products are recommended to be pre-grilled or pre-marinated or mechanically beaten before vacuum packaging to improve the texture and more pronounced taste (Kurash & Pavlyuchenko, 2015). The microbiological quality of lightly fried food was determined using sous-vide technology (Jorgensen *et al.*, 2017).

An effect was found on the sensory characteristics of pork loin, namely tenderness and juiciness, which was cooked at 60°C or 65°C for 4 hours (Kurp *et al.*, 2022).

The purpose of the study was to improve the technology of sausages recommended for healthy eating, with the replacement of food phosphates with amylopectin starch, sodium nitrite with chard powder or beet juice together with bacterial culture, using sous-vide technology.

Materials and Methods

The research was carried out during 2021 at the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine At the first stage, mathematical modelling selected the recipe composition of sausages according to the balance of nutritional and biological value, which included such dietary raw materials as chicken, turkey, and rabbit meat, including grade 1 beef. Oat bran, pumpkin, linseed, and olive oil were used to enrich sausages with fibre, as well as minerals, vitamins, and fatty acids, and turmeric was used to provide antioxidant properties.

Organoleptic parameters of sausages were evaluated on a five-point scale according to requirements of DSTU 4436:2005 (2006) "Boiled sausages, sausages, meat loaves. General technical conditions". The assessment was carried out according to the following indicators: appearance, consistency, type of minced meat on the cut, smell and taste, and size of bars.

The moisture content of sunflower seeds on the RM-450 tester was determined before and after drying, which was carried out in a drying cabinet AT t = 30°C for 15 minutes.

The nitrate content was previously determined in table beets using a portable Ecovisor F4 device.

For recipes No. 1 and No. 2, an activation medium was prepared: drinking water at room temperature was poured into the container, chard powder (Start STAR active NRB) was poured and bacterial culture (Start STAR NRC) was added, mixed and kept at room temperature for 24 hours. For recipes No. 3 and No. 4, the preparation of the activation medium was distinguished by replacing chard powder (Start STAR active NRB) with beet juice, which was previously brought to a boil, then cooled to a temperature of 0 – 4°C and diluted with water in a ratio of 1:1.

Before preparing the minced meat, oat bran was pre-moistened with water at room temperature for 30-40 minutes at a hydromodule of 1:4.

Fine grinding of raw materials and folding of minced meat was performed on a cutter.

After roasting, the sausages were packed in heat-resistant bags with vacuuming, then cooked in a sous-vide machine at 80°C for 15 minutes and at 60°C for 60 Minutes, followed by shock cooling, quality control, and storage in vacuum bags. In parallel, heat treatment of sausages was carried out in a thermal chamber at a temperature of (80 ± 5)°C, as well as the control sample.

Considering that the literature sources do not contain data on the temperature and duration of heat treatment of sausages using the sous-vide technology, and only cutting meat of various types and semi-finished products, for heat treatment using this technology, two

temperatures were chosen – 60°C and 80°C with a processing duration of 60 minutes and 15 minutes, respectively.

The readiness of sausages was determined when the temperature in the centre of the sausages reached 69-72°C.

The moisture content of minced meat and finished products was determined by the arbitration method, which is based on drying the samples in a drying cabinet at a temperature of 103 ± 2°C to a constant mass (DSTU ISO 1442:2005) (2008); active acidity (pH) – using a portable pH meter; ash content – by ozolising samples in a muffle furnace at a temperature of 600-650°C (DSTU ISO 936:2008) (2008); protein content – by Kjeldahl's method, based on the complete mineralisation of the sample suspension with concentrated sulphuric acid in the presence of a catalyst, distillation of the resulting ammonia and determination of nitrogen content by titration using the Velp Academica device (Italy); fat content – extraction and Soxhlet weight method, which consists in removing fat using a solvent on the fat analyser Soxstek SOX 406 (China) with preliminary removal of moisture in the samples (DSTU ISO 1443:2005) (2008); moisture binding ability – by pressing, which consists in the release of water from the test sample during pressing, sorption of the released water with filter paper, determination of the amount of separated moisture by the size left on the filter paper spot area; moisture retention capacity – by centrifugation; plasticity – by spot area of minced meat formed on an ash – free filter under the action of a static load weighing 1 kg for 10 minutes; penetration was determined on an Ulab 3-31 m penetrometer using conical and needle indentors, at the temperature of samples (20 ± 0.5)°C, with the conversion of the penetration value of viscoplastic systems to the value of the maximum shear stress, in Pa, and elastic products – to the value penetration stress, in Pa. The salt content was determined by the Mohr method, and the yield of the finished product was determined by the ratio of the mass of minced meat to the mass of the product after heat treatment. Microbiological parameters were determined after heat treatment of sausages in accordance with the control methods given in DSTU 4436:2005 (2006) "Boiled sausages, sausages, meat loaves". General technical conditions. "At the same time, the total content of microorganisms in 1 g of the product that can grow on the agar nutrient medium at a temperature of (37 + 5)°C was determined with the establishment of colonies that are visible at a five-fold increase, and the presence of Escherichia coli bacteria.

Results and Discussion

Previously, the nitrate content in table beets used for juice production was studied, which was 10 mg/kg at a rate of 1,400 mg/kg.

The moisture content of sunflower seeds was determined to be 8.6%. Subsequently, the seeds were dried to a moisture content of 1.4% in a drying cabinet AT t = 30°C for 15 minutes, then it was ground in a laboratory spice grinder and divided into sieves No. 1; 0.8; 0.5; 0.2. On the last sieve, the remainder was 38.9% (Table 1).

Table 1. *Separating crushed seeds on sieves*

Sieve number	Remainder on the sieve, %	Passage through a sieve, %
1	29.1	70.9
0.8	23.2	54.4
0.5	28.5	38.9
0.2	38.9	-

4 recipes of sausages were developed using chicken, turkey, grade 1 beef, rabbit meat, chard powder Start STAR active NRB, bacterial culture Start STAR NRC, beet juice, oat bran, sunflower seeds, pumpkin, linseed, olive, dried apricots, prunes (Table 2).

Table 2. *Sausage recipes, kg/100 kg of raw materials*

Name of raw materials	Control	No. 1	No. 2	No. 3	No. 4
	%	%	%	%	%
Turkey meat		45			
Chicken meat			39	36	
Beef grade 1	35	35			85
Rabbit meat			40	40	
Milk powder	2				2
Cream 20%		2	3	3	
Chicken eggs	3	3	3	3	3
Oat bran		2	2	2	
Water for hydration		8	8	8	
Olive oil					5
Sunflower seeds		2	2		
Pumpkin oil				3	
Linseed oil		3	3		
Dried apricots				5	
Prunes					5
Fatty pork	60				
Total:	100	100	100	100	100
Auxiliary raw materials, g/100 kg of raw materials					
Table salt	2.100	2.100	2.100	2.100	2.100
Granulated sugar	120	130	120	120	120
Sodium nitrite	7.5	-	-	-	-
Ground black pepper	120	-	-	-	-
Ground white pepper	-	150	150	150	150
Ground nutmeg	40	50	50	50	50
Turmeric	-	20	20	20	20
Amylopectin starch	-	300	300	300	300
Phosphates	300	-	-	-	-
Beetroot juice	-	-	-	5.000	5.000
Chard powder	-	500	500	-	-
Bacterial culture	-	125	125	125	125

In the developed formulations, food phosphates were replaced with amylopectin starch. Instead of sodium nitrite, chard powder or beet juice was used along with bacterial culture. Sausages "Milk highest grade" were taken for control.

Chard powder was used as a natural source of nitrate, it is characterised by a high content of minerals and nutrients, has a weak taste of its own, and is not allergenic. Due to the addition of bacterial culture to it, nitrate is reduced to nitrite during biological transformation, and natural nitrite is formed. Bacterial culture is a mixture of cultures, staphylococci and micrococci, *Staph. Carnosus* and *K. Salsicia*.

The originality of this technology, in addition to replacing phosphates and sodium nitrite, was the method of cooking sausages, which consisted in the fact that the classic cooking method was replaced by cooking sausages using sous-vide technology (Table 3).

Table 3. *Temperature conditions for cooking sausages*

Test samples	Heat treatment modes	
	Temperature, °C	Duration, min
Control and developed samples	80±5	15
Sous-vide samples	60	60
Sous-vide samples	80	15

This allowed reducing technological losses in the production of sausages, discovering all the taste and aroma properties of prescription components, improving juiciness, and getting tenderness and a beautiful, uniform colour on the cut. Moreover, production using this technology reduces the contact of the finished product with the environment, which protects re-contamination during product storage, ensures uniform and more efficient heat transfer from water to the product itself, increases shelf life, increases yield due to technological processing in a hermetically sealed food bag.

The literature presents studies that most often relate to the preparation of meat or semi-finished products by the sous-vide method in the following combinations: one combination of temperature and duration, or several combinations of temperature and duration. L. Kurp *et al* (2022) present a range of parameters for cooking pork loin using the sous-vide method with the study of physicochemical, microbiological, structural, and sensory parameters. The meat was cooked at 60°C and 65°C for 4 hours. Such cutting modes provided the most attractive and acceptable sensory characteristics of pork loin, that is, the most important for perception were the texture characteristics, namely tenderness and juiciness.

In this study, the preparation of sausages in a sous-vide machine was carried out at a temperature of 80°C for 15 minutes and 60°C for 60 minutes, determining the readiness of sausages by temperature and organoleptic indicators, and safety by microbiological indicators. The studied modes of processing sausages using sous-vide technology did not show significant differences in general appearance, colour, tenderness, taste, or aroma intensity, but sausages that were heat-treated at a lower temperature (60°C) and longer duration (60 minutes) were significantly juicier. Heat treatment of the control sample was carried out at a temperature of 85°C for 15 minutes. It was characterised by a denser consistency and did not differ in juiciness. According to L. Kurp *et al.* (2022), cooking pork loin at 75°C produced less tender meat than at lower temperatures, and according to references from other researchers (Baldwin, 2012), the softness of meat increased at temperatures between 50°C and 65°C, and then decreased with increasing temperatures to 80°C, which is also observed in this study.

The study focused on the comparative analysis of samples using bacterial culture and chard powder (samples 1 and 2), beet juice (samples 3 and 4), made using sous-vide technology, to ensure the necessary colour of sausages and other sensory indicators, which was carried out organoleptically. After production, an organoleptic evaluation of sausages was carried out on a five-point scale (Fig. 1).

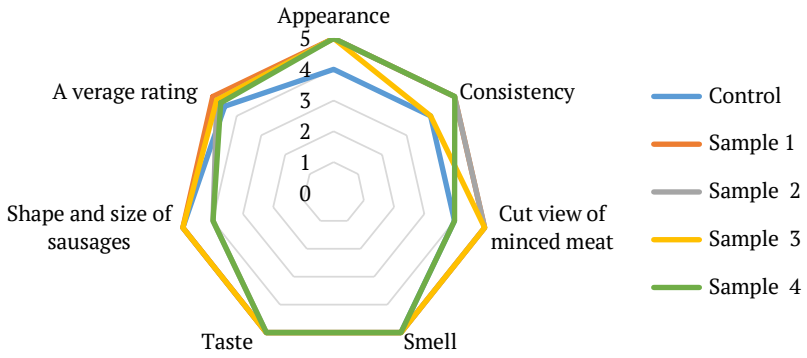

Figure 1. Organoleptic sausage evaluation profilogram

As a result of the conducted studies, a significant difference in the consistency, taste, and type of minced meat on the cut of sausages of experimental and control recipes was established. Positive changes in the organoleptic parameters of the developed sausage samples were mainly influenced by the raw material and cooking method. It was found that all samples were characterised by high taste properties due to pre-vacuuming and sealed packaging in thermal packages, which protects the evaporation of volatile aromatic substances. Samples No. 3 and No. 4 were juicier, but it was noted that all developed samples with amylopectin starch had a tender and juicy texture. They also differed in the specific taste that dried apricots and prunes gave. Sample No. 2 had a more delicate consistency than other samples due to dietary raw materials. Samples No. 1 and No. 2 had a pleasant light aroma of sunflower seeds. There was no significant difference in the organoleptic characteristics of sausages made using sous-vide technology at a temperature of 80°C or 60°C, except for juiciness. The control sample had the usual taste characteristic of sausages, without much juiciness and a pleasant aftertaste, it did not have an expressive bright colour. Chotigavin *et al.* (2023), when studying the effect of the low-temperature long-term cooking method, sous-vide, on beef muscle properties, found that beef using sous-vide technology had higher rates of tenderness and juiciness compared to the control, which is consistent with this study.

It should be noted that all four sausage samples received a high organoleptic score and differed from the control sample in that, due to the sous-vide technology, the flavours of each recipe ingredient were clearly distinguishable. This is one of the advantages of modern new cooking technology – sous-vide technology.

In terms of colour, the best samples were No. 1 and No. 2, made with chard powder Start STAR active NRB and Start STAR NRC starter culture instead of sodium nitrite, and samples No. 3 and No. 4, in which sodium nitrite was replaced with beet juice and bacterial culture Start STAR NRC, had a more pronounced colour than is inherent in similar sausage products that are made using sodium nitrite. Most likely, this was influenced by the amount of beet juice.

O.V. Skrypnyk & Ya.M. Bychkov (2018) obtained the results of improving the structural properties of beef meat with a high connective tissue content during the heat treatment for 3,600 s using sous-vide technology, other researchers – improving sensory characteristics during stewing (Cheng *et al.*, 2022).

Scientists, using sous-vide technology for cooking, obtained a reduction in losses during cooking, better flavour and juiciness of the final product, and extended shelf life. The paper shows different processing temperatures (roast beef – 65°C, roast chicken – 60°C, roast duck – 80°C), but does not specify the duration of cutting (Kurash & Pavlyuchenko, 2015), also in the study of the effect of sous-vide technology on the quality of beef ribs received maximum tenderness, minimal impact on colour change and minimal losses during cooking (Karki *et al.*, 2022; 2023).

V.V. Vlasenko *et al*. investigated the possibility of reducing the amount of sodium nitrite through the use of bacterial cultures RCI-47 and SBI-0.5, which were introduced into the minced meat of raw smoked sausages, while maintaining high organoleptic, technological and microbiological indicators (Vlasenko & Kryzhak, 2014). The researchers concluded that the use of bifidobacteria in the production of sausages ensures the effective use of sodium nitrite in the reaction of nitrosopigment formation and allows reducing the amount of sodium nitrite to 40-50% of the generally accepted norm and obtain a product with a stable colour.

In this study, which is aimed at improving the quality characteristics of sausages, a complete replacement of sodium nitrite with bacterial culture was applied in interaction with chard powder (samples 1 and 2) and beet juice (samples 3 and 4). The colour intensity of sausages in samples with beet juice was brighter and richer than in samples with chard powder and control sample, this requires further studies on the amount of juice and shelf life.

After heat treatment, the physical and chemical parameters of sausages were analysed (Fig. 2).

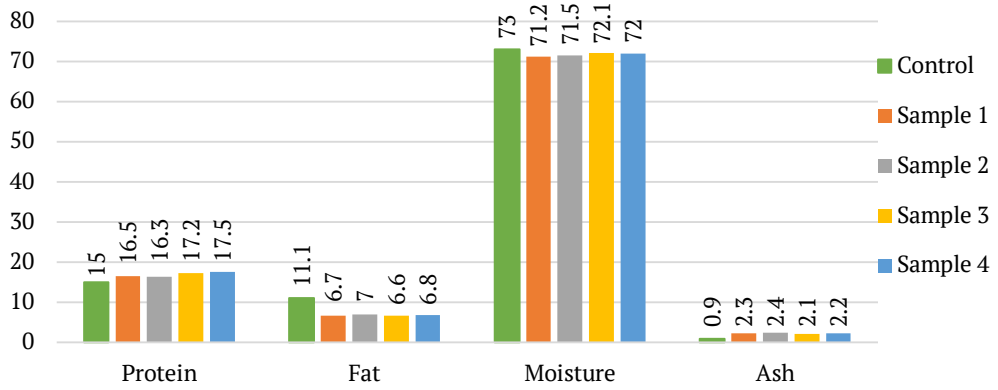

Figure 2. Physical and chemical parameters of sausages, %

The protein content in the experimental samples increased by 10% in sample No. 1, by 8.7% in sample No. 2, by 14.7% in sample No. 3, and by 16.7% in sample No. 4 compared to the control. This increase in protein content is explained by the use of raw meat in the developed samples, which is characterised by high protein content. In sample No. 1, turkey meat was used, in sample No. 3 – chicken and rabbit, and in sample No. 4 – a larger amount of grade 1 beef. Moreover, heat treatment of sausages in vacuum bags ensured the preservation of the chemical composition of meat raw materials.

The fat content of the control sample is 38% higher on average compared to the developed samples due to fatty pork in the control and its replacement with vegetable oils in small quantities in prototypes.

The moisture content in all samples is in the range of 71.2-73.0 %, which does not exceed the permissible levels for this type of product. In general, based on the results of physical and chemical indicators, it was concluded that they met the requirements of DSTU 4436:2005 (2006) "Boiled sausages, sausages, meat loaves. General technical conditions".

An important indicator of sausage products is the moisture retention capacity, which provides them with a juicy consistency, and indicates the amount of bound moisture during heat treatment (Fig. 3).

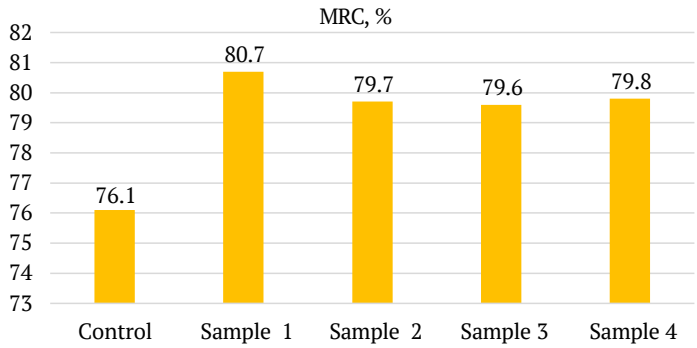

Figure 3. Moisture retention capacity of sausages, %

The moisture retention capacity of the samples with amylopectin starch increased from 4.6% to 6% compared to the control sample in which phosphates were used. This is conditioned by the increased functional and technological characteristics of amylopectin starch, which are manifested in a lower gelatinisation temperature, a sufficiently high viscosity, high moisture binding, and a high content of more than 99% amylopectin. Song *et al*. (2023) reported an improvement in water retention capacity and texture of ham from chicken breast cooked in sous-vide mode. Increasing the yield of finished products while maintaining high organoleptic characteristics, especially consistency, ensures the high economic performance of production. The yield of sausages made using classical technology and sous-vide technology was studied at different temperatures and the duration of heat treatment (Fig. 4).

The developed samples had a higher yield compared to the control by an average of 1.8% using sous-vide technology and heat treatment at 60°C and a duration of 60 minutes, and by 3.3% on average using sous-vide technology and heat treatment at 80°C and a duration of 15 minutes. Oat bran, amylopectin starch and sous-vide technology, which were applied in a complex, had a positive effect on increasing the yield. Bal'-Prylypko *et al.* (2019) noted the effect of dietary fibre on increasing the yield of meat products and the ability to bind and retain moisture.

The decrease in losses during the culinary processing of products using sous-vide technology was reported by O.H. Kurash & O.S. Pavlyuchenko (2015), L. Kurp *et al.* (2022), and a relationship was established between an increase in losses, an increase in temperature, and the duration of processing. The influence of cooking methods on the physical properties and

sensory qualities of meat (pH, cooking losses, density) was studied by A.I. Hobani *et al*. (2023). They found that cooking loss was the only parameter affected by the interaction of cooking method, temperature, and time, noting that it did not affect the pH and activity of the water. In this study, changes in the temperature and duration of heat treatment using the sous-vide method practically did not change the pH values and water activity.

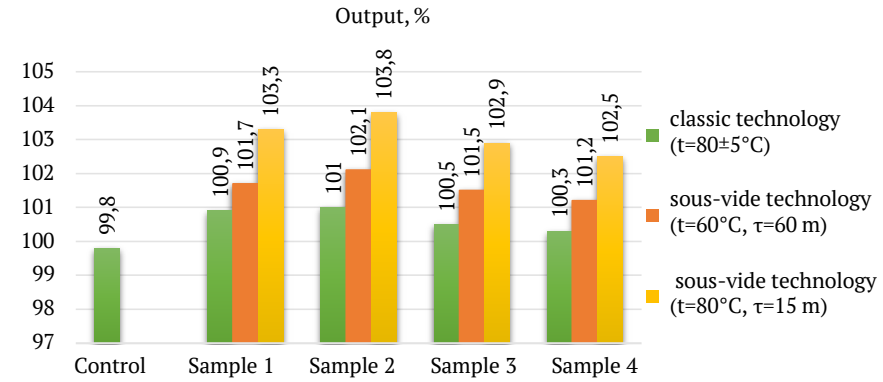

Figure 4. Sausage output, %

The change in the structure of sausages, which was influenced by oat bran, amylopectin starch, and sous-vide technology, was confirmed not only by organoleptic parameters, namely the consistency that expresses the totality of rheological properties of the food product, but also by determining penetration on a penetrometer and converting it to the values of the maximum shear stress and penetration stress (Fig. 5).

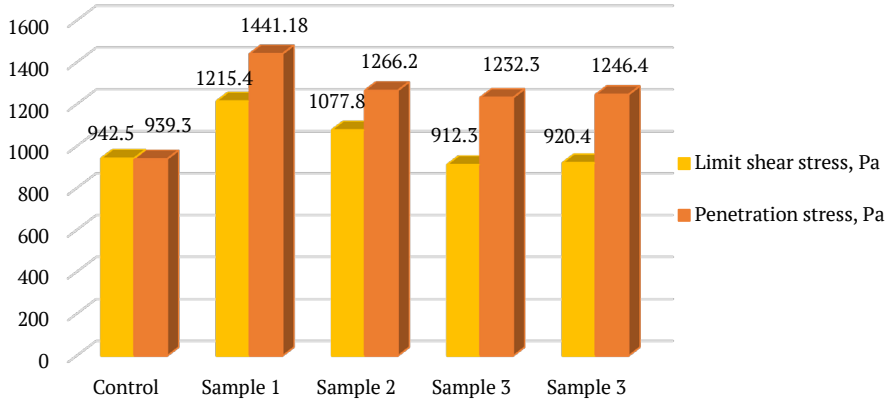

Figure 4. Boundary shear stress of viscoplastic systems and penetration stress of sausages

The studies showed that samples No. 1 and No. 2 had a more elastic consistency, which was facilitated, most likely, by a complex of components, namely, bacterial culture, oat bran, and amylopectin starch. The penetration stress of these samples is the highest, while samples

No. 3 and No. 4 had a lower penetration stress value, these samples had a more delicate consistency, which may have been the result of using beet juice instead of chard powder, which, in addition to being high in nitrate, contains many minerals and nutrients. Samples of sausages that were cooked for 15 minutes at a higher temperature (80°C) had a more elastic consistency than samples that were cooked for 60 minutes at a lower temperature (60°C), their penetration stress was lower. This is consistent with the results given by L. Kurp, who investigated the effect of sous-vide technology on improving the texture of pork loin (Kurp *et al.*, 2022). The most tender meat was obtained at temperatures of 60°C and 65°C with a shorter cooking time of 3 hours. It was suggested that the softening of meat that was cooked longer was supported by the activity of internal proteases that remained active at lower temperatures. It was also found that with the same cooking time, lower losses were established at a lower cooking temperature. Structural changes in meat proteins under the influence of heat treatment probably played a crucial role in the formation of sausage tenderness.

Investigation of the influence of temperature and time on the culinary properties of pork loin, processed by sous-vide technology conducted by Hwang *et al.*, showed an advantage in obtaining tender meat compared to traditional cooking, which was confirmed by lower shear force indicators. However, the shear force during sous-vide processing did not show any patterns in terms of temperature or time (Hwang *et al.*, 2019).

The fact that semi-finished products made using sous-vide technology had an extended shelf life was described by O.H. Kurash and O.S. Pavlichenko (2015).

Microbiological studies of the developed sausages were carried out immediately after heat treatment and storage for 48 hours in thermal packages at a temperature of 0-4°C. Studies have shown that the amount of mesophilic aerobic and facultative anaerobic microorganisms, CFU in 1 g of the product, did not exceed the permissible norms, and no bacteria of the E. coli group or pathogenic microorganisms were detected per 1 g of product, which confirmed the safety and high quality of the developed products. In addition, prototypes of sausages with the addition of chard powder Start STAR Activ NRB, beet juice and bacterial culture Start STAR NRC had better microbiological indicators compared to the control. This is conditioned by the fact that the bacteria present in the bacterial culture have an antagonistic effect on pathogenic and opportunistic microorganisms.

Conclusions

The use of modern technologies to improve the quality indicators of sausages provided for the use of dietary raw materials, namely chicken, turkey, and rabbit meat instead of fatty pork. As a result, an increase in protein content was achieved by 8.7%-16.7%. In addition, the production of sausages in sealed bags with vacuuming had a positive effect on this indicator. Replacing raw meat with less fat, and using small amounts of vegetable oil reduced fat almost twice without changes in taste properties. The addition of amylopectin starch to the recipe, which had a positive impact on the consistency, increased the moisture retention capacity, and made it possible to produce sausages that do not have the effect of accumulating unwanted phosphorus in the body, which is possible when using phosphates. Due to the exclusion of sodium nitrite from the formulation and its replacement with chard powder and starting culture, the possibility of dangerous N-nitrosamines synthesised from nitrite in the human body is excluded. A positive solution was the use of

sous-vide technology, which provided extremely high taste properties to the developed sausage samples due to better heat exchange of the wet environment in a sealed bag, a feeling of full taste, extreme juiciness, lower nutrient losses, a higher yield compared to the control sample by 1.8% during heat treatment at 60°C for 60 minutes and by 3.3% during heat treatment at 80°C for 15 minutes. Oat bran, which, like other similar dietary fibres, is widely used in the production of both semi-finished products and sausage products to provide the necessary structure, save meat raw materials and increase the economic performance of production. The results confirmed that the developed sausages can be used in the dietary nutrition of people or in general as more "healthy" products.

The study on this topic has prospects for further research on partial or complete replacement of sodium nitrite, the use of beet juice, and the use of sous-vide technology in the production of sausage products, determining temperature intervals and processing duration, extending shelf life.

Acknowledgements

None.

Conflict of Interest

None.

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Застосування сучасних технологій у покращенні якості ковбасних продуктів

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Анотація. Виробництво сосисок без застосування фосфатів та нітриту натрію покращує якість та безпечність продукту, відповідаючи попиту споживачів на натуральні та здорові харчові продукти. Метою роботи було вивчення різних технологічних аспектів ковбасних продуктів, які підвищили їх показники якості, були б привабливими для споживача і мали позитивний вплив на здоров'я людини. Органолептичну оцінку визначали за зовнішнім виглядом, консистенцією, виглядом фаршу на розрізі, запахом, смаком; вміст білка – методом К'єльдаля; вміст вологи – висушуванням наважки в сушильній шафі за температури

103 ± 2 °C до постійної маси; вміст жиру – екстракційно-ваговим методом Сокслета; вологоутримуючу здатність – центрифугуванням; пенетраційну напругу – перерахунком пенетрації з використанням голкового індентора; вихід готового продукту – зважуванням до і після термічного оброблення. Досліджено заміну нітриту натрію органічним нітритом на основі порошку мангольда разом з бактеріальною культурою, яка в результаті взаємодії виробляє нітратредуктазу та відновлює нітрат до нітриту (зразки 1, 2), в зразках 3, 4 – порошок мангольда замінено буряковим соком. Усі зразки мали рожеве забарвлення. Заміна фосфатів амілопектиновим крохмалем надала розробленим сосискам пружної та соковитої консистенції, підвищила вологоутримуючу здатність на 4,6 %-6 % порівняно з контрольним зразком та пенетраційну напругу на 31 %-53 %. Застосування sous-vide технології забезпечило розробленим зразкам сосисок більш виражений гарний смак кожного рецептурного інгредієнта окремо, ніжну, пружну консистенцію, однорідний колір на розрізі, вищий вихід на 1,8 %-3,3 %. Заміна жирної сировини дієтичною, варіння сосисок в термостійких пакетах з вакуумуванням забезпечили підвищення білка на 8,7 %-16,7 % та зниження жиру майже в два рази. Практична цінність дослідження полягала в отриманні дієтичного продукту, який відповідає потребам сучасної людини у здоровому харчуванні

Ключові слова: sous-vide технологія; амілопектиновий крохмаль; фосфати; нітрит натрію; бактеріальна культура

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Analysis of energy characteristics of vibration mixing of multicomponent mixtures of agricultural raw materials

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Abstract. Ensuring the efficiency of the use of nutrients of grain, protein, vitamin and mineral feeds in the composition of complete feed mixtures in animal husbandry and crop production, as well as the corresponding reduction in the cost of manufacturing of these products, is the relevance of the presented research and prospects for their development. Therefore, the purpose of the study is to substantiate the effective regime parameters for the preparation of premixes of feed mixtures based on the assessment of the energy parameters of the vibration mixing process. This assessment was carried out by comparing the results of applying vibration, blade, and vibro-blade technological operations. Under the conditions of low-frequency vibrations, a decrease in the working resistance of the loosened layer of the mixture is observed, which provided the effect of reducing energy consumption in this process. Therefore, in comparison with conventional vibrating mixers have a higher specific productivity of 5-6 times, provide a reduction in the mixing time by 2-3 times, metal consumption – by 17%, energy consumption – by 30%, capital costs for manufacturing – by 18%, and drive power – by 30-35%, which leads to a reduction in total energy consumption by 3-4 times. As a result, the zone of minimal energy consumption was substantiated, in which the reduction of the resistance of the technological medium allowed radically reducing the friction forces during mixing, while ensuring uniform distribution with the concentration of the components of the mixture required by technological requirements. An increase in the oscillation amplitude is accompanied by a quadratic increase in power consumption, which is conditioned by an increase in energy dissipation in the mass of the mixture in the form of heat. The implementation of reasonable operating mixing modes allowed reducing the energy consumption of the proposed vibro-blade mixing by 2.0-2.5 times compared to conventional blade processing. The practical value of these developments includes the use of vibro-blade working bodies and the vibration-free operation of the drive shaft, which, together with the minimisation of energy consumption for the process, reduces dynamic loads on the support units of the developed mixer

Keywords: vibro-blade mixing; feed mass; premixes; oscillation amplitude and frequency; drive energy consumption; bulk fluidised bed; low-frequency oscillation

Introduction

Ukrainian and international practice has accumulated extensive experience in the production and use of complete, balanced feed mixtures. These compound feeds contain components of plant, animal and biological origin, biologically active substances, medicines, and flavourings – everything that contributes to the growth and preservation of animal health (Santhiralingam & Sinniah, 2018).

Considering the physiological needs and in order to effectively use nutrients by animals and poultry, and reduce production costs, all grain, protein, vitamin, and mineral feeds are fed only in the form of complete feedstuffs or feed mixtures made according to scientifically based recipes with the necessary ratio of components (Carlson *et al.,* 2018).

Increasing the nutritional properties of such feeds is achieved by introducing amino acids (methionine, lysine, tryptophan, etc.), vitamins, trace elements, enzyme preparations, antioxidants, antibiotics, emulsifiers, tranquilisers, antibacterial substances, and other components (Piñeiro-Vázquez *et al.,* 2018).

It is impossible to immediately introduce such substances into feed mixtures due to their excessively small amount in the total volume of the mixture. The best effect is achieved when they are introduced in the form of complex sets – premixes, which are a homogeneous mixture of biologically active substances in fillers with a concentration that corresponds to the biological norm of their introduction into mixed feed in the amount of 0.5, 1%, and 5% (Liu *et al.,* 2019).

Analysis of publications on the study of regularities of changes in parameters and the course of the process of preparing multicomponent mixtures using mechanical mixing (Wang *et al.,* (2020), Sá-Caputo *et al.,* (2020) and Sun *et al.,* (2019)) showed the lack of a clear theoretical explanation for the relationship between the main parameters and characteristics, in particular, for vibration mixers that are used for adding premixes to mixed feed. Improvement of design and technological schemes of processes and equipment for mixing will allow both improving the quality of processing and technological value of mixed feed, and enabling an increase in livestock growth during feeding, reducing energy resources for the implementation of the study.

Analysis of physical and mechanical properties of raw materials for the production of mixed feeds and premixes, in particular, in the studies by C. Debnath, *et al.,* (2016), O.J. Abod-erin *et al.,* (2021), as well as conventional mixing equipment used in feed mills, revealed the following features of the technological process of preparing feed mixtures:

- multi-stage mixing process, which involves the preparation of preliminary mixtures and their sequential mixing.
- long mixing cycles: from 6-10 min up to 20-25 min;
- mixing components in a ratio of 1: 1 to 1:200;
- mixing components with different physical and mechanical properties;
- significant energy consumption for the preparation of a unit of production;
- no vibration mixing machines in feed production.

The purpose of the study is to determine the energy and frequency regime parameters of vibration, blade, and vibro-blade mixing of multicomponent bulk raw materials through the development of experimental equipment, analysis of experimental studies of this process, identification of its regularities when changing the driving force options under vibromechanical technological influence.

To achieve this goal, the following tasks were set: determination of energy consumption for the drive of a vibration-free blade shaft P_B; energy consumption for the drive of the vibration exciter shaft P_V; total energy consumption for mixing depending on the amplitude-frequency parameters of the installation – vibration mode coefficient k; oscillation amplitude A and the speed of rotation of the blade shaft n_S.

One of the most effective methods of implementing the presented properties is the use of vibro-mechanical means of preparing such multicomponent mixtures. The influence of these physical and mechanical factors on these systems is insufficiently investigated, which substantiates the relevance of this study and has broad prospects for development.

Literature Review

Based on the analysis of research papers by Ivanec *et al.*, (2014) and Silva *et al.*, (2014) it can be concluded that the preparation of mixtures of food components is complicated by the presence of active enzymes and microorganisms in them, and instability during storage.

J. Wang *et al.,* (2020), D. Sá-Caputo *et al.,* (2020) and W. Sun *et al.,* (2019) proved that as

a result of the oscillatory movement of the machine's operating elements, the technological mass performs both a circulation motion along the trajectory induced by force factors, and the rotation of individual load particles around its instantaneous equilibrium centre, resulting in a decrease in internal friction inside the load mass; intensive mixing and destruction of individual structures; changes in the main rheological characteristics of the processed product.

M. Mushtruk *et al.* (2021) and I. Palamarchuk *et al.* (2020) argued that a significant increase in the material circulation rate can be achieved when the vibrator is removed from the working chamber. The paper shows how the bulk medium is rolled along the inner wall of a cylindrical container as a single body with an amorphous surface, which significantly intensifies the mutual movements of the particles of the mixture components among themselves, but the need to seal the surfaces bounded by spring-loaded membranes significantly complicates the design of the machine; the significant thickness of the product layer in drum structures contributes to the rapid attenuation of the oscillation amplitude as it moves away from the vibration source, which creates some problems in the development of vibration mixers with a large volume of the working chamber.

Based on the research presented in the paper by H. Ding *et al.* (2021), it is proved that the use of low-frequency vibrations ensures a uniform distribution of components of bulk dispersed systems when mixing products and preparing feed mixtures, premixes, and other high-calorie components in a drum working tank.

Thus, numerous studies of the process of preparing various bulk mixtures under the conditions of a vibration field allowed the authors to highlight the main advantages of vibration mixing over conventional mixing: a significant reduction in the effective coefficients of internal and external friction, weakening of the bonds between the particles of the material. Compared to conventional vibrating mixers, they have a higher specific capacity (5-6 times) (Ahmed *et al.,* 2020), provide a 2-3-fold reduction in mixing duration (Huang *et al.,* 2021), metal content – by 17%, energy consumption – by 30%, capital costs for manufacturing – by 18%, and drive power – by 30-35%, which leads to a reduction in total energy costs by 3-4 times (Bunkin *et al.,* 2020).

Materials and Methods

To perform these tasks, an experimental model of a vibrating mixer was developed (Figure 1), which includes: a mixing tank mounted on an elastic suspension; a vibrating drive for the excitation of vibrations; a single-shaft mixing element with blades, which has a separate drive.

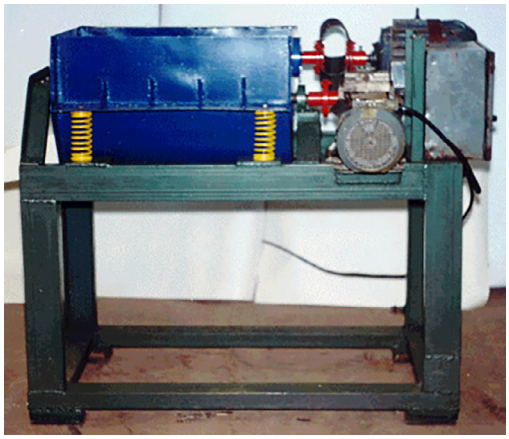

Figure 1. Experimental model of a vibration machine for preparing premixes

When performing the tasks set, experimental studies were conducted according to the developed methodology (Palamarchuk *et al.,* 2020):

- evaluation of the amplitude-frequency characteristics of the mixing process using the

above laboratory equipment, which allows implementing vibro-blade processing of bulk feed mixture;

➢ evaluation of power and energy vibro-blade mixing;

➢ evaluation of the amplitude-frequency, power, and energy characteristics of this process when disconnecting the vibration exciter from the scheme of the developed technical system, which ensures the implementation of only the process of blade mixing;

➢ disconnection from the developed scheme of the blade shaft drive motor, evaluation of amplitude-frequency, power, and energy characteristics when operating only the vibration exciter, which implements the process of exclusively vibration mixing.

The study was carried out at the speed of rotation of the vibration exciter shaft n_V=*985 min*$^{-1}$, which was measured using a time tachometer TCH 10-R GOST 21339-75 (1977), changing the amplitude of vibrations of the container from 0 to 7 mm. The degree of filling of the container was used as a characteristic that affects energy dissipation in the process environment. This parameter was determined by comparing the volume geometric dimensions according to the technical characteristics of the machine with the actual volume that can be effectively used to implement the process under study. The values of the container oscillation amplitude, vibration velocity, and vibration acceleration were taken using the ROBOTRON measurement system. The value of the drive power of the vibration exciter shaft P_V was taken using a 3-phase wattmeter of type D 124 TU-5007-71.

As a characteristic of the vibration field, a coefficient of the vibration mode is taken, or the dynamism coefficient, which is determined by the equation:

$$k = \frac{A\omega^2}{g}, \quad (1)$$

where A – oscillation amplitude of the container, m; ω_v – angular velocity of vibrations of the mixer container, s^{-1}; g – gravity acceleration, m/s^2.

For a more accurate determination of P_B power consumed by the drive motor of the vibration-free blade shaft during the mixing process, the authors developed the following method, the specific feature of which is the investigation of the time of uniform lowering of the load of the set mass, during which the blade shaft will make two complete revolutions. Further, the average time value is used to analytically determine the torque on the blade shaft and the power value P_B for every instance.

Results and Discussion

The technical system, which consists of a vibrating machine – a vibrating mixer and a process load, is influenced by many factors. The most significant of them are: vibration acceleration of container $A\omega^2$, angular velocity of blade shaft rotation ω_b, physical and mechanical properties of the mixed substance.

When evaluating the energy dissipation in the system, it was found that the optimal degree of filling of the container is φ = 1/2-3/4 of the full load of the working capacity of the vibrating machine J. Wang, *et al.* (2020), M. Mushtruk, *et al.* (2022).

Analytical determination of the drive power is impossible due to the lack of clear dependencies that would describe the patterns of interaction of the vibrating surface of the U-shaped container of the vibration mixer and its working body with the particles of technological loading – a mixture of agricultural grain crops; the behaviour of this loading under the influence of a vibration field. The limiting of the study of the influence of these factors on the drive power of the technical system to conducting one-factor experiments leads to the need to perform a large number of experiments. The amount

of work will be significantly reduced by using methods of matrix planning of the experiment.

The support units of the designed vibrating blade agitator perceive sufficiently intense power loads due to the combined technological action and the presence of alternating accelerations of the working elements, which becomes the main reason for the depreciation of the technical system under study. Therefore, for the effective implementation of technological tasks, a new scheme of an elastic system was proposed, the parameters of which directly affect the change in the regime characteristics of the mixing process. Such a design measure was the installation of additional elastic elements between the working container and the drive shaft. The selection of the stiffness of these elements was carried out on the condition that the transmission of working vibrations to the drive unit was levelled, that is, the blade shaft was made vibration-free. This improvement has significantly increased the efficiency and reliability of the support system of the developed vibration mixer. This improvement is the main difference between the proposed scheme and the conventional one. The main structural elements of a vibrating mixer (Fig. 2) are: container 3 with an inertial vibration exciter 1, which is mounted on a fixed frame using elastic supports 2. The container has a capacity of 70 litres. The shaft 6 with blades 7 passes through the mixer casing and is installed in bearing units 5, which are rigidly fixed in fixed racks 12 and placed outside the casing. When the mixer is running, the shaft with blades does not perform oscillatory movements, which significantly relieves the bearing units 5, increases their durability and reliability. In addition, the oscillating mass of the mixer decreases, which leads to a decrease in energy consumption. The flexible kinematic connection between the blade shaft and the mixer body is ensured by seals 4. An elastic coupling connects shaft 6 to the electric motor 9, which drives it in rotational motion. Components are loaded through the neck 10, and the mixture is unloaded through the hatch 11.

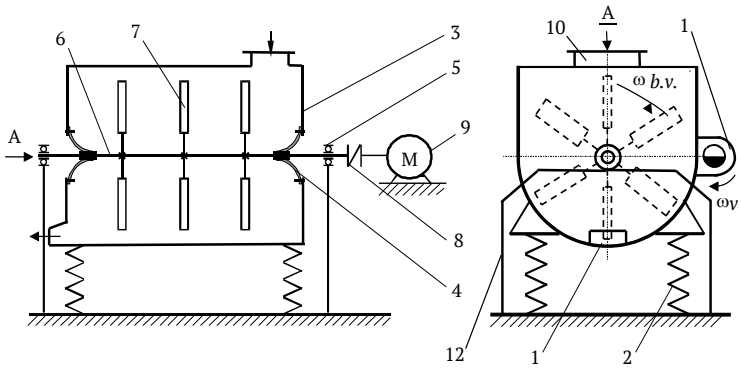

Figure 2. Diagram of a vibration mixer with a vibration-free blade shaft:
Notes: 1 – vibration exciter; 2 – spring suspension; 3 – mixer casing; 4 – seals; 5 – support units; 6 – shaft; 7 – blades; 8 – elastic coupling; 9 – electric motor; 10, 11 –pipes for entering components and unloading the mixture; 12 – fixed rack

Based on the obtained experimental data, graphical dependences of the oscillation amplitude of container A on the driving force of unbalances F are obtained (Fig. 3), showing the regularities of the introduction of loading into the mass, i.e., the degree of permeability

of low-frequency vibrations in the process under study. Vibration exciter power consumption P_V during the mixing process increase due to an increase in the strength of the vibrational component of the oscillatory system and an increase in the part of the energy dissipated in the loading mass (Fig. 4). Changes in the vibration mode coefficient k, depending on the degree of load of the working container, also have a significant impact on the mixing process (Fig. 4 *a*, 5).

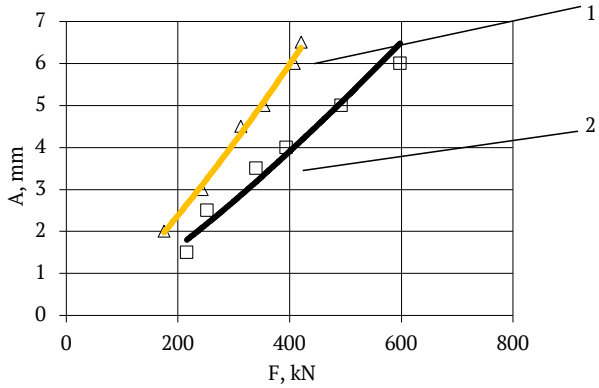

Figure 2. Dependence of the oscillation amplitude of the mixer container A on the value of the driving force F: 1 – loading of the mixer by 1/2 of the full volume; 2 – loading of the mixer by 3/4 of the full volume

According to the method presented above, experimental studies were conducted to determine the values of the amplitude-frequency, power, and energy characteristics of the studied processes of vibro-blade, blade, and vibration mixing. As experimental studies have shown, the value of the amplitude of container vibrations *A* increases exponentially as the driving force *F* increases (Figure 3), which is explained by the fact that with an increase in the load mass, the resistance to penetration of the force action into the working volume increases. Magnitude of the driving force *F* is determined solely by the mass of unbalanced elements of the drive mechanism.

The coefficient of the vibration mode k shows how much the force component of the "vibration field" exceeds this characteristic from the action of the gravitational force, which increases for large masses of the load (Figure 4*a*). Accordingly, power consumption P_v, developed by the vibration exciter, also increases with increasing technological mass. Moreover, this change is proportional to the different operating modes of the vibration installation (Fig. 4 *a, b*).

As can be seen from Figures 3 and 4, an increase in the magnitude of the driving force F leads to a proportional increase in the amplitude of vibrations of mixing container A and the power consumption by the electric motor of the drive shaft of the vibration exciter P_v. An increase in the degree of loading is accompanied by a decrease in the amplitude of oscillations of the container and an increase in the power consumption P_v. But an increase in the amplitude of vibrations A (Figure 4 a) and the vibration mode coefficient k (Fig. 4 b) is accompanied by a quadratic increase in power consumption P_v, which is conditioned by an increase in energy dissipation in the mass of the mixture in the form of heat.

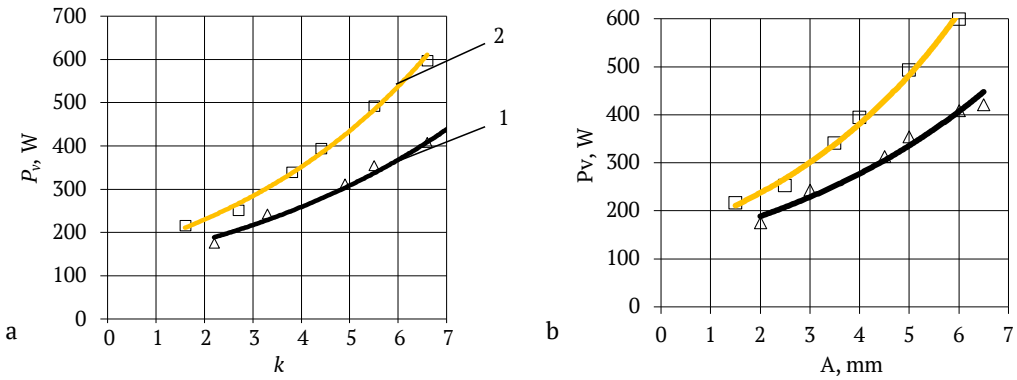

Figure 2. Dependence of the power consumed by the electric motor of the vibration exciter shaft Pv, from the vibration mode coefficient k (a) and the oscillation amplitude of the container A (b):
Notes: 1 – loading the mixer by 1/2 of the full volume; 2 – loading the mixer by 3/4 of the full volume

The experimental studies of the power P_b are necessary to substantiate the effective operating modes of the drive of a vibration-free blade shaft under different modes of vibration and mechanical action. Changes in the vibration parameters and speed of rotation of the blade shaft also affect the energy consumption for mixing. Dependences in Fig. 5 show that an increase in the number of revolutions of the blade shaft leads to an increase in the power consumption of the drive electric motor, and an increase in the value of the vibration mode coefficient k leads to its significant decrease. Under the action of the "vibration field", the circulation movement of the mixture in the mixer container creates some pressure on the blades, which causes additional resistance to the loading mass when they are counter-moving.

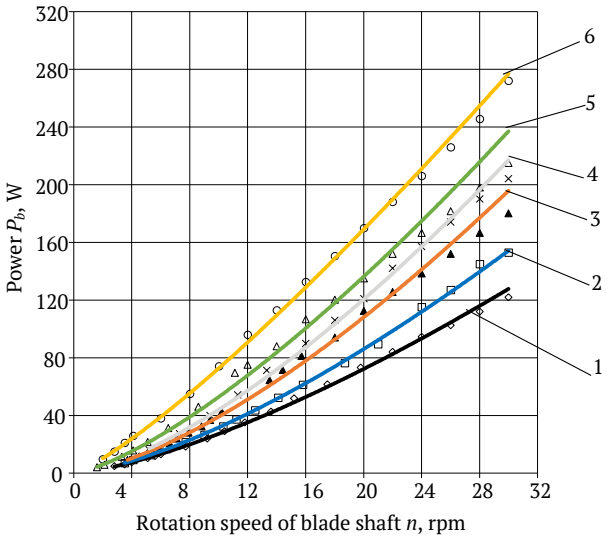

Figure 5. Dependence of power consumption P_b on the speed of rotation of the vibration-free blade shaft nb when the value of the vibration mode coefficient k is:
1–k=6.6; 2–k=5.5; 3–k=4.4; 4–k=3.8; 5–k=2.7; 6–k=1.6

A significant decrease in the power value for the vane shaft drive with an increase in the vibration mode coefficient k is explained by a decrease in the effective coefficients of internal and external friction under the influence of low-frequency vibrations. When summarising the results of experimental studies in Fig. 6, the dependences of the power consumed by the electric motor of the drive shaft of the vibration exciter P_v and the electric motor of the drive of the vibration-free blade shaft P_b are obtained, their total capacity P_Σ based on the parameters of the vibration field, which are expressed in terms of the coefficient of the vibration mode k at the speed of rotation of the blade shaft $n_b = 30$ min^{-1} and the vibration exciter shaft $n_v = 985$ min^{-1}.

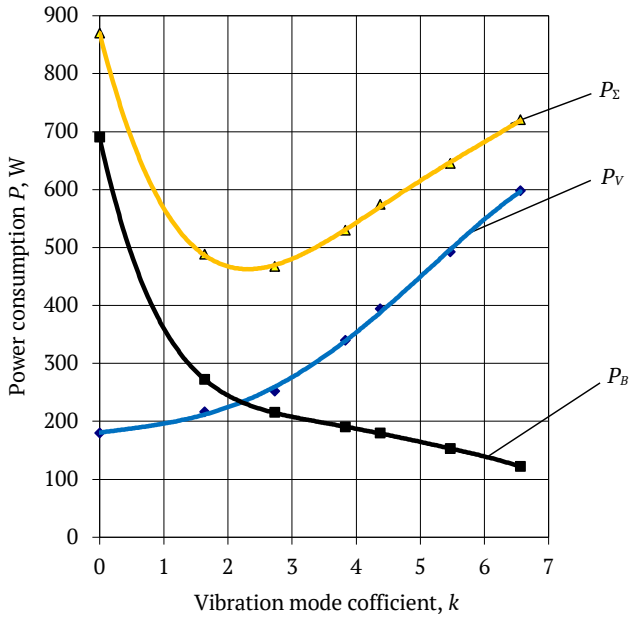

Figure 6. Dependence of the energy parameters of the vibration mixer on the value of the vibration mode coefficient k (at n_b=30 min-1, n_v=985 min^{-1}); $P\Sigma=P_v+P_b$ – total energy costs in the mixer

Figure 6 shows that an increase in the vibration parameters (coefficient k) is accompanied by a slight increase in the power consumption of the electric motor of the vibration exciter shaft and a significant decrease in energy consumption on the drive of the vibration-free blade shaft. This leads to the appearance of a minimum of total energy consumption for the mixer drive at the value of the vibration mode coefficient k≈2,5-3, that is, in the mode of continuous throwing of particles of the materials under study.

Comparative analysis of the studies by C. Debnath *et al.,* (2016), O.J. Aboderin *et al.* (2021) and L.A. Roy *et al.* (2020) showed that the main condition for achieving maximum uniformity is the creation of significant gradients of shear strain rates in micro- and macro-volumes, which is not possible in conventional mixers, which, in addition, have high specific energy consumption and long duty cycles.

The experimental studies by Y.U.E. Caixu *et al.* (2019) and M. Wathelet *et al.* (2020) show trends towards a sharp decrease in the effective

coefficient of friction in the vibrating bed. However, these studies do not specify the ranges of effective vibro-mechanical parameters for processing technological masses.

Premixes with a rate of introduction into mixed feed of 0.5% qualify as impurities of increased concentration, compared to 1% they contain twice the amount of biologically active substances by reducing the mass of filler, rheological and structural-mechanical properties of raw materials for the food and pharmaceutical industries, feed preparation, microbiological industries (Singh & Agarwal, 2021); (Li *et al.,* 2019). However, no effective design schemes of technological equipment were recommended for the implementation of these processes.

Based on the results of the study by M. Mushtruk *et al.* (2022), the influence of the design of the mixing chamber on the mixing intensity was established: vibrational mixing of the material ended after 15 seconds, while in a rotating drum, a uniform distribution of components was not achieved even after 360 seconds. vibration-pulse motion converters, in which the energy of the main or driving system is used to create the technological movement of the driven system.

Drum diagrams of machines that were presented in the paper by Ding *et al.* (2021) do not reveal the technological potential of vibro-mechanical influence on the processed products. In modern technological processes, it is quite effective to implement the mixing of bulk masses by creating shear deformations in the entire mass of the product using a complex action of shovels, augers, vibrations of working tanks or individual elements of the mixer's executive bodies.

To obtain a high-quality multicomponent mixture, it is necessary to introduce high-tech equipment for the production of mixed feed, which is advisable to produce in small feed mills or directly in fattening complexes, where the specifics of local raw materials are considered and there are no significant costs for transporting finished products (Mushtruk *et al.* (2021) Palamarchuk *et al.* (2020)). In the conditions of Ukraine, where there is a whole network of inter-district feed mills, this experience, combined with domestic achievements, should be effectively implemented in production without significant additional costs.

Conclusions

During the analysis of the findings of experimental studies, relationships were established between the power consumed by the vibrator drive motor (P_v) and the drive motor of a vibration-free blade shaft (P_b), as well as their total capacity ($p\sigma$). These dependencies correlated with the vibration field parameters expressed in terms of the vibration mode coefficient k. Studies were conducted at the speed of rotation of the vane shaft $n_L = 30$ revolutions per minute and the vibration exciter shaft $n_v = 985$ revolutions per minute. An increase in vibration parameters (coefficient k) is accompanied by a slight increase in power consumption by the electric motor of the vibration exciter shaft and a significant decrease in energy consumption on the drive of a vibration-free blade shaft. This minimises the total power consumption of the mixer drive at values of the vibration mode $k \approx 2,5\text{-}3$ coefficient k of about 2.5-3. This occurs in the mode of continuous ejection of particles of the analysed materials.

The results of the experimental study established the operating mode of the installation, in which there is a clearly defined minimum use of total power on both drive electric motors for the materials under study, which is achieved at the coefficient of vibration mode $k \approx 2,5\text{-}3$, which allows reducing energy costs for the process by 2-2.5 times, considering the

design complexity and implementation of two energy flows during vibro-blade mixing.

Due to the combined action of low-frequency vibrations of the working capacity and working blades for the mode k≈2,5-3, it is possible to achieve a mixture inhomogeneity value in the range of 0.8-3% with a process duration of 80-100 seconds with minimal total energy consumption.

Dependencies of energy consumption for the mixing process on the amplitude of vibrations of the working container A and from the mode coefficient k are almost identical; there is an increase in energy by 15-20% with an increase in these parameters by 25-30%, accompanied by a quadratic increase in power consumption P_v due to an increase in energy dissipation in the mass of the mixture in the form of a bulk process medium. Thus, the implementation of energy-saturated technological operations that require the use of combined vibro-mechanical action can be implemented in a less expensive way when choosing such a processing mode, when reducing the internal friction forces and, accordingly, the mechanical resistance of the medium through vibration action will significantly reduce the energy consumption of the process. Such processes include the grinding of a material with a complex composite structure; contact processes in a large volume, when insignificant ingredients need to be evenly distributed throughout the entire volume of the working chamber. These areas are relevant for further study when using vibration wave effects in the processes of food processing and production.

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Conflict of Interest

None.

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Аналіз енергетичних характеристик вібраційного змішування багатокомпонентних сумішей сільськогосподарської сировини

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Анотація. Забезпечення ефективності використання у тваринництві та рослинництві поживних речовин зернових, білкових, вітамінних та мінеральних кормів у складі повнораціонних кормових сумішей, а також відповідне зниження витрат на виробництво даної продукції, становить актуальність представлених досліджень та перспективи їх розвитку. Тому метою представлених досліджень є обґрунтування ефективних режимних параметрів приготування премісів кормових сумішей внаслідок оцінки енергетичних параметрів процесу вібраційного перемішування. Дана оцінка проводилась шляхом порівняння результатів застосування вібраційного, лопатевого та вібролопатевого технологічного впливу. В умовах дії низькочастотних коливань спостерігається зменшення робочого опору розпушеного шару суміші, що дозволило отримати ефект зниження енерговитрат на процес. Тому у порівнянні із звичайними вібраційні змішувачі мають більшу питому продуктивність у 5-6 разів, забезпечують зменшення тривалості змішування у 2-3 рази, металомісткості – на 17%, енергомісткості – на 30%, капітальних витрат на виготовлення - на 18% і потужності привода – на 30-35%, що зумовлює зниження загальних

витрат енергії в 3-4 рази. У результаті було обґрунтовано зону мінімальних енерговитрат, у якій зменшення опору технологічного середовища дозволило радикально зменшити сили тертя у процесі перемішування за умов забезпечення рівномірного розподілу з необхідною за технологічними вимогами концентрацією складових суміші. Збільшення амплітуди коливань супроводжується квадратичним підвищенням споживаної потужності, що зумовлене збільшенням розсіювання енергії у масі суміші у вигляді теплоти. Реалізація обґрунтованих робочих режимів перемішування дозволила зменшити енерговитрати запропонованого вібролопатевого перемішування у 2,0-2,5 рази порівняно з традиційною лопатевою обробкою. До практичної цінності приведених розробок можна віднести застосування вібролопатевих робочих органів та виконання приводного валу неколивним, що разом із мінімізацією енерговитрат на процес дозволяє зменшити динамічні навантаження на опорні вузли розробленого змішувача

Ключові слова: вібролопатеве перемішування; кормова маса; премікси; амплітуда та частота коливань; енерговитрати на привод; сипкий псевдозріджений шар; низькочастотні коливання

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Morphometric characteristics of Ukrainian steppe bees depending on the method of controlled queen mating

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Abstract. Bee breed is an important factor in determining bee family development and productivity, as it affects honey production, disease resistance, climate adaptation, and bee behaviour characteristics. The purpose of the study was to establish the relationship between the methods of mating queens and the morphological characteristics of bees of the Ukrainian steppe breed and the productive indicators of bee colonies. To conduct the research, 43 bee colonies with queen sisters of the Ukrainian steppe breed mated by different methods of natural mating were established in the Vinnytsia oblast. According to the results of mating, there were 22 queen bees in the control group, and 21 queen bees in the experimental group. The queens of the first control group mated in a normal natural way without any restrictions. The queen bees of the experimental group mated under time and space control. Based on the results of the research, the relationship between the integrity of the colony and its morphological features and productive indicators was established. Thus, experimental families have different degrees of belonging to the Ukrainian steppe breed, control – 59% and experimental – 87.2% ($p < 0.001$). According to the cubital index, the advantage was 8.2% ($p < 0.001$) in favour of the experimental group. The best family integrity on the hantel index was observed in families in which queens were mated in a controlled time and space, with a difference of 3.32% ($p < 0.001$). In the control group, where uncontrolled mating of queens was performed, more bees were found for discoid displacement with an excess of the standard indicator for the breed. Families in the experimental group were stronger by 14.5% ($p < 0.001$) compared to the control group. They provided 41.9% more honey, built 22.1% more honeycombs ($p < 0.01$), and the need for Kandy feeding was 31.8% less ($p < 0.001$). In addition, the bees of the experimental

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group had pronounced hygienic behaviour and required less labour costs. The practical significance of the study lies in the possibility of establishing patterns of action of factors on a particular breed and confirms the need to implement breeding programmes in beekeeping

Keywords: hantel index; cubital index; discoid displacement; productivity; preservation; climatic conditions; feed consumption

Introduction

The beekeeping industry plays an important role in ensuring the country's food security, which is linked to many other industries. Bees pollinate many plant species, being used to increase yields. Beekeeping products include not only honey, a valuable dietary product, but also wax, propolis, venom and other products that are widely used, in particular for human health. Today, beekeeping is mainly pollinated and honey-based. Without the use of bee pollination, it is difficult for farmers, gardeners, horticulturists, and other workers who grow insect-pollinated crops to obtain high yields. Therefore, workers in agriculture, horticulture and other industries should be interested in the development of beekeeping and the use of bees for plant pollination (Nevsky & Sverdan, 2021).

The effectiveness of the development of beekeeping, as well as a single apiary farm, depends on many factors. Admittedly, the key factor of productivity is the availability of feed resources and weather and climatic conditions, but such a component as genetic potential is also responsible for the efficiency and profitability of beekeeping production. Adaptability to local conditions is key to the efficiency of using bee colonies, because this factor depends not only on productivity, but also on the survival of bee colonies in critical periods, the strength of families during the active season, and resistance to certain diseases, in particular to varroatosis. Therefore, it is worth noting that such a process as breeding is a cheaper, more efficient and environmentally friendly factor in increasing production (Brovarskyi & Papchenko, 2014). At the same time, mixing local breeds with imported ones is dangerous because it generates substandard material. And this is confirmed by a number of researchers from all over the world. The German scientist Ruttner (1988) reported that high productivity of interbreeding hybrids can be obtained only in the first generation and from the third generation the average productivity regularly decreases. In the 1960s, researchers became interested in the interbreeding hybridisation of bees, which was forcibly introduced in apiaries, which ultimately led to significant changes (Alpatov, 1948). After three generations, when all the source material had already been hybridised and the native bees had been lost over large areas, the bred bees had increased their irritability, viciousness, and drone resistance several times, and their resistance to disease decreased. It is difficult to correct such an error due to the biological characteristics of bees, considering also such a feature of drone development as parthenogenesis (Lattorff *et al*, 2005; Papp *et al*., 2015). Researchers have established that the current distribution of breeds does not correspond to traditional zoning. The conclusion of their study is that common practice of importing genetic material *Apis mellifera* from different regions of Ukraine leads to uncontrolled hybridisation and poses a threat to the preservation of native honey bee breeds (Cherevatov *et al*., 2020).

In nature, bees themselves contribute to the crossbreeding by their way of life. In the absence of isolation, any bee breed is influenced and pressured by other breeds, but here nature controls and selects useful signs of bees over a long period of time. Studies have shown an insufficient level of breed purity as a result of the spontaneous, uncontrolled hybridisation that has been carried out in recent years. Kerek (2020) argues that the crossbreeding of bees in the country's apiaries has not spared even the highest regions of Ukraine, which can be called semi-isolated.

Economically useful signs of bees have now undergone changes due to unfavourable natural and climatic conditions (prolonged cold springs, frequent prolonged droughts), impoverishment of the food supply due to a decrease in the acreage of honey crops and the cultivation of monocultures. In such conditions of keeping bee colonies, there is a need to study a number of issues of directed breeding aimed at improving its economically useful features and creating highly productive local types that can tolerate fluctuations in the main factors of weather conditions. A breeding trait under these conditions, which is directly related to the productivity of bees, is adaptability to certain conditions of honeybee capture (Cherevko *et al.*, 2018).

In Ukraine, the zoned breeds are carpathian, Ukrainian steppe and polissian (Adamchuk & Bilotserkivets, 2015). Ukrainian steppe bee breed *(Apis mellifera sossimai)* is most widespread in Ukraine and occupies more than 70% of its territory. However, as a result of decades of hybridisation with other local breeds (carpathian *(Apis mellifera carpatica)* and polissian *subspecies Apis mellifera mellifera*), as well as with previously popular central russian (*Apis mellifera mellifera*), grey mountain caucasian *(Apis mellifera caucasica)* and popular now Italian (*Apis mellifera carnica* and *Apis mellifera ligustica)*, as a result of the unconscious use by beekeepers of bee breeds that are not registered for Ukraine, the purity of the drone background of beekeeping farms is blurred, as a result of which the economically useful features have changed (Cherevatov *et al.*, 2020). In addition, bees are susceptible to reduced genetic diversity because they are haplodiploid (Grozinger & Zayed, 2020). Considering the fact that drones develop from unfertilised haploid eggs by parthenogenesis, there is a need to use targeted breeding of Ukrainian steppe bees (zoned for the Vinnytsia oblast) to improve their economically useful characteristics (Dzitsiuk & Lytvyniuk, 2014).

Therefore, depending on their habitat, bees develop certain morphometric and behavioural qualities that they need to ensure their normal life processes. Each breed, and even the breed type, has its own unique properties and some of them, in the absence of appropriate conditions, may not manifest themselves in the homeland of this breed (for example, wintering breeds of southern latitudes in northern regions with a long non-flying period). And because of this, it is not always possible to predict the result of imported bee breeds that are not typical of the zones (Brovarskyi & Papchenko, 2014).

Keeping native bees in apiaries, which have adapted to living conditions in a certain area over the course of evolution, is an important condition for ensuring the effectiveness of this process. Preference should be given to the breed of bees that comes out of wintering with the least losses and quickly recovers in the spring. Each breed of bee, depending on the localisation zone and types of honey collection in this area, shows its abilities differently. In the forest-steppe zone of Ukraine, the most common and popular are Ukrainian steppe bees (Khamid, 2014).

One of the tasks of breeding in beekeeping is to preserve breeding material, create highly

productive bee populations, and improve the productivity of bee colonies. The Ukrainian steppe bee breed is characterised by specific morphological features and differs from others in productive features. However, haphazard crossing with non-zone bees in Ukraine has led to local breeding.

The purpose of the study is to establish patterns between morphological features and compliance of phenotypes with the standard of the Ukrainian steppe bee breed in the natural and controlled method of mating queen bees.

Materials and Methods

The research was conducted in a private apiary in Volodymyrivka village, Vinnytsia region. The apiary farm has supported the breed by purchasing over the past five years (2018-2022) of purebred queens of the Ukrainian steppe breed, in the amount of 20% annually, and breeding was carried out along the maternal lines.

The first stage is obtaining bee colonies. For this purpose, based on the research, the Nikot-100 queen breeding system, 48 queen cells (24 in each group), and three parent families were used, which were kept in 10-frame beehives on a 435×145 mm frame.

The Nikot-100 queen breeding system was used to produce queen bees of sister origin. For mating queens of the control group, in addition to their own drone background, which potentially included 50 bee colonies from the apiary under study and about 250 families from other private apiaries located within a radius of 500 m, and about 170 families located within a radius of 2 km. The queen bee was placed in the Nikot-100 system on May 15, 2021, after it was isolated and the eggs were placed in care families for growing larvae until the queen cells were sealed. On May 30, 2021, 48 queen cells were placed in micronuclei. In the future, two groups of analogues were formed for the study, which, according to the results of successful mating, included 43 sister bee colonies. Micronuclei were placed at one location, at a distance of 50 m from the pollinating-honey part of the apiary.

The second stage began with checking the queen bees for the seeding quality, marking with a marker and wing capping, after which they were placed in layers that contained 2 forage combs and 8 combs of different ages of brood, which were seeded by bees, and 10 frames of the dryer (10-frame body per frame size 435×145 mm). Planting queen bees in the formed layers took place only with the help of a perforated cap with a check of their acceptance on the third day. Layers were formed on June 15-16 and were intended for use in pollination of sunflower seeds from July 19 to August 10, 2021. The formed layers were placed on specialised platforms in a staggered order, to equalise the influence of factors such as geographical location, the presence of wind and shade.

At the third stage, the degree of belonging of bees to the Ukrainian steppe breed, productive indicators of bee colonies, wintering features, the degree of safety, hygienic behaviour, and the intensity of feed consumption were determined.

To organise a time-controlled flight, the experimental farm used 12 double micronuclei for queens and 3 parent families placed in hull hives with a separate grid for monitoring the flight activity of drones. Parents' families were provided with a daily evening flight from 18:00 to 06:00. The micronuclei were also equipped with flight barriers, which prevent the queen from leaving before a certain time. On Day 22, micronuclei were transferred in the winter garden until the next day before 17 o'clock. At 17:30, the micronuclei were opened together with the parent families, as a result of which a mass flyby and mating of queens took place. At approximately 20:30, the micronuclei were

closed and the operations of the previous day were repeated again the next day, after which the gate valve was returned to a position that allowed only worker bees to exit.

In the course of research, the breed affiliation of the resulting offspring of worker bees was primarily determined. The assessment was carried out visually, based on the uniformity of the colony and the colour of the tergites of the abdomen of worker bees. For morphometric analysis, six samples were taken from each analogue group, which included 60-70 bees no older than three days of age. Each sample was taken from two families, according to the method, a perforated cap was applied to the sealed brood, after the bees left the cells, they were preserved in an alcohol solution in disposable containers, which were marked with numbers 1-12, without indicating belonging to a specific group (Brovarskyi *et al.*, 2017). The assessment was performed using the Morphoxl – programme for morphometric analysis of bee wings. 618 wings from 12 bee colonies and at least 50 bee wings from one bee family were used for evaluation. Using the Morphoxl software suite, measurements of the bee's wing and their relationship to each other were determined, namely, the cubital index, the hantel index, and the angular discoid displacement. This study was conducted at the state educational institution "Hadiach higher professional agricultural school". The cubital index was calculated as a percentage. To do this, the measurements of the sides of the third cubic cell of the front wing were determined, the results of the measurements of the smaller side were divided by the measurements of the larger side and multiplied by 100%. Discoid displacement was determined using a stereomicroscope. For this purpose, the scale with divisions of the eyepiece-micrometre of the stereomicroscope was combined with the centreline of the radial cell of the bee's front wing. In this case, the line perpendicular to the scale must pass through the intersection point of the longest vein of the cubital cell with the lower vein of the radial cell. The hantel index was determined by the ratio of the length of segments of the wing cubital cell, one of which is a straight line, the second – a line connecting the uneven edges of the opposite section.

Results and Discussion

The weather and climatic conditions of the two years of study cannot be called typical, the decrease in the number of honey plants and the cultivation of monocultures negatively affected the nectar supply of the area, the quality of wintering, the development and productivity of bee colonies, so the indicators of biological characteristics of bee colonies involved in the research process do not always meet the standard "Technological requirements for breeding and breeding work in the field of beekeeping" (2016).

During the first stage of research, namely obtaining fertile queens, for their subsequent planting in layers, it can be stated that the method of limited space and time mating of queens does not actually reduce the number of successful mating, and does not entail additional losses of breeding material compared to the natural flight of queen bees. The control group included 22 queen bees fertilised by free mating, and the control group included 21 queen bees fertilised by mating controlled in time and space.

The tables below show the results and their compliance with standards (breed ranges) (2015, 2020).

According to Table 1, bee colonies in the control group have a high degree of variation and are slightly outside the range of breed values according to the cubital index (0.931-3.783), which is a consequence of free mating with a rich drone background. At the same time, the

experimental group has significantly smaller deviations from the breed ranges and does not cross its upper limit. But it is also necessary to consider the coefficient of variation (colony integrity), as a sign of stable transmission of economically useful traits. The control group had a coefficient of variation from 15.4 to 26.1%, and the experimental group – from 7.3 to 15.6%. The average value for this indicator in the control group was 20.0 ± 1.49%, while in the control group it was significantly lower – 11.8%. The difference between the groups was 8.2% ($p < 0.001$).

Table 1. *Indicators of the cubital index of Ukrainian steppe bees*

No. of sample	Cubital index (breed range – 1.86-3.0)					
	control group			experimental group		
	variability	average value	variation coefficient, %	variability	average value	variation coefficient, %
1	1.587...3.731	2.404 ± 0.064	19	1.723...2.790	2.200 ± 0.033	11
2	1.438...3.152	2.182 ± 0.054	17.7	1.880...2.472	2.146 ± 0.022	7.3
3	1.279...3.783	2.349 ± 0.073	21.4	1.719...2.973	2.247 ± 0.041	13.4
4	1.256...3.110	2.046 ± 0.058	20.5	1.833...3.612	2.420 ± 0.052	15.6
5	1.389...2.650	2.049 ± 0.044	15.4	1.791...2.984	2.187 ± 0.039	13
6	0.931...3.699	2.155 ± 0.077	26.1	1.760...2.692	2.112 ± 0.030	10.3
By group	-	2.197 ± 0.0612	20.0 ± 1.49	-	2.219 ± 0.0444	11.7 ± 1.17***

Note: *** – $p < 0.001$

The cubital index is not always an accurate breed classifier due to the variability of the feed base and the influence of bee feeding conditions at different stages of their development. Therefore, the hantel index is used to confirm the breed of bees. The hantel index also shows better family integrity in the experimental group – 6.95% and 10.27% for the control group. The difference between the groups was 3.32% ($p < 0.001$) (Table 2).

Table 2. *Results of the hantel index of the wing of a bee of the Ukrainian steppe breed*

No. of sample	Hantel index (breed range 0.829-1.113)					
	control group			experimental group		
	variability	average value	variation coefficient, %	variability	average value	variation coefficient, %
1	0.776...1.283	0.995 ± 0.014	9.8	0.840...1.106	0.982 ± 0.009	6.3
2	0.779...1.157	0.974 ± 0.013	9.3	0.859...1.179	0.984 ± 0.010	7.2
3	0.795...1.382	1.006 ± 0.020	13.3	0.831...1.167	0.0995 ± 0.010	7.1
4	0.752...1.106	0.942 ± 0.012	9.2	0.832...1.168	0.995 ± 0.010	6.9
5	0.827...1.275	1.014 ± 0.015	10.4	0.756...1.034	0.893 ± 0.008	6.5
6	0.781...1.228	0.939 ± 0.012	9.6	0.765...1.094	0.898 ± 0.010	7.7
By group		0.978 ± 0.0132	10.27 ± 0.631		0.957 ± 0.0198	6.95 ± 0.206***

Note: *** – $p < 0.001$

The obtained data on the hantel index in some samples slightly went beyond the breed range (0.829-1.113). Although the average score in the experimental group was 0.957, the control group – 0.978, which was within the range. The angular discoid displacement also in both

groups of bee colonies is in the breed range (1.89-5.68) and shows the uniformity of offspring and indicates the level of breeding due to the saturation of different drone backgrounds (Table 3).

Table 3. *Morphometric characteristics of Ukrainian steppe bees by angular discoidal displacement*

No.	Angular discoid displacement (breed range – 1.89-5.68)					
	control group			experimental group		
	variability	average value	hybridisation degree	variability	average value	hybridisation degree
1	-4.443...8.614	2.886±0.351	Acceptable	-1.125...5.688	2.534 ± 0.238	Insignificant
2	-3.188...7.985	1.943±0.013	Acceptable	-1.422...6.236	2.355 ± 0.247	Insignificant
3	-3.402...8.779	2.802±0.351	Hybrid	-0.365...6.983	3.017 ± 0.027	Acceptable
4	-2.318...6.016	2.55±0.285	Insignificant	-1.104...7.352	3.109 ± 0.238	Insignificant
5	-1.529...7.140	3.28±7.140	Acceptable	-1.798...4.715	0.817 ± 0.226	Absent
6	-1.265...8.625	3.096±0.331	Acceptable	-3.137...6.269	1.056 ± 0.260	Insignificant

The Morphoxl software suite detects the following levels of bee hybridisation gradation: missing; insignificant; acceptable; hybrid. In the conducted experiment, this level is more acceptable for the control group, and insignificant for the experimental group. That is, in the control group there are more samples in which these values go beyond the range towards increase (more than 5.68), in the experimental group there were a small number of such values. Table 4 shows the results, which combine all previous indicators and shows a forecast of the breed composition of bees for each colony. The data obtained indicate that the average value of bee samples belonging to the breed in the control group was 59.0%, and in the experimental group – 87.2%, which is 28.2% higher ($p < 0.001$).

Table 4. *Summary indicators of morphometric indicators of the Ukrainian steppe bees*

Group	Belonging to the breed under study (%)						Group average (%)
	Sample						
	1	2	3	4	5	6	
Control	70.6	56.9	48.9	58.5	70.2	49.1	59.0 ± 3.93
Experimental	94.2	90.2	83	92.3	80.8	82.7	87.2 ± 2.33***

Note: *** – $p < 0.001$

Studies of economically useful characteristics were also conducted, in particular, on honey productivity, the number of honeycombs built up, the strength of the bee family before wintering, and the effectiveness of feed use (feeding in spring). The data were averaged and entered in Table 5.

The highest productive indicators were obtained from a group of bee colonies with queens that controlled mating in space and time. During the experimental period, 41.9% ($p < 0.001$) more honey was received from established families. Bee colonies on the eve of wintering were stronger by 0.98 cells, or 14.5% ($p < 0.001$), which had a positive effect on the consumption of Kandy feed in the spring. Stronger families consumed 31.8% ($p < 0.001$) less than this feed. Moreover, during the season, the bees of the experimental group rebuilt 22.1% ($p < 0.01$) more honeycombs.

Table 5. *Summary data on the average productivity of bee colonies at the end of the season*

Group	Number of families in the group	Strength of families, cells (before wintering)	Produced honey, kg	Number of built-up honeycombs (435×145 mm), units	Kandy consumed in spring, kg
Control	22	6.78 ± 0.138	37.4 ± 0.91	24.8 ± 1.29	4.68 ± 0.138
Experimental	21	7.76 ± 0.194***	53.1 ± 2.01***	30.3 ± 1.20**	3.19 ± 0.088***

Note: ** – $p < 0.01$; *** – $p < 0.001$

During visual observation of the uniformity of the colony, it was found that the body colour of bees is mostly grey, sometimes with brown spots on the first two tergites of the abdomen, which fully meets the standards of the Ukrainian steppe bee breed. In addition, the families of the experimental group were more homogeneous in productivity, did not have early development (as of 23.03.2022), did not loosen the club and, as a result, required less attention from the beekeeper. Families of the control group generally had lower productivity, 9 out of 22 had early development, which led to overspending of feed, 6 of them did not clean the bottom of the hive well, and one did not clean at all, despite the strength of 7 cells. As a result, such bee colonies required increased attention from the beekeeper.

During the wintering period in the experimental groups, not a single bee family died, and all the queens retained their reproductive capacity at the beginning of the 2022 season (in one family of the experimental group, a humpback brood was noticed and subsequently such a defect disappeared without any operations on the part of the beekeeper). Over the past three years (2020-2022), an early flyby of bee colonies was observed at the end of the second decade of February, at a temperature of +12-+15°C, this provoked some families to start the reproductive activity of queens. With the beginning of prolonged cold snaps, during the research period from 26.02.2022 to 16.03.2022 (daytime temperature dropped from +10°C to -2°C, and night temperature was up to -5°C), negative changes were observed in the bee nest, which led to the death of part of the brood, the number of which at the time of inspection on 23.03.2022 was 3-4 honeycombs (435×145 mm) and the weakening of these bee colonies. In 2022, there were two non-mass flybys of bees on 02.01.2023 and 19.01.2023, which was not observed before, at least in the last 5 years.

Smoliński *et al.*, (2021) investigated the effect of temperature on the Autumn abundance of *Varroa destructor* in bee colonies during 1991-2020 in Central Europe. Researchers tested the hypothesis that temperatures can affect autumn tick populations with different time periods that regulate the number of bees and brood, and found that increased spring (March-May) and autumn (October) temperatures increase autumn infestation of bee colonies with *Varroa destructor*. Critical temperature values cover periods of bee activity, i.e., immediately after the first cleaning flights of bees and directly before the last autumn ones. These effects were potentially associated with increased bee reproduction at certain times of the year, rather than with a long period of activity or an accelerated onset of spring.

There is also a study showing the impact of climate change on the prevalence of infectious diseases such as acute bee paralysis virus, deformed wing virus, and chronic bee paralysis virus in wild bee populations (bumblebees and solitary bees), which is positively associated with the prevalence of these viruses in

honeybees. This highlights the need for good breeding practices in beekeeping, including such a trait as resistance to *Varroa destructor*, which is a breed feature, to reduce the infection rate of honeybees. According to the projected climate change, temperatures will continue to rise, which may affect the prevalence of viruses in wild bees and, as a result, in bee populations (Piot *et al*., 2022)

A number of Ukrainian researchers are working on the problems of preserving the honey bee gene pool, and they believe that the solution to this is to create breeding programmes that improve the efficiency and behaviour of endangered breeds, while maintaining their adaptation to the environment (Hrechka & Senchylo, 2022; Cherevatov *et al*., 2014; Kerek, *et al*., 2017).

This process of hardware is typical not only for Ukraine, and the first consequences can already be traced in research. But in those countries where they managed to stop the crossbreeding of bees in time and began to comply with the requirements of the legislation, there were no such problems. In Ukraine, the process of deliberate and uncontrolled hybridisation is currently taking place, so beekeeping should function in close cooperation between beekeepers and science (Razanova & Skoromna, 2020).

Honeybees are a rather complex object of breeding. This is primarily conditioned by the way of life and the specifics of reproduction. In turn, their productivity depends on a combination of factors, namely: the strength of families during the honey harvest, the state of the food supply, the conditions of the beekeeping season, and on the skilful care of bees. The influence of genotype is of great importance (Kerek *et al*., 2017). The establishment of bee colonies as an integral biological unit takes place not only under the influence of the presence of feed reserves in nature, but also the climatic conditions of the range, which corrects the main economic and useful features, rational use of feed reserves and timely development, the rate of which corresponds to these climatic conditions (Razanova *et al*., 2021; Saranchuk *et al*., 2021). In addition, not the least position among the survival mechanisms is occupied by the adaptation of bees to existing pests and pathogens.

The fascination with the "best properties" of uncharacteristic breeds can be disastrous for bees, plants and people, as happened with Africanised bees in Brazil in 1957. Nowadays, due to their predominant properties and excessive aggressiveness, these bees displace native breeds already in the United States (Kadri *et al*., 2016). But this does not mean that all bees need to be propagated on such a trait as peacefulness, because it is scientifically proven that this trait directly correlates with tick tolerance. That is, more aggressive bees are less affected by the tick, because they clean it off better, and this, in turn, ensures the maintenance of healthy and strong families, their wintering, development, and productivity. And as a result, less labour and economic costs are required for the production of a unit of bee products. This trait should not be confused with the inadequate aggressiveness that occurs during uncontrolled interbreeding hybridisation (Cherevko *et al*., 2018; Kerek, 2020).

However, to develop appropriate genetic models and breeding strategies, it is necessary to consider the genetic aspects and population characteristics of honeybees. Petersen *et al*. (2020) point to the fact that obstacles to breeding honeybees are the lack of pedigree due to free mating, and low penetration of genetic improvement into the general population. The conducted studies of morphometric characteristics of bees of the Ukrainian steppe breed confirm the results of Ukrainian and foreign researchers on the level of purebred breeding in apiaries (Kerek, 2020). According to these

characteristics, the belonging of bees to the breed with uncontrolled mating of the queen was 59.0%, and with the control of this process in time and space – 87.2%, which is 28.2% higher ($p < 0.001$). These results indicate that the level of hardware of bee colonies is at a high level, due to the fascination of amateur beekeepers with breeds that are not typical for the Vinnytsia oblast and Ukraine as a whole, and with such a rich drone background, the method of pedigrees along the maternal line is not enough. Apiary farms are recommended to organise a time-limited flight of queen bees or purchase more queens from certified breeders, which will ensure the disclosure of the productivity potential of bee colonies, their safety during wintering and resistance to infectious and invasive diseases.

The main breeding characteristics are a strong wintering ability, resistance to diseases, and different ability to collect nectar in the low and high honey harvest seasons (Panziera *et al*., 2022). Maucourt *et al*. (2020) and Arechavaleta-Velasco *et al*. (2021) note that traits such as honey production, spring development, winter feed consumption, hygiene behaviour, and Varroa destructor infection are inherited. In addition, genetic correlations between these traits are positive or zero, and these traits can be used for the genetic selection of honeybees. In the conducted studies, bee colonies in which queens mated under control in space and time received 43.0% more honey, they were stronger by 15.7%, rebuilt the honeycomb by 27.3% more and consumed less Kandy in the spring by 31.9%.

Genetic improvement of the health and productivity of zoned honeybees through the genetic breeding programme is a sustainable solution that would reduce the import of honeybees and help support the Ukrainian honeybee industry. Genetic correlations between bee productivity, behaviour, worker bees, and the queen are established in the studies by Arechavaleta-Velasco *et al*. (2021), which also proposed models for assessing the breeding value of honeybees.

Research is underway to explore the diversity of reproductive and morphological traits that may be useful in breeding programmes to improve the productivity of honey bee colonies and their survival in modern conditions. Many phenotypic correlations are related to the size of queen bees, with weak correlations found between morphology and reproductive traits (Facchini *et al*., 2021).

Cherevko (2018) states that the production of hybrids and the use of heterosis in purebred breeding is no less effective compared to crossing different breeds. In purebred breeding, the success of hybridisation is achieved due to the genetic diversity of bee colonies within the breed. The hybridisation process gives the phenomenon of heterosis in the first generation and such crosses can be carried out between different types of the same breed, which was confirmed by the research (Kerek, 2020), using the Carpathian bee breed and its subtypes *Vuchkovsky* and *Kolochavsky* (Kerek *et al*, 2017).

Papp also substantiates the effectiveness of using the newly created type of Carpathian bee breed *Synevyr* but despite the fact that this type proved to be the best in those sesearch conditions, the author allows hybridisation between adjacent types *Hoverla, Rakhiv* and *Vuchkivsky* to obtain the heterosis effect (Papp *et al*., 2021). For example, for the Carpathian bee breed, the conditions for maintaining breed purity can be conditionally called somewhat simpler, due to a certain uniqueness of the area of the Carpathian region, the remote location of apiary farms among themselves, and the presence of virtually semi-closed flyovers, due to which the degree of crossbreeding is orders of magnitude less than on apiary farms in the forest-steppe.

Hrechka & Senchylo, O. (2022) investigated economically useful indicators, in particular, the winter hardiness of the Ukrainian steppe bees. In their work on the intra-breed type of the Ukrainian steppe breed *Hadyatsky* compared to the local population, they described the benefits of using breeding tools on the economic value of bee families, in particular on development and productivity. Holinei (2017), based on the results of the study, found that local breeds are crossbred and their morphological features are more characteristic of the Carpathian and Ukrainian steppe breeds, as a result, the honey productivity of these bee colonies decreases. During visual observation of bees by body colour, compliance with the standard of the Ukrainian steppe bee breed was revealed.

Conclusions

The results obtained suggest that families of the experimental group in which the queens mated under control in time and space have potentially better winter hardiness capabilities, as evidenced by a 31.8% lower ($p < 0.001$) need for feeding in the spring. They were stronger by 14.5% ($p < 0.001$), had higher honey productivity by 41.9% ($p < 0.001$), and rebuilt 22.1% ($p < 0.01$) more honeycombs. This reflects the negative impact on the productivity and safety of bees of uncontrolled crossbreeding, because the drone background potentially included about 250 families from other private apiaries located within a radius of 500m and about 170 more families located within a radius of 2 km, with queens of unknown origin.

According to morphometric and visual indicators, all families met the standard of the Ukrainian steppe breed: the average indicator of the cubital index was in the range of the breed 1.86-3.0, the hantel index – 0.829-1.113, and the discoid displacement – 1.89-5.68. However, in the samples, there were indicators that significantly went beyond the range of the breed in the control group, in the experimental group there were a small number of such indicators. Bees from queens mated by the free method of the control group had a degree of belonging to the Ukrainian steppe breed of 59.0%, in the experimental group, where queens mated according to the method of time and space restriction, this indicator was 87.2 % ($p < 0.001$). Some bee colonies of the control group did not clean the bottom of the hive well in the spring after wintering, 6 out of 22, so they needed increased attention from the beekeeper. Moreover, 9 out of 22 had a tendency to early production of offspring by bee colonies, which is not typical for the Ukrainian steppe bee breed and in the conditions of the Vinnytsia oblast, which led the families of the experimental group to lose part of the brood and noticeably weaken.

Further research will be aimed at studying the egg production of queen bees and the dynamics of bee brood development. The practical significance of the results is also used for conducting experiments on the influence of individual feed factors, microclimate factors for the use of new structural components of the hive on this breed, which is a determinant of the reliability and repeatability of the results, establishing patterns, and confirming the need to implement breeding programmes in beekeeping.

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Conflict of Interest

None.

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Морфометричні ознаки бджіл української степової породи залежно від способу контрольованого парування маток

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Анотація. Порода бджіл є важливим фактором, що визначає розвиток бджолиних сімей та продуктивність, оскільки вона впливає на виробництво меду, стійкість до хвороб, адаптацію до кліматичних умов та характеристики поведінки бджіл. Метою дослідження було встановлення залежності між способами парування маток і морфологічними ознаками бджіл української степової породи та продуктивними показниками бджолиних сімей. Для проведення досліджень у пасічному господарстві Вінницької області було сформовано 43 бджолосім'ї з бджоломатками-сестрами української степової породи, спарованих різними способами природного парування. За результатами парування в контрольній групі було 22 бджолині матки, дослідній – 21 матка. Матки першої контрольної групи спаровувалися звичайним природнім обльотом без будь-яких обмежень. Матки дослідної групи спаровувались за контролю в часі та просторі. За результатами досліджень встановлено

взаємозв'язок між цілісністю колонії та її морфологічними ознаками і продуктивними показниками. Так, піддослідні сім'ї мають різні ступені приналежності до української степової породи, контрольної – 59% та дослідної – 87,2 % ($p < 0,001$). За кубітальним індексом перевага становила 8,2% ($p < 0,001$) на користь дослідної групи. Краща цілісність сімей за гантельним індексом прослідковується у сім'ях, в яких маток спаровували контрольовано у часі та просторі, з різницею у 3,32% ($p < 0,001$). У контрольній групі, де проводилося безконтрольне парування маток, за дискоїдальним зміщенням виявлено більше бджіл з перевищенням стандартного показника по породі. Сім'ї дослідної групи, порівняно з контрольними, були сильнішими на 14,5% ($p < 0,001$). Від них отримано більше меду на 41,9%, ними відбудовано більше стільників на 22,1% ($p < 0,01$), а потреба у підгодівлі канді була меншою на 31,8% ($p < 0,001$) менша. Крім того бджоли дослідної групи мали яскраво виражену гігієнічну поведінку та вимагали менше трудових затрат. Практичне значення дослідження полягає у можливості встановлення закономірностей дії факторів на конкретну породу та підтверджує необхідність реалізації селекційних програм у бджільництві

Ключові слова: гантельний індекс; кубітальний індекс; дискоїдальне зміщення; продуктивність; збереженість; кліматичні умови; витрати корму

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Methodology for assessing the heat potential recovery regime at food industry enterprises

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Abstract. Areas of improving energy saving and the environmental situation in the processing and food industry In Ukraine are relevant, as technologies and equipment by their nature and degree for efficient use of fuel resources are practically achievable for their improvement, especially today. The purpose of the study is to improve the methodology for the optimisation of the mode of reuse of the thermal potential of exhaust process gases in the implementation of a two-stage cooling process. The indicators of process gas emissions with a volume consumption of 0.54 m^3/s and temperature – 1600°C with the parameters of the furnace operation A2-SHBG were used to construct local temperature characteristics. Their construction is carried out based on the heat balance and heat transfer at short surface intervals, considering the parameters of coolant flows. The results were analysed by the Flow Vision software suite under the structure of the graph, according to the laws of thermodynamics. A method for calculating the amount of cold heat agent for reuse in the technological process is proposed. It is established that under the accepted heat exchange conditions, the required amount of atmospheric air with an initial temperature of -300°Ccan be heated to a temperature of +640°C, and with an initial temperature of +300°C, can be heated to +1450°C. Natural gas consumption will change from 20 $m^3/$ h, without preheating atmospheric air, up to 12.7 m^3/h when heating atmospheric air in the heat exchanger at an initial temperature of + 300°C. It is stipulated that when calculating energy resource savings, it is necessary to consider the initial temperature of the cold heat agent when using the heat of exhaust process gases. The proposed method for calculating the optimal heat recovery mode allows calculating changes in the consumption of the primary fuel and energy resource and creating a database for the effective implementation of energy-saving technologies when reusing waste gas heat into production

Keywords: energy saving; heat exchanger; heat pump; primary fuel and energy resource; food industry

Introduction

Given the current situation caused by russia's full-scale invasion of Ukraine, the international community is making great efforts to develop a technological and technical solution to reduce energy consumption. The solution of rational use of energy resources can be solved by the energy-saving policy of the state and the modernisation and creation of efficient equipment.

According to the energy strategy of Ukraine until 2035 (Order of the Cabinet Ministers of Ukraine No. 605, 2017) "Safety, energy efficiency, competitiveness", the priority of energy saving is to reduce the energy intensity of production and consumption of fuel and energy resources. This can be facilitated by an event to introduce the latest energy-efficient and energy-saving technological equipment.

Waste heat from industrial ovens in the food industry is the energy generated during the baking process. It is practically not used, but is consumed and released into the environment. Maximum positive results in this area can be achieved only by introducing comprehensive and effective energy-saving measures into industrial and household activities. Special attention should be paid to intensive energy saving in heat technology, which has popularity in developed countries (Pili *et al.*, 2020). C. Wieland, *et al*. (2023) evaluated in more detail Central and Eastern Europe as the regions with the

highest energy growth potential and small heat recovery plants. It is noted that these regions will be the most relevant sources of heat recovery in the coming years.

Ukraine has not yet received such a general spread due to the lack of interest from some enterprises, state incentives, and lack of a standard for certification o f heat exchangers of the research system for the conditions of Ukraine.

Since about 2/3 of organic fuel is spent on all the variety of heat-technological processes, and the integral useful factor of primary fuel and energy resources in heat-technological complexes, based on the final result of using primary raw materials of material production, does not exceed 10-15%, the areas of energy saving and environmental improvement are relevant (Kim, 2019).

Among the effective energy-saving measures, special attention should be paid to the heat recovery of exhaust process gases, which provides for their cooling and reuse of accumulated heat. The level of recovery is estimated by the recovery coefficient. Its value indicates the level of heat utilisation of the exhaust process gas. The higher the recovery coefficient, the lower the specific costs of primary fuel and energy resources. There are various schemes for restoring latent heat in flue gases. To reduce these problems, various approaches are being developed to summarise experimental data in the construction of efficient use of energy resources. Research and analysis of energy for waste heat recovery in the manufacturing sector were reviewed by Abrar Inayat (2023). The researcher provided information on the potential of using waste heat in the metallurgical sector with further application. He also noted that in the development, design and analysis of the efficiency of surface heat exchangers, matmodels and a technique that has a simplified empirical relationship in determining the integral characteristic are used. J.F. Wang, *et al*. (2020**)** considered traditional ways in the technical representation of heat exchange processes are logically supplemented by heat recovery options in drying units of the food industry. They noted the influence of the correct calculation of average temperatures of heat carriers when estimating the thermophysical properties and material of the pipe wall and on the parameters of heat transfer and heat transfer coefficients during cooling or heating in a heat exchanger.

Phenomenological analysis of energy integration and strategies for applying technologies for using energy potentials in heat resource redistribution systems and prospects for using secondary energy resources in the food industry creates conditions for a global review of the use of heat exchangers.

Thus, the purpose of the study is to further search for and develop analytical dependencies and methods for estimating the calculation of thermal potential based on the main provisions of the theory of thermodynamics and heat and mass transfer. The created dependencies and methods should adequately reflect the processes in the developed heat exchanger design, considering the design and technological thermal and hydraulic parameters, operating mode and conditions. Thus, parameters for regulating the main characteristics of the heat exchanger appear in the general balance of all thermophysical variable modes of heat reuse of exhaust process gases. Solving the search and development of analytical dependence and methodology will help reduce losses of fuel, energy, and material resources. This will definitely reduce the negative impact on the environment and improve the quality of energy sources supplied to consumers.

Literature Review

There are a large number of literature sources devoted to energy conservation and reduction

of the negative impact of energy-intensive industries on the environment. H. Jouhara *et al*., (2020**)** conducted a comprehensive review of waste heat utilisation methodologies and state-of-the-art technologies used in industrial processes. They considered the possibility of heat recovery to optimise energy in the metallurgical, food, and ceramic industries. From the review of sources, it can be stated that the vast majority of them relate to energy generating, metallurgical, chemical, construction, and other branches of the economy. All these enterprises are characterised by technologies that take place at high temperatures, high productivity, and energy intensity. Energy-saving measures in such industries allow getting a significant economic effect and achieving a quick return on invested funds. In European countries and the United States, the use of heat exchangers is consolidated by the ANSI/AHRI standards (Standard 1060-2005 (2005) and ASHRAE (Standard 62.2-2003). It considers the basic principles of building heat recovery systems, energy indicators of operation, and the efficiency of heat exchangers in general. Moreover, the indicator of the efficiency of total heat should be at least 50%.

M. Kum Ja *et al*., (2022) investigated a flat plate module with a diagonal channel and a countercurrent heat exchanger configuration. In such a heat exchanger, the ratio of "fresh" air to "exhaust" had the least positive effect (8-10%) on overall efficiency. The authors propose the design of a heat exchanger (Bulejko *et al*., 2022) and the stability of polyamide hollow fibres in the heat exchanger, which were tested at various temperatures in the range from -40 to 160°C was analysed. The results showed differences in theoretical models with experimental data, which fluctuated significantly. The results indicated the practical use of such heat exchangers in the automotive industry. Jafarizave (2019) and H. Jouhara *et al*. (2021) reduced gas heating costs by properly stabilising the temperature of the gas process flow by means of automation. A study was also conducted to regulate temperature changes at the outlet of the pressure-reducing valve. This allowed effectively using the heat in the heater. Gendebien *et al*. (2018) note that the maximum heat flow of a hypothetical heat exchanger is possible with an extremely large heat transfer surface. This result, in practice, can be achieved by using a surface made of materials with high heat transfer coefficients.

Despite the absolute expediency, energy-saving measures do not find proper attention in the processing and food industries (Tchuen *et al*., 2021). Among the reasons for the appearance of this situation, researchers I. Stadnyk *et al*., (2021) note that the analysis in the conditions and modes of operation of the device and the method of heat recovery are insufficient. From the materials of the Duda and Balaban conference (2021), it is known that a temperature drop of 1 m^3 process gas emissions by 10°C allows saving 10 KJ of heat energy. With a calorific value of 1 m^3 of 33.5 mJ and 1 m^3/s of exhaust process gas cooled by 10°C, 1.4 m^3/h of natural gas can be saved. In this case, the amount of savings in primary fuel and energy resources depends on the cooling of the exhaust process gases.

General issues of design and operation in justifying the use of heat recovery schemes for process gas emissions at an enterprise are considered by Stadnyk *et al*. (2022). This study is mainly focused on the optimal selection and functioning of the recovery system, issues of heat utilisation of exhaust process gases, and the exhaust heated medium is described quite superficially. No less attention is paid to the introduction of energy-saving technologies in the food industry (Yevtushenko, 2019). The author described in more detail and considered the disposal system with an intermediate heat

carrier. Formulas for calculating the efficiency of heat exchangers are also presented.

Waste heat can be used using various recycling technologies to provide valuable energy sources and reduce overall energy consumption (Bulejko, 2022). Today, thermal pumps are used for high-quality deep cooling of process gas emissions. Thus, the study (Stadnyk *et al.*, 2021) shows the use of a heat-upgraded pump in brewing. They considered cooling of exhaust process gases to lower temperatures from the dew point temperatures in the heat pump condenser. In this case, water vapour condenses, which helps to obtain additional energy for heating cold thermal agents and reducing the release of water vapour into the atmosphere, which is a greenhouse gas. Researchers of the Institute of Thermophysics of the Academy of Sciences of Ukraine and the National Technical University of Ukraine "Kyiv Polytechnic Institute" publish information on the successful use of heat pumps during the drying of grain and other products of the processing and food industry, which are subjected to heat and mass transfer processes at low temperatures. General requirements in the design and operation of production lines with installed heat pumps show that an increase in the temperature of heat agents accompanies an increase in the cost of their organisational work. After all, heat pumps must be used if they do not exceed 40°C temperature of the hot heat agent.

Exhaust process gases with a temperature above 40°C are cooled in a heat exchanger before being cooled in the heat pump. These considerations relate to the intended ways and intentions of the approach to improving and improving the characteristics of individual processes. The above methods of energy saving in local areas of power equipment, i.e., confectionery ovens, are not enough. Therefore, calculations and economic indicators in the total result should be considered in two planes. Having separate possibilities for minimising heat costs in local areas of the furnace, it is advisable to formulate requirements for the parameters of the total heat agent, which should be considered by a specific methodological approach. The issue of calculating the parameters of a cold heat agent remains particularly insufficiently studied under conditions when the constant amount of hot heat agent is cooled to a constant temperature, and the initial temperature of the cold heat agent changes.

Materials and Methods

Materials. The calculation of optimal recovery modes is based on the use of heat readings of exhaust process gases formed during the operation of the A2SHBG-type working furnace. The primary fuel is natural gas. Its calorific value is 33.5 MJ/m^3 and the highest temperature of the process gas in the furnace is 280°C. Gas outlet parameter of exhaust systems: volume flow – 0.54 m^3/C; temperature – 160°C.

Features of the study. The use of the seasonal energy potential of a confectionery oven for the reuse of reclaimed heat is considered. The proposed scheme for implementing such heat exchange is shown in Figure 1. The scheme includes the main components of the main and auxiliary equipment for the normal operation of the power confectionery oven.

Given the complexity of performing calculations in the proposed scheme (Fig. 1) operating power equipment, the model method for their implementation according to optimal heat recovery modes, provides for two stages. The first stage involves the installation of an air-to-air heat exchanger 3, and the second stage involves the use of a heat pump 4. During the period of heat exchange, the exhaust process gases have the function of hot thermal agents. Accordingly, ф̧ir performs the function of cold thermal agents.

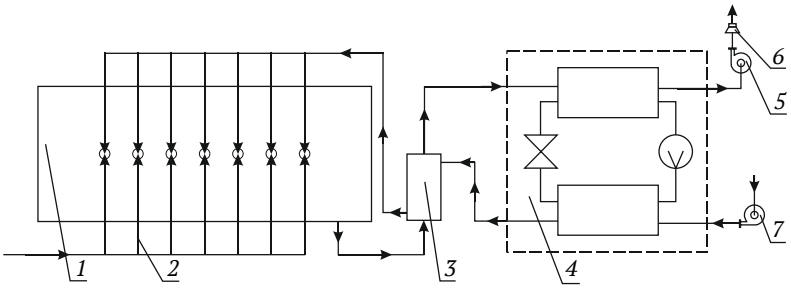


Figure 1. Diagram of two-stage cooling of exhaust process gases of power generating equipment
Notes: 1 – housing of power generating equipment; 2 – supply system of primary fuel and energy resources; 3 – heat exchanger; 4 – heat pump; 5 – exhaust fan; 6 – exhaust gas exhaust system; 7 – fan of heated atmospheric air supply
Source: 1 – developed by the author

Research methodology. The object of study is a confectionery shop with an installed ventilation system. The ventilation system is used to utilise explicit and latent heat. The supply and exhaust ducts have air flow rates in the range of 70-150 m^3/h, depending on the operating modes of the fans. The ventilation system under study consists of air ducts, filters, anemostats, louver grilles, gates and sleeves for measuring air parameters. Heat exchange scheme (Fig. 2) and the design of the heat exchanger (Fig. 3) provides for its operation in offline mode.

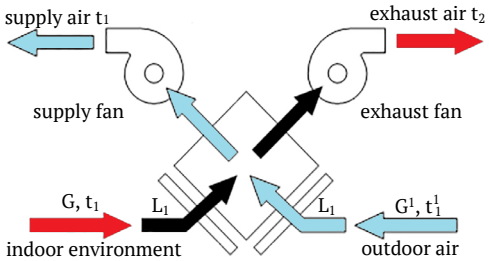


Figure 2. Diagram of heat exchanger in the installation
Source: developed by the author

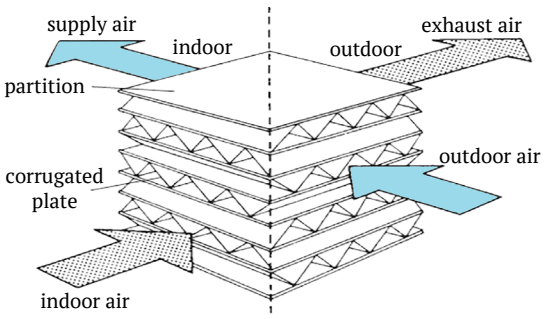


Figure 3. Heat exchanger design
Source: developed by the author

In a heat exchanger with partitions and corrugated plates (Fig. 3), a thin polymer film with low thermal resistance is used. This heat exchanger allows you to utilise heat and hidden water vapour contained in the exhaust air. The heat exchanger channels are separated by a corrugated plate. The two streams of medium and air are not mixed.

The proposed model method for calculating heat recovery involves the use of a plate heat exchanger with countercurrent movement of thermal agents. This heat exchanger design allows organising heat exchange in two modes. The first mode provides heating of a constant amount of cold heat agent to a constant temperature. In this case, if the initial temperature of the cold heat agent changes, the temperature of the hot heat agent will change.

The second mode provides cooling of hot thermal agents to a constant temperature with the appropriate amount. In this case, the final temperature of the cold heat agent will change. Stability in the operation of the heat pump requires ensuring the supply of hot heat agent at constant temperatures. Because of this, it is advisable to carry out heat exchange in the heat exchanger according to the second mode.

The proposed model method for calculating optimal heat recovery modes provides for the passage of the heat exchange process in the heat exchanger under conditions of constant and variable values of the initial and final temperatures of the hot heat agent. Their value depends on the time of year and the initial and final temperatures of the cold heat agent.

Preheating of the cold heat agent enters the combustion zone of primary fuel and energy resources. During fuel combustion, the resulting process gases provide technological conditions for the temperature and aerodynamic regime.

A change in the temperature of a cold heat agent affects the variable consumption of the initial fuel and energy resource. At the stage of research on the consumption of this resource, the economic efficiency of reusing the heat of exhaust process gases is evaluated. Therefore, it is necessary to have data on the effect of the final temperature of the cold heat agent on its consumption.

Measuring devices. According to the diagram (Fig. 1), the following devices were used:

- exhaust and supply air anemostats;
- measurement of temperature and relative humidity, with the testo 605 device;
- temperature and relative humidity measurement using DS 1923-F5;
- air velocity measurement (testo 405).

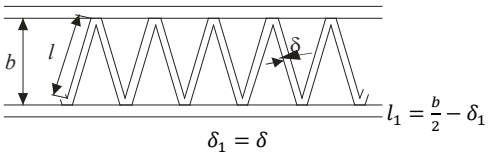
Substantiation of the model methodology. The main task of the proposed model methodology for calculating heat on power-generating equipment is to develop the procedure for preliminary calculation. It is based on changes in the consumption of the initial value of the fuel and energy resource when the final temperature of the cold heat agent changes. Therefore, the solution of this problem requires knowing the data of the maximum temperature to which a cold thermal agent can be heated under known conditions. This order of research was followed by the authors (Kouemou Hatou *et al.*, 2021), (Kim, 2019) when developing a mathematical model for use as a tool in designing and predicting efficiency, under various load conditions of input parameters. Known methods for calculating heat exchange processes (Chakravarty & Kumar, 2020) do not solve this problem. Therefore, the volume consumption of a cold heat agent at different values of the initial and final temperatures allows establishing the dependence for the heat exchanger and the parameters of the technological process. Using the resulting dependency $Lx = f(Tx)$ sets the parameters of the heating temperatures of the cold heat agent at a known initial temperature.

Clearly, the dependence also determines the change in the primary fuel and energy resource relative to the consumption of a cold heat agent and its final temperature.

Studies have determined the influence of the initial temperatures of thermal agents (cold) on the final temperature at various costs. Therefore, the limit of change in the initial temperatures of thermal agents -30°C ⩽ Tx ⩽ +30°C sets the dependences of the final temperatures of the cold heat agent $Tx_2 = f(Tx_1)$ with straightforward character. The process can be described by an expression using numerical coefficients: $Tx_2 = ATx_1 + B$.

The obtained dependence allows performing an updated calculation of the consumption of the primary fuel and energy resource and the optimal mode of heat recovery of exhaust process gases.

Temperature distribution of heat carriers during cross-flow. To increase the heat exchange area, a plate heat exchanger with a triangular fin is used. Its calculation of the heat exchange process in a cross-plate heat exchanger is based on the work of Hausen (2012). The edge efficiency equation is defined by the expression: $N = \sqrt{\frac{2\alpha}{\lambda\delta_1}} l_1, \eta_f = \frac{th(N)}{N}$, where



In the case of cross-current, the temperature distribution of heat carriers is calculated by dividing the heat exchanger plate by $n \times n$ individual elements. The heat balance is calculated for each one. In Figure 4, the point of the plate is characterised by coordinates x and $x`$. Value $L$ and $L`$ reflect the length of the wall. Moreover: $G, G`$ – mass consumption of the first and second heat carriers; mass consumption of two heat carriers; $t_1, t_2$ – temperature of the first coolant at the inlet and outlet; $t_1`, t_2'$ – temperature of the second coolant at the inlet and outlet

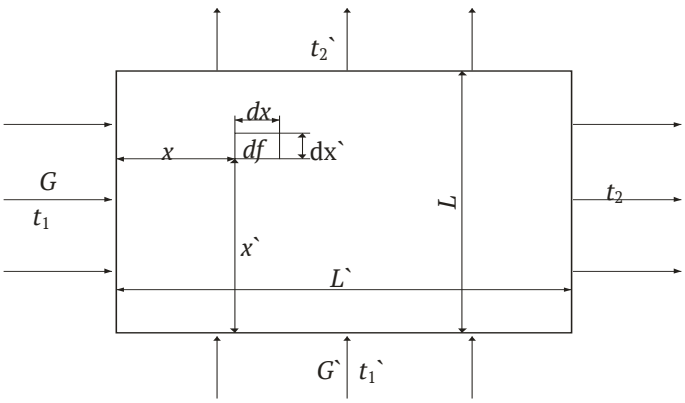


Figure 4. Cross-flow heat exchange of a flat plate: $G, G`$ – mass consumption of two heat carriers; $t_1, t_2$ – temperature of the first coolant at the inlet and outlet; $t_1`, t_2'$ – temperature of the second coolant at the inlet and outlet

Surface element $df = dx \cdot dx'$ at the point $(x, x`)$ transfers heat per unit of time (dq):

$$dq = kdxdx`(t - t`). \quad (1)$$

A unit of time near the surface of the first heat carrier df equals $\frac{Gdx`}{L`}$. The change in cooling is $\frac{\partial t}{\partial x}dx$. Amount of second heat carrier $\frac{Gdx`}{L`}$

heats up on $\frac{\partial t`}{\partial x`} dx`$. Accordingly $c_p$, $c_p`$ – heat capacity of both heat carriers. Determination of the heat flow through the element df is carried out by the expression: $dq = -c_p G \frac{dx`}{L`} \frac{\partial t}{\partial x} dx$,

$$dq = c_p` G` \frac{dx}{L} \frac{\partial t`}{\partial x`} dx`. \quad (2)$$

These solutions of system (1-2) determine the temperature of both heat carriers at the outlet and their distribution along the coordinates x and $x`$. The exact solution of diffraction patterns can be obtained by the finite difference method. To do this, set the coordinate function x_*: linear ($T_{\text{wall}, x^*} = a_0 + a_1 x_*$) or polynomial ($T_{\text{wall}, x^*} = a_0 + a_1 x^* + a_2 x^{*2} + a_3 x^{*3}$).

Figure 5 shows a local heat flow with a uniform velocity profile at the inlet, according to numerical coefficients: $a_0 = 276{,}71$; $a_1 = 313{,}4$; $a_2 = -2334{,}6$; $a_3 = 6395{,}5$.

These coefficients correspond to the temperature of the cold air channel of the heat exchanger, according to the study (Helmuth, 2018).

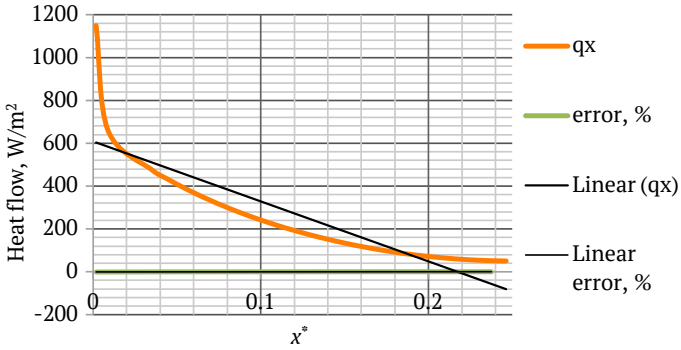


Figure 5. Local temperature change in the heat flow of the wall with the definition of errors

Local heat flow error within the tolerance range of ± 2%. Figure 6a shows a simulation of the temperature distribution of both heat carriers over the heat exchange surface with an airflow rate of 150 m³/h, and Figure 6b shows temperature change along the length of the plate in increments of 0.045 m in its average cross-section.

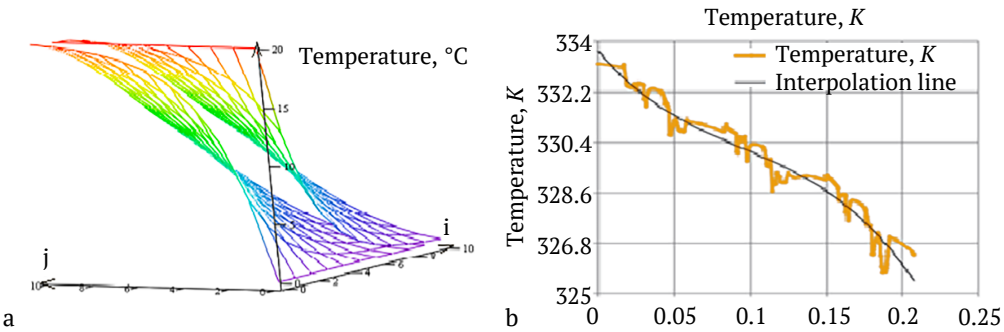


Figure 6. Graphs: a – surface temperature distribution of the coolant:
(i, j) – elements; → – exhaust air (hot coolant); → – supply air;
b – temperature change along the length of the plate in increments of 0.045 m

Comparative analysis of mathematical modelling of graphical curves (Fig. 6 a, b) reveals the essence of the characteristics of temperature fields in a heat exchanger with cross current along the length of the sides of the heat exchanger *L*.

Results and Discussion

The analysis shows that energy indicators should not be the only criterion that should be considered at the design stage of the heat exchanger. Prior to this, in many previous studies, theoretical correlations or optimisation techniques were commonly used to develop the overall process. Technical, economic, and environmental aspects should also be considered. After all, any development of a heat exchanger is practically impossible without an experiment.

During the study, the speed of heat carrier flows, temperature changes along triangular fins, and the average temperature of the heat exchange surface at the inlet and outlet of the heat exchanger. Moreover, verification of theoretical calculations using criterion equations allowed generalising the results obtained. Graphical curves (Fig. 6 a, b) reveal the essence of temperature fields along the length of the sides of the heat exchanger *L*. Thus, the curves (Fig. 6 a, b) show that the calculated heat transfer area of a heat exchanger with side lengths equal to *L* and L^1 is within the specified average efficiency value. In turn, the input temperature of the exhaust gases and cold coolant in the middle plate is $t_1 = 64^oC$ and $t_2 = 31°C$. Temperature difference between the initial and final temperature of heat carriers: $\Delta t = 33°C$.

Thus, in cross-current, the temperature distribution of heat carriers in the heat exchanger has a certain distribution of data on temperature, heat flow, and surface heat transfer efficiency.

Analysis of energy efficiency optimisation of the use of regenerative and regenerative burners at the expense of heat exchanger surfaces for capturing and using waste heat in the combustion process (BDF Industries 2017), allowed providing for heat transfer to the incoming air to the burner in the furnace under study. A scheme for using a heat exchanger when selecting a hot medium for heating a colder one for the burner has been developed. Based on this, a methodology is proposed to determine the best trade-off between reclaimed heat and energy for a particular geometry. This considers a certain temperature difference in the room/outside. All these analyses were aimed at designing the heat exchanger configuration using an optimisation algorithm. Under such conditions, improving the efficiency of the heat exchanger in using the energy potential, recovery was carried out according to the proposed scheme in Figure 1. As noted, the study of the recovery system was carried out in two stages using air, the temperature of which varies from -30°C to +30°C. The calculation of the heat exchanger, considering the cooling of the exhaust process gas in the heat pump condenser, allowed choosing a plate heat exchanger with a heat exchange area of 16.7 m^2. The temperature of the exhaust process gas at the outlet of the heat exchanger established by the study was up to +40°C, which made it possible to calculate the heat balance.

The calculation of the heat balance established that maintaining the thermal regime of the furnace must burn 20 m^3 of natural gas per hour or 5.47 10^{-3} m^3/s. At the same time, to ensure temperature and aerodynamic conditions, the furnace receives air from the production room in the amount of 0.53 m^3/s at a temperature of +20°C. The temperature of atmospheric air changes both throughout the year and during the day. Based on the considered conditions and results of heat exchange and temperature changes (Fig. 4, 5) preheated atmospheric air,

will lead to a change in the flow rate of natural gas. To visually display changes in the volume flow rate of natural gas and the economic effect of the supply of preheated atmospheric air at different values of the final temperature, it is shown in Figure 7.

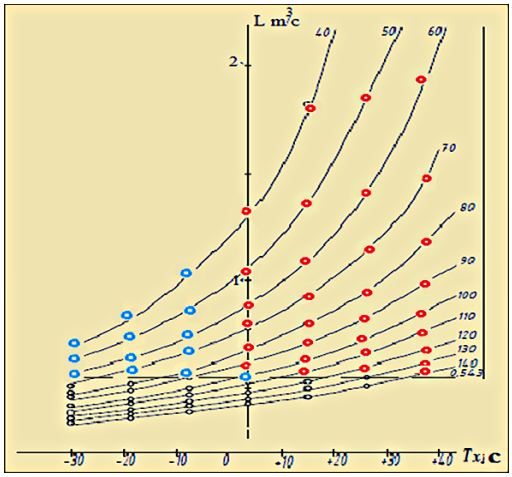


Figure 7. Dependence of the effect of the initial temperature at different values of the final temperature on the volume flow rate of a cold heat agent: 1 – Tx_2 = 40°C; 2 – Tx_2 = 50°C; 3 – Tx_2 = 60°C; 4 – Tx_2 = 70°C; 5 – Tx_2 = 80°C; 6 – Tx_2 = 90°C; 7 – Tx_2 = 100°C; 8 – Tx_2 = 110°C; 9 – Tx_2 = 120°C;10 – Tx_2 = 130°C; 11 – Tx_2 = 140°C

The resulting dependence (Figure 7) indicates that under the accepted heat exchange conditions, the required amount of atmospheric air with an initial temperature of -30°C can be heated to a temperature of +64°C, and with an initial temperature of +30°C, can be heated to +145°C. Accordingly, the consumption of natural gas will vary from 20 m³/h, without preheating atmospheric air, up to 12.7 m³/h when preheating atmospheric air in the heat exchanger at its initial temperature of + 30°C.

The design and technological operating conditions of the furnace under study require compliance with a stable aerodynamic regime. In this case, a decrease in the supply of natural gas leads to an increase in the supply of atmospheric air. Within the studied temperatures, this change is $5.1_{*}10^{-3}$ m³/s – $3.5_{*}10^{-3}$ m³/ s. The influence of the initial temperature of atmospheric air on its final temperature for various flows is determined. The results of the assessment of the dependence of the final temperature of a cold heat agent on its initial temperature are shown in Figure 8.

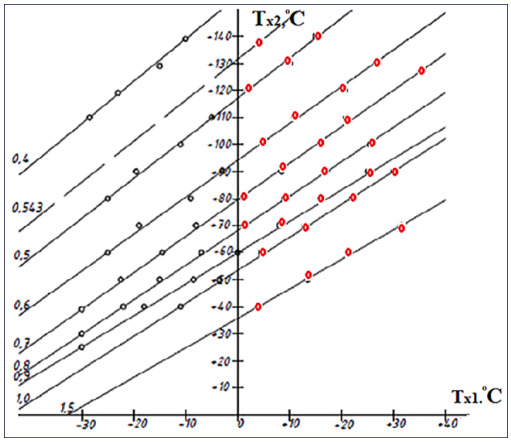


Figure 8. Dependence of the effect of the initial temperature at different values of the volume flow rate on the final temperature of the cold heat agent: 1 – Lx = 0.4 m³/s; 2 – Lx = 0.5 m³/s; 3 – Lx = 0.6 m³/s; 4 – Lx = 0.7 m³/s; 5 – Lx = 0.8 m³/s; 6 – Lx = 0.9 m³/s; 7 – Lx = 1.0 m³/s; 8 – Lx = 1.5 m³/s.

The obtained calculation results indicate that within the studied initial temperatures of the cold heat agent Tx_1 influence of changes in its consumption Lx at the final temperature Tx_2 can be neglected.

Despite a wide range of research on the problem, the issues of energy saving and the use of secondary resources in the food industry remain relevant and require further development. Therefore, like the researchers (Kamarul Aizat Abdul Khalid 2016), the authors focused on the development of a heat exchanger for a

ventilation unit with heat recovery using numerical approaches. Consideration of a mathematical model (Shuichiro Miwa *et al*., 2022**)** of heat and mass transfer to determine the effect of internal airflow leakage on the efficiency of the heat exchanger allowed the proposed heat exchanger to be studied at low ambient air temperatures. Changing the internal design by installing turbulators in the internal section in a compact air-to-air heat exchanger (Ahmad *et al*., 2022**)**, resulted in an improvement in ΔT at the pipe outlet. However, it has been proven (Javanjal *et al*., 2019**)**, that plate heat exchangers with gaskets provide efficient and efficient heat transfer with a recovery rate of up to 90%. Consideration of the characteristics of the internal air flow inside the heat exchanger made it possible to envisage the design of a plate heat exchanger with the countercurrent movement of heat transfer agents.

The main indicator of creating any ventilation system is based on the norms of air consumption from the medium and air exchange multiplicity, and the criterion for evaluating the effect of recovery methods is its level, according to the authors (Galish *et al*., 2021,). This hypothesis allowed proposing and conducting a model method for calculating optimal thermal recovery modes.

Reducing fuel consumption emissions is the main topic in the implementation of complex technological and design parameters, the interaction of which must ensure proper and reliable operation of the control of such a system (Zamboni *et al*., 2021). Studies of the emission of gases from the furnace and studies by G. Zamboni *et al*. (2021) were aimed at developing integrated management strategies for gas recovery and fuel consumption systems, analysing their mutual impact on the expansion of working conditions. The presented and discussed characteristics of systems in a wide range of operating modes show how this affects the performance and emissions of thermal agents with their subsequent use. The interaction of parameters confirms the potential for a significant reduction and improvement in fuel consumption if the recovery control scheme is followed.

Review of the studies noted the effect of complex apparatuses that depend on shutdown schemes, the number of sections, and rows of pipes in one section and their arrangement by moves, the degree of mixing of each coolant (Manente *et al*., 2021). This opens up another way to improve the efficiency of surface recomposition, considering the distribution of local thermohydraulic parameters. Based on this consideration of the problem, it is reflected in the local temperature distribution of heat carriers when determining the thermal state of the surface of the developed heat exchanger, considering the operating modes of the confectionery oven. The researchers (Manuel Jiménez-Arreola, *et al*. 2023) also confirmed the achievement of final under-recovery. So the local advantage of the heat reserve of the heating flow is in the warmer part of the heat exchanger, the cooling heat reserve is in the colder part. This conclusion of their study is also shown in this paper.

G. Tchuen *et al*., (2021) raised the issue of energy savings with an analysis of the possible use of heat from the exhaust ventilation flow of gas for the needs of hot water supply. Their research reveals the efficiency of using a heat pump in the recovery of a low-potential heat source. In comparison with this study, at the second stage, the use of a heat pump allows the exhaust process gases to perform the function of hot thermal agents for heating the air. Consideration in choosing a refrigerating agent for heat pumps also deserves attention. In addition, the researchers (Jiménez-Arreola *et al*., 2019) noted, that the dynamic behaviour of heat exchangers

when recuperation of industrial thermal waste in the system approach is assessed at the level of limiting negative impacts on the environment.

The analysis of the heat consumption of the exhaust gases of the drying and cooling zone of the mine grain dryer using various heat recovery schemes based on the wet content of gases allowed the author (Gaponyuk, 2017) to theoretically substantiate the possible and economic feasibility of using the exhaust operating heat of the gas. He proposed a method for heating stationary grain layers with exhaust gases and substantiated heat exchange by semi-empirical equations. These equations involve the use of different values of moisture gradients and temperature differences in determining the heat balance, but without determining the heat flow through the element of a stationary grain layer. The approach proposed in this study allows simplifying the use of semi-empirical equations and improving the heat recovery scheme of the cooling zone of a mine grain dryer using a plate heat exchanger. Ultimately, supply and exhaust systems with plate heat exchangers can reduce the cost of heating the supply air by 60-70% (Tchuen *et al*., 2021).

Conclusions

Based on observations and studies, a calculation model is proposed under real operating conditions of a confectionery oven. The temperature fluxes of heat carriers obtained from measuring devices and consistent with modelling, as well as those mentioned in other studies, indicate a change in the local heat flow of the variable wall temperature in the heat exchanger from 1,200 to 200 W/m^2. Improving the efficiency of a surface recuperative heat exchanger with the given design, mode and operating conditions and layout features, under the accepted heat exchange conditions, the consumption of natural gas can be changed from 20 m^3/h up to 12.7 m^3/h. In addition, the negative impact on the environment is reduced.

Evaluation of both dependences showed that the mode movement of heat carriers affects the efficient operation of the heat exchanger. Therefore, choosing the optimal mode of movement of heat carriers will ensure maximum heat transfer. The proposed model method for calculating the optimal heat recovery mode allows:

- pre-calculate the variable consumption of the initial fuel and energy resource when reusing the heat of exhaust process gases of power generating equipment;
- the base of the results obtained can be used to calculate the economic efficiency of implementing energy-saving technologies in production;
- when calculating the savings of the primary fuel and energy resource when reusing the heat of exhaust process gases, it is necessary to consider the initial temperature of the cold heat agent
- evaluation of the effect of energy-saving systems and comparison of heat exchangers of different types, it is advisable to use the efficiency indicator of heat exchangers.

This technical solution is conditioned by the ability to control the characteristics of temperature carriers and create high-efficiency heat exchangers. This is provided for by reducing the size of the heat exchange surface, but also does not exclude the possibility of using other areas to improve the efficiency of the heat exchanger.

The use of such heat exchangers or their elements, methods for evaluating the heat potential recovery mode, is relevant due to their simplicity, reliability, and practical safety. This makes allows continuing the promising line of increasing energy and resource savings in the utilisation of heat not only in confectionery furnaces, but also in internal combustion engines (diesel generators, steam boilers).

Special attention should be paid to combining the thermal potential into a single complex of heat recuperators when using compact, high-efficiency, regenerative heat exchangers. This approach allows controlling the characteristics of temperature carriers and creating heat exchangers of increased efficiency while reducing the size of the heat exchange surface.

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Conflict of Interest

None.

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Методика оцінки режиму рекуперації теплового потенціалу на підприємствах харчової галузі

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Анотація. Напрями підвищення енергозбереження та екологічної ситуації у переробній і харчовій промисловості України є актуальними, оскільки технології й обладнання за характером та ступенем для ефективного використання паливних ресурсів практично досяжні для їх удосконалення, особливо сьогодні. Мета дослідження – удосконалення методики оптимізації режиму повторного використання теплового потенціалу відпрацьованих технологічних газів при реалізації двоетапного процесу їх охолодження. Використано показники викидів технологічного газу за розходу об'єму – 0,54 м^3/с й температурі – 1600°С із параметрами роботи печі А2-ШБГ у побудові локальних температурних характеристик. Їх побудову проведено на основі теплового балансу й теплопередач при малих інтервалах поверхні з врахуванням параметрів течій теплоносія. Аналіз результатів виконано програмним комплексом Flow Vision при будові графіку, згідно законів термодинаміки. Запропоновано методику розрахунку кількості холодного теплового агенту для повторного використання у технологічному процесі. Встановлено, що за прийнятих умов теплообміну,

необхідну кількість атмосферного повітря з початковою температурою -300С можна нагріти до температури +640°С, а з початковою температурою +300°С, можна нагріти до +1450°С. Розхід природного газу зміниться від 20 м^3/год, без попереднього підігріву атмосферного повітря, до 12,7 м^3/год за підігріву атмосферного повітря у теплообміннику при початковій температурі +300°С. Передбачено, що під час розрахунків економії енергетичного ресурсу, необхідно враховувати початкову температуру холодного теплового агенту при використання тепла відпрацьованих технологічних газів. Запропонована методика розрахунку оптимального режиму рекуперації тепла дозволяє розрахувати зміни розходу первинного паливно-енергетичного ресурсу, створити базу даних для ефективного впровадження енергозберігаючих технологій при повторному використанні тепла відпрацьованих технологічних газів у виробництво

Ключові слова: енергозбереження; теплообмінник; тепловий насос; первинний паливно-енергетичний ресурс; харчова індустрія

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Influence of males of the paternal line with different weight index on the productivity of rabbits of the maternal form of the Hyla Cross

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Abstract. The maternal form of modern rabbit crosses is obtained by crossing ancestral lines. Therefore it is relevant to investigate the effect of using males of the parental line of the Hyla cross with different weight indices on the performance of the main breeding traits of the female rabbits of the parental form of the cross. The purpose of the study was to investigate the level of productivity of rabbits of the maternal form of cross by reproduction signs and to consider the dynamics of the main breeding traits for a number of births. The experiments used 223 rabbits of the maternal form of the Hyla cross, which came from males with different weight indices. To achieve this goal, groups of rabbits were formed, depending on the value of their father's weight Index – Group 1 – ⩽ 100 units, Group 2 – from 100 to 120 units, Group 3 – ⩾ 120 units. The live weight of rabbits after kindling, multiparity, the weight of newborn rabbits, milk yield, and the live weight of rabbits at the time of weaning were determined. Female rabbits that came from males with a high weight index at first kindling significantly outnumbered their peers in multiparity by 1.16-1.23 animal units ($p \leqslant 0.05$), and in milk yield – by 6-6.5%. Rabbits whose parents were males with a high weight index according to the results of the 3rd kindling prevailed over their peers from other males in multiparity ($p \leqslant 0.05$), milk yield ($p \leqslant 0.05$), and also had significantly higher values

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of complex indices ($p \leq 0.05$). From the 1st to the 3rd kindling, the multiparity of rabbits increases, on average, by 6.5%. Live weight at birth of rabbits in Groups 2 and 3 had a positive trend and increased by 3.2% and 4.2%, respectively. On average, the milk yield of rabbits increased by 38.6% from the first to the third kindling. The practical significance of the results lies in the fact that to obtain highly productive rabbits of the maternal cross form, it is advisable to use males of the ancestral form with a weight index ⩾ 120 units

Keywords: crossbreeding; live weight; multiparity; fertility; milk yield; breeding

Introduction

One of the main indicators of the sustainability of rabbit breeding is the profitability of farms, the improvement of which is achieved through technical and economic management and improvement of work with the rabbit population (Pascual, & Gómez, 2020; Honchar *et al.*, 2020). Rabbit breeding programmes for the production of rabbit meat provide for crossing rabbits of specially selected lines, in which the parent line mates with the mother form (Juárez *et al.*, 2020). Maternal traits are a key factor in economic efficiency in rabbit breeding. Improving the maternal ability of rabbits is one of the goals of the Hyla D breeding line (Loussouarn *et. al*, 2012).

The main factor in the profitability of rabbit meat production is the number of weaned rabbits per female (Cartuche *et al.*, 2014). Therefore, breeding programmes focused on genetically improving the size of the nest, which led to a significant increase in the overall multiparity of rabbits (García & Argente, 2020; Behiry *et al.*, 2021). The problem of increasing the productivity of rabbits of the maternal form of cross is urgent and requires attention from breeders. However, the literature sources available to us do not sufficiently cover information about the impact of males on the productivity and reproduction of their daughters. Therefore, the purpose of the study is to investigate the influence of males of the paternal line of the maternal form of cross on the indicators of breeding traits of rabbits of the maternal form.

The live weight of a rabbit determines the mass of newborn rabbits. Rabbits with the 1st kindling have lower rates of live weight at birth than females with more litters (Belabbas *et al.*, 2021).

Researchers note that an increase in the total number of rabbits born leads to a decrease in the weight of newborn rabbits and an increase in their mortality in the nest (Szendrö *et al.*, 2019). The reproductive longevity of rabbits is an important feature of the parent lines of rabbits and is determined by the health and high reproductive capacity of females. The safety, growth rate and survival of rabbits during the lactation period determine the size of the nest and the weight of rabbits at the time of weaning (El Nagar *et al.*, 2020).

Live weight at birth is associated with various productive and reproductive characteristics, such as the behaviour of rabbits in the nest, their feeding and milk consumption, growth intensity during fattening, carcass properties and meat quality, and the reproductive ability of replacement rabbits. Newborn rabbits with higher body weight have a higher live weight during the first mating and during the reproductive period than rabbits with a lower live weight (Belabbas *et al.*, 2021).

Lactation and milk yield of rabbits is a crucial factor not only for the safety of rabbits,

but also for achieving appropriate productivity and maturity at the time of weaning. Researchers report a negative correlation between live weight at weaning and post-weaning mortality. There are several factors that affect milk yield at a particular stage of lactation, such as genotype or the length of the period between kindling and subsequent insemination (Arnau-Bonachera *et al.*, 2015).

Thus, the question of the influence of males on the productivity and reproduction indicators of maternal rabbits is relevant. Therefore, the purpose of the study was to investigate the level of productivity of rabbits of the maternal form of cross based on reproduction traits obtained from males with different weight indices and to analyse the dynamics of the main breeding traits for a number of litters.

Materials and Methods

The research was conducted at the premises of LLC "Ferma Krolikoff" in Cherkasy oblast from March 2020 to December 2022. 223 animal units of maternal NG (new generation) cross rabbits were used for the study, which came from males of the paternal line of the maternal form GPS (Grandparents line C) with different weight index (n = 47) and maternal rabbits of the maternal line of the maternal form GPD (Grandparents line D) (n = 79) of the Hyla cross. The weight index was calculated using equation 1:

$$\text{Weight index} = \frac{\text{Live weight, g}}{\text{Straight body length, cm}}. \quad (1)$$

Groups of NG rabbits were formed according to the weight index of their father – Group 1 (n = 64) – weight index ⩽ 100 units, Group 2 (n = 89) – weight index value from 100 to 120 units, Group 3 (n = 70) – ⩾ 120 units. All female rabbits were crossed with males of the parent form Hyla Max, which were analogous in live weight and age.

The rabbits used in the study were kept in rooms with an adjustable microclimate and automatic ventilation. During the study, the room temperature was in the range of 15-22°C, humidity – 60-70%. Rabbits were kept in cages in numbers, depending on their age: rabbits aged 5-10 weeks – 7 animals in a cage, repair young animals aged 10-14 weeks – 3 animals in a cage, aged 14-19 weeks – one animal in a cage. The size of the cages was 0.9×0.425×0.4 m. Rabbits were fed with granulated compound feed, which included wheat bran, sunflower husks, soy cake, and vitamin supplements. Feeding of rabbits was dosed, the animals' access to water was unlimited. Rabbits were first inseminated at 19 weeks of age, and then every 18 days after kindling. The production cycle was 49 days. Controlled feeding of rabbits was used in the first 10 days after kindling.

The live weight of the animals was determined by weighing them on an electronic scale in the morning before feeding. Multiparity was determined by calculating the number of live-born rabbits in the nest. Animal live weight at birth was determined by the average live weight of rabbits after birth. The milk yield of rabbits was calculated using equation 2 proposed by Fortun-Lamothe & Sabater (2003):

$$MY = 1.69 \times DG + 362, \quad (2)$$

where MY – milk yield of rabbits, kg; DG – weight gain of the nest from birth to 21 days, g; 1, 69, 362 – correction factors.

The milk yield coefficient was calculated using equation 3 proposed by Niedzwiadek (1982):

$$M = [(LW^2 - LW^1) : (21 \times LW_2)] \times 100, \quad (3)$$

where LW_1 – nest weight at birth; LW_2 – nest weight at the age of 21 days.

At the age of 3 and 5 weeks, the average live weight of rabbits in the nest was determined. The preservation of rabbits before weaning was determined as the ratio of the number of rabbits at the time of weaning to the number of live newborn rabbits. Weaning of rabbits was carried out at the age of 5 weeks.

For an objective comprehensive assessment of the reproductive capacity of rabbits, a complex indicator of the reproductive qualities of rabbits (CIRQ) was used, which was determined by equation 5 (Kovalenko *et al.*, 2001):

$$CIRQ = 1,1X_1 + 0,3X_2 + 3,3X_3 + 0,35X_4 \quad (5)$$

where X_1 – multiparity, units; X_2 – milk content, kg; X_3 – number of newborn rabbits at 35-day age, units; X_4 – nest weight at the time of weaning, kg, 1.1, 0.3, 3.3, 0.35 – correction factors;

The index of reproductive qualities of rabbits (IRQ) was also calculated by equation (6) (Boiko *et al.*, 2020):

$$IRQ = B + 10\,m + 5Z, \quad (6)$$

where B – average weight of one newborn rabbit, g; *m* – milk content of the rabbit, kg; Z – number of rabbits at weaning at 35 days of age, units; 10,5 – correction factors.

Empirical data were statistically processed using SPSS and Excel software suites using descriptive statistics methods. The mean values of features (M), their errors (m), variance, root-mean-square deviation, and coefficient of variation (Cv) were calculated (Ibatullin *et al.*, 2017).

Results and Discussion

The productivity of rabbits is the basis for the economic efficiency of rabbit breeding. The number and quality of rabbits of the final hybrid, which will be transferred to fattening and sold for slaughter, depends on the multiparity and milk yield of females of the maternal form of the cross. Therefore, the authors studied the level of selection traits of rabbits obtained from males with different weight indices in 3 litters. The productivity of rabbits for the 1st kindling is shown in Table 1.

Table 1. *Significance of the main selection traits in maternal rabbits by the results of the 1st kindling*

Trait	Indicators					
	Group 1 (n = 64)		Group 2 (n = 89)		Group 3 (n = 70)	
	M ± m	Cv,%	M ± m	Cv,%	M ± m	Cv,%
Live weight after kindling, g	4,583.7 ± 75.68	9.56	4,547.4 ± 69.84	8.49	4,684.6 ± 74.30	9.63
Multiparity, animal units	8.54 ± 0.323	34.62	8.61 ± 0.312	33.17	9.77 ± 0.476*	34.85
Live weight at birth, g	62.53 ± 1.161**	13.19	59.34 ± 0.971	11.87	58.29 ± 1.262	15.32
Milk content, g	4,398.0 ± 105.10	26.98	4,439.8±111.46	25.82	4,698.0±133.06	29.99
Milk yield ratio	3.83 ± 0.056	8.72	3.84 ± 0.051	7.85	3.91 ± 0.059	9.17
Weight of a baby rabbit at the age of 3 weeks, g	413.19 ± 11.678	16.72	407.21 ± 9.89	14.60	386.60 ± 11.068	16.94
Weight of a baby rabbit at the age of 5 weeks, g	922.49 ± 12.945	8.13	938.51 ± 8.428	5.89	935.63 ± 10.239	6.56
Preservation of rabbits before weaning, %	88.21 ± 1.470	19.04	88.72 ± 1.172	15.12	89.94 ± 1.521	18.76
CIRQ, points	39.70 ± 1.228	33.20	40.12 ± 1.070	30.45	43.94 ± 1.490*	33.52
IRQ, points	149.86 ± 2.488	9.82	147.68 ± 2.317	8.97	146.19 ± 2.613	10.57

Note: * – $p \leq 0.05$, ** – $p \leq 0.01$ compared to Group 2 rabbits
Source: developed by the author

As can be seen from the Table, Group 3 rabbits had 137.2 g more live weight than Group 2 and 100.9 g more than Group 1, but the difference was not significant. Rabbits obtained from males with a high weight index (Group 3) had the highest multiparity at the 1st kindling – 1.16 units more ($p \leqslant 0.05$) than rabbits of Group 2 and 1.23 units more than rabbits of Group 1. In terms of live weight at birth, the trend was reversed – its highest value was in rabbits of Group 1, while in rabbits of Groups 2 and 3 it was 3.19 g ($p \leqslant 0.01$) and 4.24 g less, respectively. The milk content of Group 3 rabbits was 5.8% higher than that of Group 2 rabbits and 6.8% higher than that of Group 1. According to the milk yield coefficient, which indicates the growth of rabbits during lactation, there was no significant difference between the rabbits of the experimental groups. The live weight of rabbits in the nest, which is an additional criterion for assessing milk yield, was highest in rabbits of Group 1, in Group 2 it was 5.98 g less, and in Group 3 rabbits – 26.59 g less. The live weight of rabbits at weaning in rabbits of different groups did not differ significantly, as well as the safety of rabbits before weaning.

The highest value of the CIRQ index, which determines the reproductive capacity of rabbits in the aggregate, was in females of Group 3, while in rabbits of Group 2 it was 3.82 points less ($p \leqslant 0.05$), and in rabbits of Group 1 – 4.24 points less.

Rabbits of the maternal form are characterised by a high intensity of reproduction, because, according to the technology, insemination of females occurs 17-18 days after kindling. Thus, a valuable biological feature of rabbits is used – the ability to combine pregnancy and lactation. Table 2 shows the productivity of rabbits based on the results of the 2nd kindling.

Table 2. *Significance of the main breeding traits in maternal rabbits based on the results of the 2nd kindling*

Trait	Indicators					
	Group 1 (n = 59)		Group 2 (n = 84)		Group 3 (n = 62)	
	M ± m	Cv,%	M ± m	Cv,%	M ± m	Cv,%
Live weight after kindling, g	4,928.7 ± 72.68	7.63	5,024.5 ± 64.72	6.85	5,274.3 ± 74.97*	7.23
Multiparity, animal units	9.10 ± 0.464	35.49	9.22 ± 0.373	31.94	10.37 ± 0.447*	31.21
Live weight at birth, g	62.51 ± 0.696	6.94	61.24 ± 0.518	5.87	60.73 ± 0.689	6.82
Milk content, g	6,102.7 ± 143.21	23.58	6,158.6 ± 107.36	19.67	6,497.3 ± 131.22*	21.38
Milk yield ratio	4.09 ± 0.010	4.57	4.15 ± 0.015	5.21	4.22 ± 0.016	5.39
Weight of a baby rabbit at the age of 3 weeks, g	418.35 ± 5.513	7.80	414.26 ± 4.231	8.15	416.00 ± 7.740	11.01
Weight of a baby rabbit at the age of 5 weeks, g	942.79 ± 10.219	6.38	940.27 ± 8.438	5.76	941.71 ± 13.715	8.62
Preservation of rabbits before weaning, %	91.34 ± 1.981	16.49	91.57 ± 1.827	15.76	92.58 ± 2.090	17.39
CIRQ, points	43.48 ± 1.569	34.96	45.21 ± 1.146	31.53	48.87 ± 1.465*	30.47
IRQ, points	160.14 ± 6.214	12.96	164.31 ± 4.684	11.39	177.41 ± 4.123*	14.23

Note: * – p≤0.05 compared to Group 2 rabbits

Source: developed by the author

Analysing the data of the results of the 2nd kindling of maternal rabbits, it can be seen that the indicators of reproductive ability have increased compared to the first kindling. Live weight after kindling was the highest in rabbits of Group 3. In terms of multiparity, rabbits that

were obtained from males with a high weight index prevailed over the peers of Groups 1 and 2 by 0.92 and 0.80 units, respectively. After the 2nd kindling, the largest live weight at birth was in rabbits of Group 1. According to this trait, they outnumbered the Group 2 by 1.76 g ($p \leq 0.05$), and Group 3 – by 2.51 g. In Group 3 rabbits, the milk yield index was 435.7 g higher ($p \leq 0.01$) than in Group 2 and 511.6 g higher than in Group 1. According to the milk yield coefficient, rabbits of Group 3, although not significantly, prevailed over their peers of Groups 1 and 2.

The live weight of rabbits aged 3 weeks obtained from rabbits of Group 3 was 1.65 g and 5.87 g higher than that of rabbits descended from rabbits of Groups 2 and 1, respectively. The indicator of the average live weight at the time of weaning in rabbits obtained from rabbits of Group 3 was the highest, it prevailed by the same indicator of rabbits that were obtained from rabbits of Group 2 by 1.5%, and from rabbits of Group 1 – by 2.2%. The preservation of rabbits before weaning in rabbits of all groups was at a high level, but its highest value was recorded in rabbits of Group 3.

According to the indicators of complex indices, rabbits that came from males with a high weight index prevailed over their peers of Groups 2 and 1. Thus, according to the CIRQ index, the difference was 1.11 and 1.46 points.

The productivity of rabbits gradually increases and reaches maximum values at 3-4 kindling. In our studies, there is a certain dynamics of increasing the indicators of reproduction traits from the 1st to the 2nd kindling. The results of the 3rd kindling are presented in Table 3.

Table 3. *Significance of the main breeding traits in maternal rabbits based on the results of the 3rd kindling*

Trait	Indicators					
	Group 1 (n = 59)		Group 2 (n = 84)		Group 3 (n = 62)	
	M ± m	Cv,%	M ± m	Cv,%	M±m	Cv,%
Live weight after kindling, g	4,928.7 ± 72.68	7.63	5,024.5 ± 64.72	6.85	5,274.3 ± 74.97*	7.23
Multiparity, animal units	9.10 ± 0.464	35.49	9.22 ± 0.373	31.94	10.37 ± 0.447*	31.21
Live weight at birth, g	62.51 ± 0.696	6.94	61.24 ± 0.518	5.87	60.73 ± 0.689	6.82
Milk content, g	6,102.7 ± 143.21	23.58	6,158.6 ± 107.36	19.67	6,497.3 ± 131.22*	21.38
Milk yield ratio	4.09 ± 0.010	4.57	4.15 ± 0.015	5.21	4.22 ± 0.016	5.39
Weight of a baby rabbit at the age of 3 weeks, g	418.35 ± 5.513	7.80	414.26 ± 4.231	8.15	416.00 ± 7.740	11.01
Weight of a baby rabbit at the age of 5 weeks, g	942.79 ± 10.219	6.38	940.27 ± 8.438	5.76	941.71 ± 13.715	8.62
Preservation of rabbits before weaning, %	91.34 ± 1.981	16.49	91.57 ± 1.827	15.76	92.58 ± 2.090	17.39
CIRQ, points	43.48 ± 1.569	34.96	45.21 ± 1.146	31.53	48.87 ± 1.465*	30.47
IRQ, points	160.14 ± 6.214	12.96	164.31 ± 4.684	11.39	177.41 ± 4.123*	14.23

Note: * – p≤0.05 compared to Group 2 rabbits
Source: developed by the author

Analysis of the obtained indicators indicates that rabbits that descended from males with a high weight index are characterised by higher indicators of maternal traits. Live weight after the 3rd kindling was 249.8 g higher ($p \leq 0.05$) than in rabbits of Group 2 and 345.6 g higher than in rabbits of Group 1. Rabbits of Group 3 outnumbered their peers of Groups 2 and 1 in multiparity by 1.15 ($p \leq 0.05$) and 1.27 units, respectively. Along with this, rabbits of

Group 1 had the highest live weight at birth, which confirms the inverse correlation between these traits. In terms of milk yield, rabbits of Group 3 had an advantage – it was 338.7 g more ($p \leq 0.05$) than Group 2 and 394.6 g more than Group 1. The milk yield coefficient was also higher in Group 3 rabbits, which indicates a more intensive growth of rabbits in nests from these rabbits.

The average weight of rabbits at the age of 3 weeks in rabbits of the experimental groups was approximately the same, with an insignificant difference between the groups. According to the live weight of rabbits at the time of weaning, there was also no significant difference between the rabbits of the experimental groups. The preservation of rabbits before weaning was highest in rabbits of Group 3. According to this indicator, they outnumbered females of Groups 1 and 2 by more than 1%.

In terms of indices, female rabbits of Group 3 had an advantage over their peers. Thus, according to the CIRQ index, they outnumbered females of Group 2 by 8% ($p \leq 0.05$), and females of Group 1 – by 15.4%. The IRQ index in Group 3 rabbits was 13.1 points higher ($p \leq 0.05$) than in Group 2 and 17.27 points higher than in Group 1.

Analysis of the results of the experiment shows that the main breeding characteristics of rabbits varied from the 1st to the 3rd kindling. The dynamics of indicators of multiparity, live weight at birth, and milk yield can be observed in Figures 1, 2, and 3.

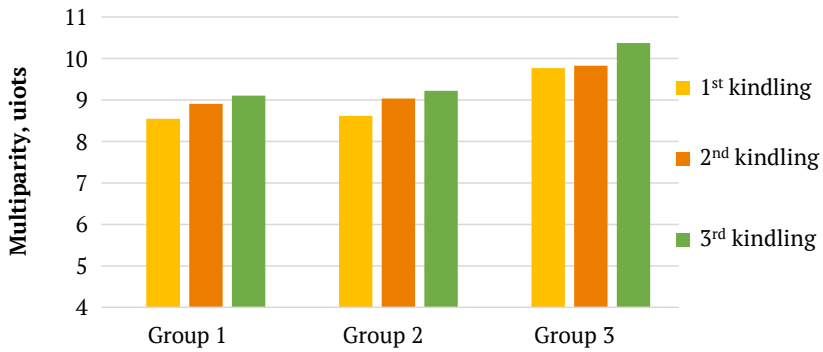

Figure 1. Dynamics of multiparity of female rabbits by kindlings
Source: developed by the author

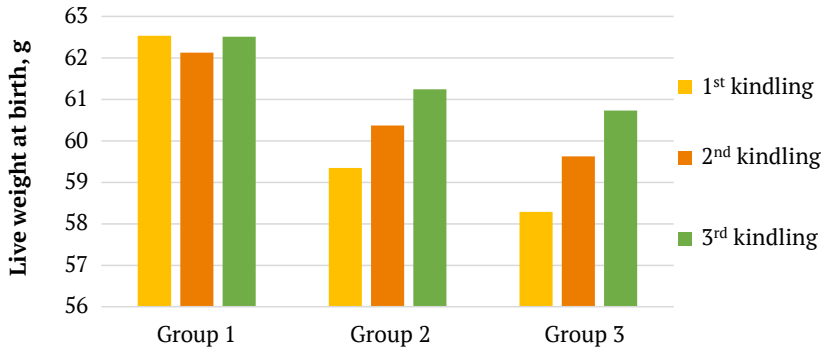

Figure 2. Dynamics of live weight at birth by kindlings
Source: developed by the author

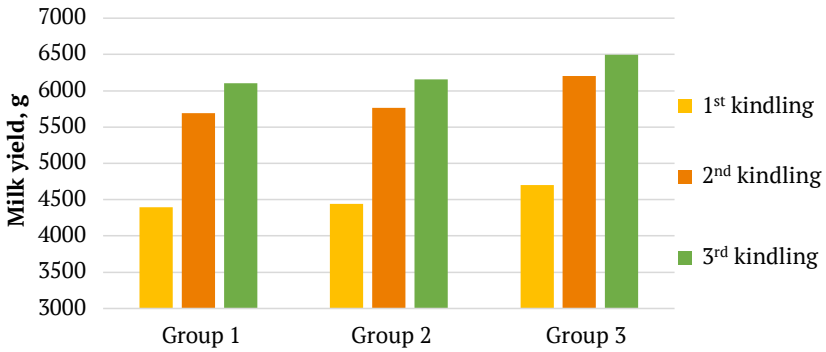

Figure 3. Dynamics of milk yield of maternal rabbits by kindlings
Source: developed by the author

It was found that the multiparity of Group 1 rabbits from the 1st to the 2nd kindling increased by 0.35 animal units or 4.1%, and from the 2nd to the 3rd – by 0.19 units, or 2.1%. In Group 2 rabbits, the increase in multiparity from the 1st to the 2nd kindling was by 0.42 units or 4.9%, and from the 2nd to the 3rd – 0.21 units, or 2.3%. The multiparity of rabbits of Group 3 from the 1st to the 2nd kindling increased by 0.06 animal units, which is 0.6%, and from the 2nd to the 3rd kindling – by 0.54 units or 5.5%.

Live weight of rabbits of Group 1 for the 2nd kindling was 0.4 units less than for the 1st kindling and 0.38 less than for the 3rd kindling. In rabbits of Group , the difference between the 1st and 2nd kindling was 1.03 g in terms of live weight at birth, and between the 2nd and 3rd – 0.87 g. In Group 3 rabbits, the dynamics of live weight at birth was also positive. The growth of this trait from the 1st to the 2nd kindling was 1.33 g, and from the 2nd to the 3rd – 1.11 g.

The milk content of rabbits of all groups increased from the 1st to the 3rd kindling. Thus, in rabbits of Group 1, the increase in milk yield from the 1st to the 2nd kindling was 1,290.9 g, and from the 2nd to the 3rd – 413.8 g. The increase in milk yield in rabbits of Group 2 from the 1st to the 2nd kindling was by 1,325 g, and from the 2nd to the 3rd – by 393.8 g. In females of Group 3, from the 1st to the 2nd kindling increased by 1,502.5 g, and from the 2nd to the 3rd – by 296.8 g.

As indicated by the results of the conducted studies, rabbits of the maternal form of Hyla NG cross are characterised by high productivity. Analysis of these studies suggests that the use of males with different weight indices affects the reproductive capacity of rabbits.

In studies, the multiparity of rabbits obtained from males with a high weight index ranged from 9.77 to 10.37 animal units. Ludwiczak *et al*. (2021) in their studies obtained data on the productivity of rabbits of the maternal form of Hycole cross for a number of kindlings. Researchers point that the multiparity of rabbits increases from 11.2 to 12.1 units from the 1st to the 3rd kindling, and then decreases. High live weight at birth of rabbits of the Hycole cross had a positive trend from the 1st to the 4th kindling, but then decreased. Notably, the live weight at birth of rabbits of Hycole cross was slightly higher than in this study, it ranged from 70.8 to 72.5 g. The researchers also noted an increase in the milk content of rabbits from the 1st to the 3rd kindling, and after the 4th kindling it decreased.

Findings indicate that the size of the nest also affects the live weight of rabbits during weaning. Thus, rabbits from smaller nests have

a higher weight at weaning than rabbits raised in nests with a larger number of rabbits (Fayeye & Ayorinde, 2008). The study by Pałka *et al*. (2018) analysed the growth of young rabbits of the Popelino White and Termon White breeds. The researchers found a significant effect of nest size on the time of birth on the growth of rabbits. The average live weight of newborn rabbits of the Popelino White breed was 64 g due to the smaller size of the nest, and not because of the breed. The live weight of newborn rabbits of the Termon White breed was 72 g.

Ologbose & Bennett (2019) in studies on the productivity and reproduction of rabbits obtained from males of different breeds, found that females obtained from males of the New Zealand White Breed had a higher multiparity, but were inferior to rabbits obtained from males of the Danish breed in terms of live weight at birth. These data describe to a certain extent the influence of males on the productivity of rabbits.

Several similar indicators of the reproductive capacity of rabbits were obtained by researchers (Ludwiczak *et al*., 2020), which examined the milk yield of females and the weight of Hycole rabbits, depending on the number of rabbits in the nest. The researchers found that the average weight of rabbits aged 21 days was higher in nests of 8 rabbits, compared to nests of 10 rabbits. The milk yield coefficient in experimental rabbits ranged from 3.65 to 3.82 and was higher in rabbits with 10 rabbits in the nest. The obtained data on the milk ratio in the current study were slightly higher.

In experiments to study the productivity of rabbits of different genotypes from crossing Hyla rabbits of the New Zealand white breed, researchers found that the multiparity of rabbits that descended from Hyla males was 8.1 units, and crossed rabbits – 8.5 units (Brahmantiyo *et. al*., 2021). These values were lower than those obtained in this study, which may indicate the effectiveness of selecting males with different weight indices for obtaining maternal rabbits.

Results (Savietto *et al*., 2021) of reserchers who investigated the dynamics of changes in the productivity indicators of rabbits for a number of kindlings indicate that the multiparity of rabbits of the burgundy breed, line 1777 and their crossbreeds increased from the 1st to the 3rd kindling from 2.6 to 6.3 animal units in the Burgundy breed, from 6.3 to 10.7 in the line 1777, and from 5.1 to 5.6 in crossbreeds of these genotypes.

In experiments to investigate the influence of the kindling season and its sequence number on the productivity of female rabbits of the cross and local breeds, researchers (Zerrouki *et al*., 2008) obtained data on the likely effect of these factors on the total number of births and multiparity of rabbits, the interval between two kindlings, and preservation during the suckling period. The researchers, as in this study, found a classic pattern of increasing multiparity from the 1st to the 3rd kindling, and in the subsequent litter, there was a tendency to reduce the multiparity of rabbits. High mortality during the suckling period was also found in the 3rd and 4th kindlings (17 and 23% vs. 11-14% for other litters).

According to the data, the milk yield coefficient of rabbits depends on the breed and feed composition. Pałka *et al*. (2017) found that females of the Termon White are characterised by the highest milk yield coefficient – 3.76. The rabbit of the Grey Flemish Giant, on the contrary, had the lowest value of this coefficient (3.18) among the analysed rabbit breeds. Other breeds analysed by these authors showed a similar level of milk productivity (California – 3.63, New Zealand White – 3.72, Popelino White – 3.73). Kowalska & Bielanski (2004) investigated the reproductive capacity of rabbits fed two different compound feeds (5.05% crude fat vs. 3.24% crude fat). Females who received food

with a higher fat content were characterised by a higher milk yield coefficient (4.0 vs. 3.4). In addition, higher milk productivity led to a higher weight of rabbits on the 21st day of lactation (962.6 g vs. 810.6 g).

In experiments with purebred rabbits of the Burgundy breed, the 1777 line, and their cross-breeds (Savietto *et al.*, 2021), the live weight at birth of purebred rabbits from the 1st to the 3rd kindling decreased, and in cross-bred rabbits – remained unchanged.

Similar data on the milk content of rabbits were obtained by Ali *et al.*, (2021); Abd El-latif *et al.*, (2021), who studied the dynamics of milk yield of rabbits of synthetic line V. It was found that the milk content of rabbits increases from the 1st to the 4th kindling, however, less intensively than in the studies conducted by the authors.

Conclusions

The study results indicate the influence of males of the ancestral form with different weight index on the reproductive traits of female rabbits. Female rabbits that came from males with a high weight index outnumbered peers that were obtained from males with a low and medium weight index, in terms of multiparity – by 12.5%, in terms of milk yield – by 5.5%, and in terms of the safety of rabbits before weaning – by 1%. At the same time, the difference in the live weight of rabbits at the time of weaning obtained from rabbits of different groups has not been established. The effect of heterosis on the milk yield of rabbits obtained from males with a high weight index was revealed. By complex rabbit indexes, women who came from males with a high weight index also outnumbered females who came from men with a low and medium weight index. The study of the dynamics of reproductive traits in rabbits over a number of litters showed that in rabbits obtained from males with a high weight index, the growth of multiparity and milk yield is more intense. It was also found that the milk yield of rabbits obtained from males with a high weight index increases intensively from the 1st to the 3rd kindling. Thus, the results suggest that males with different weight indices have a positive effect on the performance of daughters. Based on the research data, it is recommended to use males of the paternal line of the maternal form with a high weight index (⩾ 120 units) to obtain maternal rabbits and use them for crossing with males of the paternal form of the cross. The obtained results indicate that the daughters of males with a weight index of more than 120 units have higher indicators of the main breeding characteristics, in particular, multiparity, milk yield, and preservation of rabbits before weaning, which directly affect the economic efficiency of rabbit breeding.

Further study will be aimed at investigating the genotypic parameters of rabbit selection and determining the strength of the influence of the father's factor on the traits of breeding rabbits of the maternal form of cross.

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Conflict of Interest

None.

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Вплив самців батьківської лінії з різним ваговим індексом на показники продуктивності кролематок материнської форми кросу Hyla

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Анотація. Кролематок материнської форми сучасних кросів кролів отримують внаслідок схрещування прабатьківських лінії. Тому актуальним є дослідження впливу використання самців батьківської лінії материнської форми кросу Hyla з різним ваговим індексом на показники основних селекційних ознак кролематок материнської форми кросу. Метою роботи було дослідити рівень продуктивності кролематок материнської форми кросу за ознаками відтворення та вивчити динаміку основних ознак селекції за ряд окролів. У дослідах використовували 223 кролематки материнської форми кросу Hyla, які походили від самців з різним ваговим індексом. Для досягнення мети було сформовано групи кролематок, залежно від значення вагового індексу їх батька – I група – ⩽ 100 одиниць, II група – від 100 до 120 одиниць, III група – ⩾ 120 одиниць. Визначали живу масу кролематок після окролу, багатоплідність, масу новонароджених кроленят, молочність, живу масу кроленят на час відлучення. Кролематки, які походили від самців з високим ваговим індексом за I окріл вірогідно переважали ровесниць за багатоплідністю на 1,16-1,23 голови ($p \leqslant 0,05$), а за молочністю – на 6-6,5%. Кролематки, батьками яких були самці з високим ваговим індексом за результатами III окролу переважали ровесниць від інших самців за багатоплідністю ($p \leqslant 0,05$), молочністю ($p \leqslant 0,05$), а також мали вірогідно вищі значення комплексних індексів ($p \leqslant 0,05$). Від першого до третього окролу багатоплідність кролематок зростає, у середньому, на 6,5 %. Великоплідність кролематок II і III груп мала позитивну динаміку і зростала на 3,2 % та 4,2 % відповідно. У середньому, молочність кролематок зростала на 38,6 % від першого до третього окролу. Практичне значення результатів полягає у тому, що для отримання високопродуктивних кролематок материнської форми кросу доцільно використовувати самців прабатьківської форми з ваговим індексом ⩾ 120 одиниць

Ключові слова: кросбридинг; жива маса; багатоплідність; великоплідність; молочність; селекція

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