

# ТВАРИННИЦТВО ТА ТЕХНОЛОГІЇ ХАРЧОВИХ ПРОДУКТІВ

## **Співзасновники:**

Національний університет біоресурсів і природокористування України  
ТОВ «Наукові журнали»

## **Рік заснування: 2010**

*Рекомендовано до друку та поширення  
через мережу Інтернет Вченою радою  
Національного університету біоресурсів і природокористування України  
(протокол № 8 від 27 квітня 2022 р.)*

**Свідоцтво про державну реєстрацію  
друкованого засобу масової інформації  
серії КВ 25125-15065 ПР від 17 лютого 2022 р.**

## **Журнал входить до переліку наукових фахових видань України**

Категорія «Б». Галузь знань: Сільськогосподарські науки,  
спеціальності – 181 «Харчові технології»,  
204 «Технологія виробництва і переробки продукції тваринництва»,  
207 «Водні біоресурси та аквакультура»  
(Наказ Міністерства освіти і науки України від 17 березня 2020 р. № 409)

**Журнал представлено у міжнародних наукометричних базах даних,  
репозитаріях та пошукових системах: Index Copernicus International,  
Google Scholar, Academic Resource Index ResearchBib,  
Національна бібліотека України імені В. І. Вернадського, MIAR, BASE, AGRIS**

## **Адреса редакції:**

Національний університет біоресурсів і природокористування України  
вул. Героїв Оборони, 15, м. Київ, 03041, Україна  
E-mail: [info@animalscience.com.ua](mailto:info@animalscience.com.ua)  
www: <https://animalscience.com.ua/uk>

© Національний університет біоресурсів і природокористування України, 2022  
© ТОВ «Наукові журнали», 2022

# ANIMAL SCIENCE AND FOOD TECHNOLOGY

## **Co-founders:**

National University of Life and Environmental Sciences of Ukraine,  
LLC “Scientific Journals”

**Year of foundation: 2010**

*Recommended for printing and distribution  
via the Internet by the Academic Council  
of National University of Life and Environmental Sciences of Ukraine  
(Minutes No. 8 of April 27, 2022)*

## **Certificate of state registration of the print media**

Series KV No. 25125-15065 PR of February 17, 2022

## **The journal is included in the list of Professional Scientific Publications of Ukraine**

Category “B”. Field of knowledge: Agricultural Science,  
specialties – 181 “Food Technology”,  
204 “Technology of Production and Processing of Livestock Products”,  
207 “Aquatic Bioresources and Aquaculture”  
(order of the Ministry of Education and Science of Ukraine of March 17, 2020, No. 409)

## **The journal is presented international scientometric databases, repositories**

**and scientific systems:** Index Copernicus International,  
Google Scholar, Academic Resource Index ResearchBib,  
Vernadsky National Library of Ukraine, MIAR, BASE, AGRIS

## **Editors office address:**

National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony, Kyiv, Ukraine  
E-mail: [info@animalscience.com.ua](mailto:info@animalscience.com.ua)  
www: <https://animalscience.com.ua/en>

© National University of Life and Environmental Sciences of Ukraine, 2022  
© LLC “Scientific Journals”, 2022

## Редакційна колегія

**Головний редактор:**  
Наталія Слободянюк

**Заступник  
головного редактора:**  
Михайло Муштрук

**Відповідальний секретар:**  
Дмитро Носевич

### **Основний склад редколегії**

**Лариса Баль-Прилипко**

**Володимир Василів**

**Андрій Гетья**

**Вадим Кондратюк**

**Роман Кулібаба**

**Анатолій Угнівенко**

**Віталій Бех**

**Ганна Котовська**

**Наталія Рудик-Леуська**

**Олена Бабенко**

### **Міжнародні члени редколегії**

**Мирослава Качаньова**

**Джованні Сілія**

**Міхайела Корнеа-Сіпчіган**

**Маргаоан Родіка**

**Марія Клопчич  
Лукаш Зіта**

**Ян Бріндза**

**Галя Замарацкая**

**Мохаммадабаді Мохаммадреза  
Бранко Гламузіна  
Світлана Ленгель**

**Олександр Маліновський**

Кандидат сільськогосподарських наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат технічних наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат сільськогосподарських наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Доктор технічних наук, професор, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат технічних наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Доктор сільськогосподарських наук, професор, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат сільськогосподарських наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Доктор сільськогосподарських наук, старший науковий співробітник, Національний університет біоресурсів і природокористування України, Київ, Україна

Доктор сільськогосподарських наук, професор, Національний університет біоресурсів і природокористування України, Київ, Україна

Доктор сільськогосподарських наук, професор, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат біологічних наук, старший науковий співробітник, Національний університет біоресурсів і природокористування України, Київ, Україна

кандидат біологічних наук, доцент, Національний університет біоресурсів і природокористування України, Київ, Україна

Кандидат сільськогосподарських наук, доцент, Білоцерківський національний аграрний університет, Біла Церква, Україна

Професор, Словацький сільськогосподарський університет в Нітрі, Жешувський університет, Нітра, Словачія

PhD., науковий співробітник, Рада сільськогосподарських досліджень та економіки Науково-дослідний центр сільського господарства та навколишнього середовища, Болонья, Італія

MD, Університет сільськогосподарських наук та ветеринарної медицини Клуж-Напока, Клуж-Напока, Румунія

PhD., науковий співробітник, Університет сільськогосподарських наук та ветеринарної медицини Клуж-Напока, Клуж-Напока, Румунія

Доктор, доцент, Люблянський університет, Любляна, Словенія

PhD., доктор інженерії, доцент, Чеський університет природничих наук, Прага, Чехія

PhD., доктор інженерії, доцент, Словацький сільськогосподарський університет в Нітрі, Словачія

PhD., доцент, Шведський університет сільськогосподарських наук, Упсала, Швеція

Професор, Керманський університет Шахіда Бахонар, Керман, Іран

Професор, Дубровницький університет, Добровник, Хорватія

доктор, науковий співробітник, Угорський університет сільського господарства та природничих наук, Будапешт, Угорщина

PhD., науковий співробітник, Південночеський університет у Ческі-Будейовиці, Чеські Будейовиці, Чехія

## Editorial Board

### ***Editor-in-Chief:***

**Nataliia Slobodianiuk**

PhD in Agricultural Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

### ***Deputy Editor-in-Chief:***

**Mykhailo Mushtruk**

PhD in Technical Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

### ***Executive Editor:***

**Dmytro Nosevych**

PhD in Agricultural Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

### ***Main Members of the Editorial Board***

**Larysa Bal-Prylypko**

Full Doctor in Technical Sciences, Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Volodymyr Vasylyv**

PhD in Technical Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Andrii Getya**

Full Doctor in Agricultural Sciences, Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Vadym Kondratiuk**

PhD in Agricultural Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Roman Kulibaba**

Full Doctor in Agricultural Sciences, Senior Research Fellow, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Anatolii Uhnivenko**

Full Doctor in Agricultural Sciences, Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Vitalii Bekh**

Full Doctor in Agricultural Sciences, Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Anna Kotovska**

PhD in Biological Sciences, Senior Research Fellow, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Nataliia Rudyk-Leuska**

PhD in Biological Sciences, Associate Professor, National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

**Olena Babenko**

PhD in Agricultural Sciences, Associate Professor, Bila Tserkva National Agrarian University, Bila Tserkva, Ukraine

### ***International Members of the Editorial Board***

**Myroslava Kachanova**

Professor, Slovak Agricultural University in Nitra, University of Rzeszów, Nitra, Slovakia

**Giovanni Celia**

PhD, Research Fellow, Council for Agricultural Research and Economics Research Center for Agriculture and the Environment, Bologna, Italy

**Michaiela Cornea-Sipchigan**

MD; University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania

**Margaoan Rodica**

PhD, Research Fellow, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania

**Maria Klopčič**

Full Doctor, Associate Professor, University of Ljubljana, Ljubljana, Slovenia

**Lukash Zita**

PhD, Doctor of Engineering, Associate Professor, Czech University of Life Sciences Prague, Prague, Czech Republic

**Jan Brindza**

PhD, Associate Professor, Slovak Agricultural University in Nitra, Slovakia

**Halia Zamaratskaia**

PhD, Associate Professor, Swedish University of Agricultural Sciences, Uppsala, Sweden

**Mohammadabadi Mohammadreza**

Professor, Shahid Bahonar University of Kerman, Kerman, Iran

**Branko Glamuzina**

Professor, University of Dubrovnik, Dubrovnik, Croatia

**Svitlana Lengel**

Doctor, Research Fellow, Hungarian University of Agriculture and Life Sciences, Budapest, Hungary

**Oleksandr Malinowski**

PhD, Research Fellow, University of South Bohemia in České Budějovice, České Budějovice, Czech Republic

## ЗМІСТ

|  |    |
|--|----|
| <b>З. А. Бурова, Л. Й. Воробйов, С. О. Іванов, О. Л. Декуша</b><br>Заходи і засоби підвищення енергоефективності харчових виробництв .....   | 7  |
| <b>Р. М. Двикалюк, Л. О. Адамчук, А. Д. Антонів, С. Севин</b><br>Перегляд національних нормативних вимог до якості прополісу<br>на відповідність міжнародним стандартам.....                                       | 16 |
| <b>В. Я. Лихач, А. В. Лихач, Р. В. Фаустов, Є. В. Баркарь, Л. Г. Леньков</b><br>Вплив нового комплексного сорбенту мікотоксинів у раціонах свиней на їхні показники росту,<br>відгодівельні та м'ясні ознаки ..... | 26 |
| <b>І. П. Паламарчук, В. І. Паламарчук, В. В. Сарана, Я. В. Гейпель, Б. Ю. Бородич</b><br>Техніко-економічне обґрунтування процесу семіфлюїдизаційної обробки плодючої продукції ...                                | 35 |
| <b>О. С. Пилипчук, Л. М. Тищенко, В. М. Ізраелян, Н. М. Муштрук</b><br>Вплив параметрів маринування м'ясних напівфабрикатів на якість готового продукту.....   | 44 |
| <b>М. В. Рябовол</b><br>Математичне моделювання процесу вібраційного перемішування сосисочного фаршу.....  | 53 |
| <b>О. В. Самойліченко, О. А. Прядко, В. М. Мокійчук, Ю. В. Слива</b><br>Методологічні аспекти оцінювання компетентності персоналу лабораторій<br>визначення якості картоплі насінневої .....                       | 63 |
| <b>О. О. Сніжко, І. В. Момот</b><br>Використання інулінвмісної сировини у технології ковбасних виробів.....  | 71 |

---

## CONTENTS

---

|   |    |
|---|----|
| <b>Z. Burova, L. Vorobiov, S. Ivanov, O. Dekusha</b><br>Measures and Means to Improve the Energy Efficiency of Food Production .....  | 7  |
| <b>R. Dvykaliuk, L. Adamchuk, A. Antoniv, S. Sevin</b><br>Review of National Regulatory Requirements for Propolis Quality<br>for Compliance with International Standards .....                            | 16 |
| <b>V. Lykhach, A. Lykhach, R. Faustov, Ye. Barkar, L. Lenkov</b><br>The Effect of a New Complex Sorbent of Mycotoxins in Pigs Diets on Their Growth Performance,<br>Fattening and Meat Traits .....       | 26 |
| <b>I. Palamarchuk, V. Palamarchuk, V. Sarana, Ya. Heipel, B. Borodych</b><br>Technical and Economic Substantiation of the Process of Semi-fluidisation Treatment of Fruit<br>and Berry Products .....     | 35 |
| <b>Oksana Pylypchuk, Liudmyla Tyshchenko, Valentyna Israelian, Nataliia Mushtruk</b><br>Influence of Parameters of Marinating Meat Semi-Finished Products<br>on the Quality of the Finished Product ..... | 44 |
| <b>M. Riabovol</b><br>Mathematical Modelling of the Process of Vibration Mixing of Minced Sausage .....   | 53 |
| <b>O. Samoilichenko, O. Priadko, V. Mokiichuk, Yu. Slyva</b><br>Methodological Aspects of Assessing the Competence of Laboratory Personnel<br>Determining the Quality of Seed Potatoes .....              | 63 |
| <b>O. Snizhko, I. Momot</b><br>The Use of Inulin-Containing Raw Materials in the Technology of Sausage Production.....  | 71 |



UDC 536:664

DOI: 10.31548/animal.13(2).2022.7-15

## Measures and Means to Improve the Energy Efficiency of Food Production

Zinaida Burova<sup>1\*</sup>, Leonid Vorobiov<sup>2</sup>, Serhii Ivanov<sup>2</sup>, Oleh Dekusha<sup>3</sup>

<sup>1</sup>National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<sup>2</sup>Institute of Engineering Thermophysics of NAS of Ukraine  
03057, 2a Maria Kapnist Str., Kyiv, Ukraine

<sup>3</sup>Institute of General Energy of NAS of Ukraine  
03150, 172 Antonovych Str., Kyiv, Ukraine

**Abstract.** Improving the energy efficiency of modern enterprises, including the food industry as one of the priorities for the life support of the population, is of strategic importance for Ukraine. The purpose of the study is an analysis of the energy-saving potential of food industry enterprises and the search for ways to reduce the energy intensity of technological processes, devices, and equipment, as well as transmission heat losses of buildings and structures. For field tests of industrial and technological objects, a combined thermal imaging and thermometric research methodology was chosen, which combines thermal imaging of characteristic thermal zones to detect anomalous areas and contact measurements of thermophysical parameters in these zones. A computerised information and measuring system equipped with a set of primary sensors of temperature, heat flux, humidity, etc. was used for long-term monitoring of thermophysical parameters simultaneously at different sites of the facilities. As a result, an array of data was obtained and processed, the parameters of complex convective and radiation heat transfer were calculated, and the heat transfer resistance was determined, which allows assessing the degree of danger of the detected thermal anomalies and developing measures for thermal modernisation of facilities using modern thermal insulation materials. Reduction of heat loss in production processes is also achieved by organising high-quality thermal insulation of technological apparatuses, pipelines and refrigeration equipment. The main parameter for selecting the required material is its low thermal conductivity in the operating temperature range of the equipment. For the effective heat insulator selection, the thermal conductivity of a number of popular materials of world-famous manufacturers was studied based on the certified information-measuring system of Ukrainian design by the stationary plate method with the use of heat flux and temperature sensors. The thermophysical parameters of heat-insulating materials in the range of 0.02...0.045 W/(m·K) were estimated and thereby revealed the thermal conductivity of materials with a closed microporous structure to be half that of fibrous ones and not dependent on the density of the material, which makes them the best option for high-quality insulation of buildings and equipment of food production

**Keywords:** energy saving, energy audit, thermal insulation, monitoring, heat transfer resistance, thermal resistance, thermal conductivity

### Introduction

The energy supply of the economy and efficient use of fuel and energy resources of Ukraine is one of the main national priorities in terms of its economic significance.

The economic condition of each enterprise is determined by its ability to effectively reduce energy consumption. Ukraine's industry, including food and processing, has a

#### **Suggested Citation:**

Burova, Z., Vorobiov, L., Ivanov, S., & Dekusha, O. (2022). Measures and means to improve the energy efficiency of food production. *Animal Science and Food Technology*, 13(2), 7-15.

\*Corresponding author

huge potential for energy and resource saving with the introduction of the latest technologies and equipment, the use of secondary energy sources, as well as the modernisation of obsolete energy equipment, buildings, and structures for industrial purposes.

Leading scientists and economists dedicated their works to the study of energy saving issues in Ukraine, the formation of mechanisms for the implementation of energy saving measures of industrial enterprises, development of an energy efficiency strategy that accounts for the conditions and features of the functioning of energy supply systems of industrial enterprises and will allow solving key challenges of efficient use of energy resources in the long term.

Experts distinguish the following main types of energy-saving measures: organisational, technological and investment [1-3]. The latter include highly effective measures for the transition to alternative energy sources and the use of modern energy-saving production technologies [2], but require higher capital investments, while others are less costly and no less effective.

Organisational measures include internal energy audit and compiling the "Energy passport of the enterprise" developed by the State Committee of Ukraine on Energy Saving according to the Law of Ukraine "On Energy Saving" [4; 5]. The introduction of energy certification offers an opportunity to create an information database on the state of use and reserves of fuel and energy resources and creates conditions for the development of energy-saving measures for the future [3; 6; 7]. Every enterprise, including industrial or agricultural, and its boiler rooms must undergo this procedure once every 5 years.

Ukrainian [1; 3; 6] and foreign experts [8] agree that the basic energy-saving measures are technological. First of all, it is the optimisation of technological processes, replacement or modernisation of outdated industrial equipment, as well as the introduction of energy efficiency standards in the use of industrial buildings and structures. The norms of modern industrial construction already include European requirements for energy saving and energy efficiency, and old enterprises need the so-called "thermal modernisation". Usually, it is a set of measures aimed at increasing the resistance to heat transfer of building envelopes and structures using modern heat-insulating materials, resulting in energy savings and reduction of heat loss [6; 7].

Thermal insulation of production equipment, technological heat and mass exchange apparatuses, vessels and pipelines is also an important part of the complex of energy-saving measures in the food and processing industry [7-9]. Thermal insulation of pipelines, vessels and apparatuses is a mandatory procedure after their strength and density tests. Heat losses from poorly performed insulation works lead to an increase in thermal loads on equipment, violation of thermal conditions of technological processes, and deterioration of product quality. Materials must provide high-quality protection of production equipment and pipelines during temperature and humidity fluctuations, which is especially important in the processes of cooling and cold storage of food products.

Refrigeration technologies are a significant segment of energy consumption in the food industry, because without which any processing of livestock products, food production and its proper storage is impossible [9].

The main aspects of cold insulation measures are:

- insulation of trucks with isothermal vans for perishable products equipped with refrigeration units;
- insulation of refrigerated railway wagons;
- insulation of domestic and industrial refrigerators;
- insulation of pipelines and containers with refrigerants;
- insulation of mobile and stationary freezers for food, special chemicals and other materials.

Cold insulation, like thermal insulation, also contains an energy-saving potential aimed at reducing or preventing the transfer of heat from the environment to an object that is artificially cooled to maintain a negative temperature and vice versa, which can be ensured by the use of efficient low-heat-conducting heat insulators.

*The purpose of the study* is to determine the transmission heat losses of industrial facilities and equipment of food production and to justify the choice of the most effective heat-insulating materials for their maximum reduction.

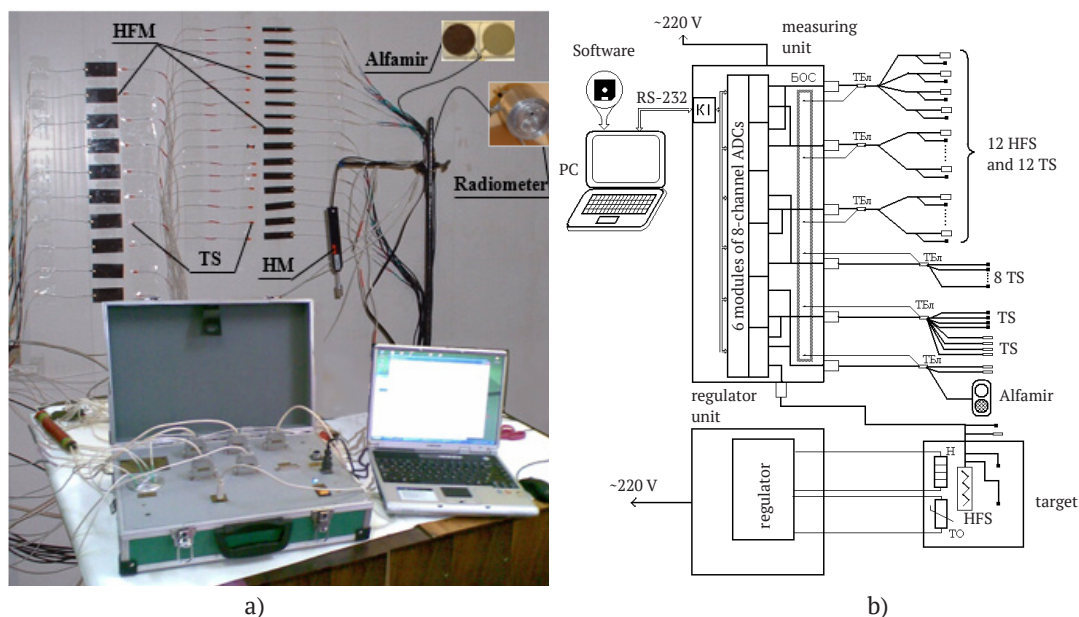
## Materials and Methods

*1. Determination of heat transfer resistance of multilayer enclosing structures of industrial buildings and structures, power equipment, energy-intensive equipment and technological apparatuses.*

The traditional method for determining transmission heat losses is a calculation method based on the average annual temperature of the object and the environment and empirical coefficients. Such a method is approximate and gives a generalised notion of the actual state of the object. Real results can be obtained only by long-term monitoring of the thermal state of the object in in-situ conditions, followed by processing the obtained data array.

The most modern method of such studies is the combined thermal imaging and thermometric method [6; 7], recommended by regulatory documents [4; 10]. At the first stage, thermal imaging of the elements of enclosing structures (ES) of buildings, structures or equipment is carried out, based on the results of which the images of temperature fields are analysed to determine the zones of thermal anomalies. The next step is to study the thermal protection properties of the ES using a wide range of devices to determine a number of characteristic parameters: the temperature of the ES surfaces and the environment, the density of heat flux through the ES and from energy sources, air humidity and materials, air velocity, heat exchange coefficients. At the same time, the use of a number of separate devices can lead to a multiplication of the total measurement error and is technically and economically unprofitable.

ES of objects usually consist of various structural elements with different thermal resistance, so for surveys and qualitative assessment of heat loss, it is necessary to conduct long-term monitoring of the thermal state of the structure or apparatus, while simultaneously measuring and recording the values of temperature and heat flux density in several dozen characteristic and abnormal areas. Therefore, to conduct synchronous and long-term studies, it is advisable to use an information-measuring system, which is presented in Figure 1, the computerised system "RESOURCE" [7], developed for the complex instrumentation support of the research of objects' ES according to the methods of standards [4; 10].



**Figure 1.** Appearance (a) and functional diagram (b) of the information-measuring system “RESOURCE”: HFS – heat flux sensors (transducers); TS – temperature sensors (transducers), HM – humidity meter (sensor), PC – personal computer

“RESOURCE” is a multichannel measuring system that allows determining the density of the heat flux, the temperature of the surface and the air near it at many different sites of the object under study, humidity, thermal conductivity, heat transfer coefficient and components of the heat flux in complex heat exchange and calculating the value of transmission heat losses on the surface of the object in production and laboratory conditions.

The system is fully equipped (Fig. 1) with:

- specialised heat flux sensors HFS and temperature TS in quantities determined by the relevant regulatory documents [4; 10] for heat engineering tests of construction objects;
- radiometer – absolute cavity receiver of hemispherical thermal radiation for non-contact measurement of thermal radiation flux density;
- “Alfamir” devise for the determination of convective and radiative heat transfer coefficients and flow components in complex heat transfer, which is a flat structure of two HFSs on a common isothermal substrate, with thermocouples for measuring the temperature of the substrate and adjacent air. Free surfaces of both HFSs have contrasting degrees of blackness, the range of values of which is from 0.85 to 0.90 for black and from 0.02 to 0.25 for white HFS;

- the primary air humidity sensor HM.

Specialised measuring devices, such as Fluke, are used for thermal imaging and non-contact temperature measurements [11]. To simultaneously measure the thermal conductivity of the material of the structure, a portable probe express thermal conductivity meter can be connected to the system [7].

Main technical characteristics of the resource system:

- range of measured values of surface heat flux density from 10 to 500 W/m<sup>2</sup>;
- basic permissible relative error of measuring the surface heat flux density  $\pm 4\%$ ;
- measured temperature range from minus 40 °C to +50 °C;
- the main permissible absolute error of temperature measurement is  $\pm 1$  K.

When surveying natural objects, their individual characteristic zones can be located at a considerable distance – up to several tens of meters, which necessitates the use of a distributed measuring system with several modules. To monitor the thermal condition of such objects, a modified measuring system “RESOURCE-RC” with a radio communication channel between the modules (Fig. 2) and the central control unit was developed.



**Figure 2.** Multichannel measuring module “RESOURCE-RC”

Each measuring module can be connected to eight primary sensors of different types, and it is powered by a built-in 12 V battery. Low-power transceivers with a capacity of up to 10 mW, which do not require special permission, are used to transmit data over the radio channel. Each module, working separately, collects measurement data from its sensor group and discretely transmits it to the central control unit, where it is processed in the software environment.

Primary heat flux sensors are bimetallic converters of the auxiliary wall type according to DSTU 3756-98 [12]. The visual appearance of the specialised HFSs is presented in Figure 3 in several modifications that account for the specific features of the surveyed objects and can be mounted on different types of structures. Primary temperature sensors are represented by a set of standard thermoelectric transducers the THC(L) type [13] and resistance thermometers Pt-100 [14].



**Figure 3.** Measuring sensors of various modifications (a) and their installation during field tests on the inner surface – heat flux sensors (b); on the outer surface – temperature sensors (c)

Data on the thermal regime of the inspected building structure or equipment is converted by primary sensors into analogue electrical signals and submitted to the input of the electronic unit, where they are sequentially registered. The electronic unit is designed as a portable case, and has slots for connecting primary converters and a computer communication interface. The unit also contains a built-in device for stabilising the reference junctions of differential thermocouples, the temperature of which is taken into account in calculations. Depending on the system modification, the number of DC voltage measurement channels in the measuring unit varies from 32 to 96. The measurement results are transmitted to the data acquisition and processing system and converted into heat flux density and temperature in the appropriate units ( $W/m^2$  and  $^{\circ}C/C$ ). The duration of continuous recording of research results can vary up to 3-5 days depending on the number of measuring channels and the amount of RAM of the system.

The computing programme of the RESOURCE system allows creating individual configuration files for each monitored object and defining the order of channel polling, time intervals and frequency of polling, exchange rate and computer port number. During operation, signals are measured according to a given programme, and their primary processing and visualisation are performed both tabularly in numerical form and in the form of functional graphs. At the same time, the data is stored in an MS Excel file, which makes it possible to further process it if necessary.

## 2. Study of thermal resistance and coefficient of effective thermal conductivity of thermal insulation materials.

Materials based on foamed rubber, foamed polyethylene, and mineral wool are recommended for the insulation of food-grade industrial equipment. Less often, shells made of polyurethane foam and expanded polystyrene are used [15]. The selection of material depends on the operating conditions of the facility, safety requirements, manufacturability, and cost-effectiveness of installation work, but the main requirement is low thermal conductivity of the material in the range of operating temperature of the equipment.

Mineral wool and expanded polystyrene are traditionally considered the cheapest and easiest to install. However, in practice, they are effective only for insulation of equipment operating at temperatures above  $0^{\circ}C$ , because in aggressive conditions of fluctuations in temperature and humidity and condensation at negative temperatures, mineral wool insulators lose their properties. foam polystyrene can be inhabited by rodents, which is not consistent with the high hygienic requirements for the storage and transportation of food products.

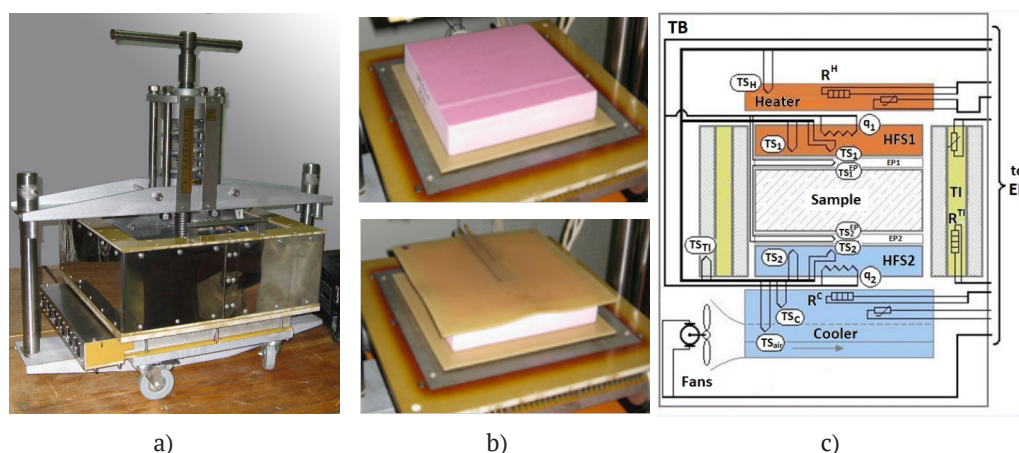
Therefore, the insulation material must be non-porous or contain only closed pores, be eco-friendly, resistant to corrosion, fungal formation, and rodent damage. All these qualities are characteristic of polyurethane foam (PU foam), which is obtained from polyurethanes by foaming by the reaction of two liquid components – isocyanate and polyol in the presence of catalysts, emulsifiers, and other

impurities, resulting in the formation of microcapsules filled with filler gas. PU foam is applied using a low-pressure device in several layers to achieve the desired thickness for thermal calculations of the object, the foam hardens, forming a dense, uniform and sealed thermal insulation layer that does not require an additional vapour barrier. Sandwich panels based on PU foam are commonly used for the construction of industrial facilities, in particular, warehouses-refrigerators for long-term storage of food products, mobile and stationary freezers, etc.

The Ukrainian market of heat insulators is constantly expanding through both import and domestic manufacturers offering a wide range of products. The main indicators of the effectiveness of thermal insulation materials are their thermophysical characteristics: thermal resistance, which depends on the thickness of the material, and the coefficient

of effective thermal conductivity, which has a clearly defined temperature dependence. Measurement of thermal conductivity of thermal insulation materials in Ukraine is regulated by a number of state and international standards [16–18].

Since most thermal insulation materials are non-homogeneous (including fibres, cavities, etc.), according to the current standards, the dimensions of the test samples of materials should be at least 250×250 mm in plan, while the measurement error should not exceed  $\pm 3\%$ . To conduct the research, we used a specialized information-measuring system (Fig. 4) developed in Ukraine, which implements a symmetrical scheme of the thermometric method using two identical primary heat flux sensors [19; 20] and embodies a modern standardised approach to ensuring the necessary requirements for the accuracy and reproducibility of measurement of thermophysical parameters and quantities [21].



**Figure 4.** Information and measuring system: a) external appearance of the heating unit; b) placement of samples in the measuring cell; c) functional blueprint

The main element of the information and measurement system is a thermal unit (Fig. 4, a), in which a sample of the test material is placed (Fig. 4, b) with the necessary temperature and thermal conditions provided (Fig. 4, c). The system is also equipped with a device for temperature control of the thermocouple reference junctions. All primary measurement information is accumulated and processed in an electronic unit containing means for regulating thermal conditions, receiving, and processing data and transferring them to a computer for further processing in a specialised software environment. Measurement of thermophysical characteristics of samples of construction and thermal insulation materials can be carried out on samples up to 120 mm thick with maximum performance and standardised accuracy in accordance with the requirements of national and international standards. Main technical characteristics of the system:

- range of values of the thermal conductivity coefficient 0.02...3.0 W/(m·K);
- limits of permissible basic relative measurement error  $\pm 3\%$ ;
- operating temperature range of  $-40\text{ }^{\circ}\text{C} \dots 180\text{ }^{\circ}\text{C}$ ;
- the sample size is  $300 \times 300 \times (10 \dots 120)$  mm.

When preparing samples for the study, they are given a shape suitable for placement in the measuring cell: hard samples are ground to give the working surfaces a plane-parallel shape, and for soft and fibrous ones, additional equipment

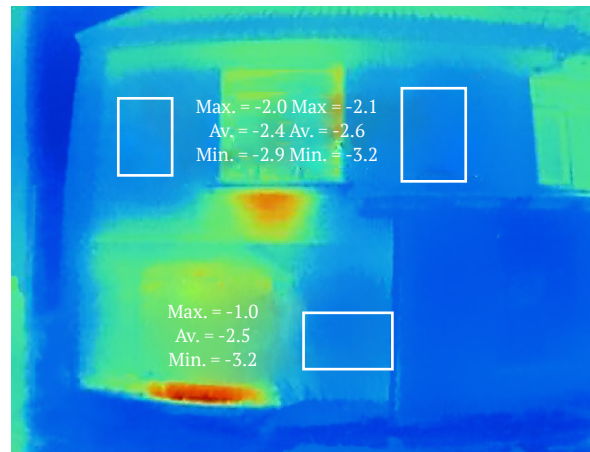
is made – spacers or a limiting frame. Before placing the samples in the measuring cell of the thermal unit, they are measured and weighed to calculate their density.

According to the standardised procedure [16], measurements are carried out on at least three samples of the same material in a dry state at average temperatures of  $10\text{ }^{\circ}\text{C}$  and  $25\text{ }^{\circ}\text{C}$ , or in the entire operating temperature range, depending on the purpose of the experiment. Calculations of the coefficient of thermal conductivity are carried out according to standard dependences based on the average results of measurements of temperature, heat flux density and sample thickness [16; 17; 19]. The final result is calculated as the arithmetic mean for the tested samples, considering the measuring error of  $\pm 3\%$ .

## Results and Discussion

### 1. Determination of heat transfer resistance of multilayer enclosing structures of buildings, structures, power, and technological equipment

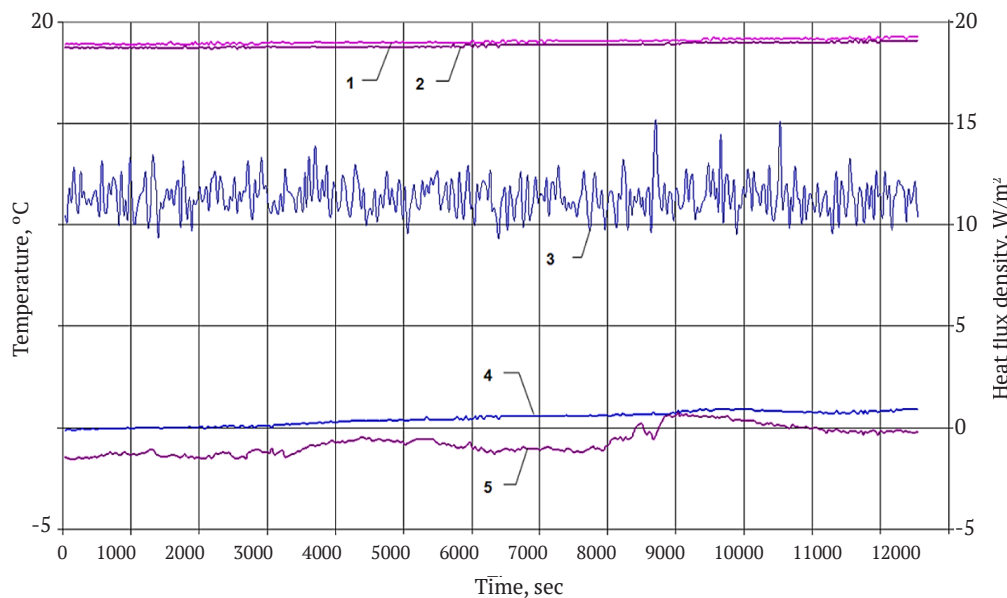
The combined thermal imaging and thermometric method was successfully tested in the study of building structures [22] and was included in the regulatory document [10]. Figure 5 demonstrates the results of a thermal imaging survey of the facade of the two-storey building by Fluke [11], conducted as part of a preliminary examination of its thermal condition.



**Figure 5.** Thermogram of the facade of a two-storey administrative building

The study was conducted during the heating season, and the results of the thermogram analysis accurately identify areas with increased heat loss. The measuring sensors of temperature and heat flux (Fig. 3) of the “RESOURCE”

system were installed on such zones outside and inside the building and the thermophysical parameters of the characteristic part of the object were monitored for a certain period of time. The measurement results are shown in Figure 6.



**Figure 6.** Record of thermophysical parameters for a characteristic area of an object (wall):  
1 – internal air temperature; 2 – internal surface temperature of the object;  
3 – density of heat flux through the research object; 4 – temperature of the external surface of the object; 5 – outdoor air temperature

The result of the observations is an array of data on the change of thermophysical parameters in real time, which can be further processed according to the relevant standardised methods [4; 7; 10], determining the necessary parameters, analysing, and providing an expert opinion. During quantitative analysis, the actual values of the main heat engineering characteristics of the ES are determined and compared with the values of transmission heat losses obtained by the calculation method. This makes it possible to assess the degree of danger of detected thermal anomalies for the normal functioning of the surveyed objects. Significant defects, assessed by the level of thermal resistance, are considered to be those that lead to a local decrease in thermal resistance by more than 15%.

The combined thermal imaging-thermometric technique can be effectively used in the inspection and determination of heat transfer resistance not only of multilayer enclosing structures of buildings and structures but also of power units and industrial apparatus of food enterprises. The use of the information-measuring system “RESOURCE” for such studies has the following advantages:

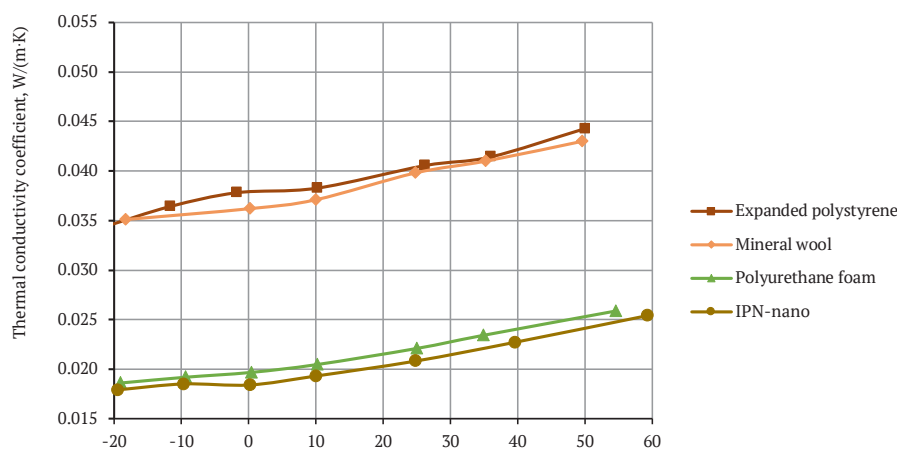
- the ability to conduct continuous synchronous observations of the thermal state of objects at several characteristic points for a long time (up to 3-5 days) without stopping the technological process;
- high metrological level of measurements in real conditions, automation of processing and documentation of results;

– ability to conduct an energy audit and take energy-saving measures, in particular, carry out thermal modernisation of industrial buildings or perform thermal insulation of technological equipment, choosing the optimal material.

2. The results of thermal conductivity studies of modern thermal insulation materials are presented in Table 1 at temperatures of 10 °C and 25 °C and graphically in the operating temperature ranges – in Figure 7.

**Table 1.** Coefficients of effective thermal conductivity of heat insulators

| No | Material name                      | Material density, kg/m <sup>3</sup> | Thermal conductivity coefficient, W/(m·K) |
|----|------------------------------------|-------------------------------------|---|
| 1  | IPN-nano KINGSPAN [23]             | 32 ... 35                           | 0.019...0.021                             |
| 2  | Polyurethane foam “ELASTOPOR” [24] | 40 ... 45                           | 0.020...0.022                             |
| 3  | ISOVER mineral wool [25]           | 10 ... 13                           | 0.037...0.040                             |
| 4  | Expanded polystyrene               | 35 ... 38                           | 0.038...0.042                             |



**Figure 7.** Temperature dependences of thermal conductivity coefficients of modern heat insulators

The values given in Table 1 correspond well with the results of certification tests of established materials [24; 25], while for the newest material IPN-nano [23] the experimental results were obtained for the first time. This material demonstrates high thermal insulation qualities, now it is used mainly as a filler for sandwich panels for the construction of industrial refrigerators-warehouses and modern refrigeration and logistics complexes.

According to Fig. 6, it is possible to select the material that will best meet the requirements for the operation of technological equipment or pipelines in a wide temperature range. The results of the research confirm the high thermal insulation properties of polyurethane foam, which, along with operational and hygienic properties, makes it one of the leading effective heat and cold insulation of refrigerators and freezers, especially for complex-shaped structures.

### Conclusions

Solving the issue of energy saving in the food industry requires a comprehensive approach to identifying and eliminating sources of heat loss. The procedure includes inspection and evaluation of thermal parameters of structures of buildings and equipment, and, if necessary, carrying out measures for thermal modernisation of industrial buildings and structures, industrial and power equipment using high-quality thermal insulation.

A modern approach to research of the thermal state of objects is provided by a combined thermal imaging and

thermometric technique, and modernisation of testing of enclosing structures of buildings and apparatuses in characteristic zones is provided by the use of a multi-channel information and measurement system equipped with various sensors and devices. Such a system allows long-term monitoring simultaneously at many points of the object in automatic mode, which significantly increases the accuracy of research and eliminates the subjective influence of the operator, conducting energy audits and certification of industrial buildings and structures in accordance with the requirements of regulatory documents and develop the necessary energy saving measures, choosing the most optimal material for this.

The main characteristic that confirms the quality of the insulation material is the coefficient of effective thermal conductivity. The study of the thermal conductivity of modern materials on a certified information-measuring system in a wide range of temperatures confirms the high thermal protection properties of polyurethane foam 0.020...0.022 W/(m·K) and IPN-nano 0.019...0.021 W/(m·K). These materials not only provide protection in conditions of temperature and humidity fluctuations, but also meet the requirements of industrial sanitation, which makes it possible to use them for heat or cold insulation of technological devices, pipelines, and equipment of food production. More traditional materials – mineral wool and polystyrene – have almost twice worse thermal conductivity but are more cost-effective in the thermal modernisation of industrial buildings and structures for various purposes.

## References

- [1] Kasianova, N. (2017). Implementation of energy savings strategy for industrial enterprises. *Efficient Economy*, 2. Retrieved from <http://www.economy.nayka.com.ua/?op=1&z=5916>.
- [2] Dzhedzhula, V.V. (2014). *Energy saving of industrial enterprises: Methodology of formation, management mechanism*. Vinnytsia: VNTU.
- [3] Bevz, V.V. (2011). Development of the energy saving mechanism at food industry enterprises. *Scientific Notes: A Collection of Scientific Papers*, 13, 169-173.
- [4] Law of Ukraine No. 89 “On the Approval and Implementation of the Procedure for Issuing, Designing, and Registering the “Energy Passport of the Enterprise” and Paying for Services Upon Its Implementation”. (1998, November). Retrieved from <https://zakon.rada.gov.ua/laws/show/z0804-98#Text>.
- [5] DBN B.2.6-31:2016 “Thermal insulation of buildings”. (2017). Kyiv: Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine.
- [6] Farenjuk, G.G. (2009). *Fundamentals of energy efficiency of buildings and thermal reliability of enclosing structures*. Kyiv: Gamma-Print.
- [7] Grishchenko, T.G. (Ed.). (2018). *Heatmetric: Theory, metrology, practice. Thermometric equipment for solving applied problems*. Kyiv: Institute of Technical Thermophysics of the NAS of Ukraine.
- [8] Clairand, J., Briceño-León, M., Escrivá-Escrivá, G., & Pantaleo, A.M. (2020). Review of energy efficiency technologies in the food industry: Trends, barriers, and opportunities. *IEEE Access*, 8, 48015-48029. doi: 10.1109/ACCESS.2020.2979077.
- [9] Palamarchuk, I.P. (Ed.). (2018). *Refrigeration processes in food technology*. Kyiv: Comprint.
- [10] DSTU B V.2.6-101:2010 “Constructions of Houses and Buildings. Method for Determining the Heat Transfer Resistance of Enclosing Structures”. (2010). Kyiv: State Standards of Ukraine.
- [11] Website of the Fluke test and measurement tools. (n.d.). Retrieved from <https://www.fluke.com/>.
- [12] DSTU 3756-98 “Energy Saving. Heat Flux Sensors Thermoelectric for General Purpose. General Specifications”. (2000). Kyiv: State Standards of Ukraine.
- [13] DSTU EN 60584-1:2016 “Thermocouples. Part 1. Technical Characteristics and Permissible Deviations of Electromotive Force (EMF) (EN 60584-1: 2013, IDT)”. (2016). Kyiv: State Standards of Ukraine.
- [14] DSTU 2858:2015 “Thermo-Converters of Resistance. General Technical Requirements and Test Methods”. (2017). Kyiv: State Standards of Ukraine.
- [15] Jelle, B.P. (2011). Traditional, state-of-the-art and future thermal building insulation materials and solutions. Properties, requirements and possibilities. *Energy and Buildings*, 43(10), 2549-2563.
- [16] DSTU ISO 8301:2007 “Thermal Insulation. Determination of Steady-State Thermal Resistance and Related Properties. Heat Flow Meter Apparatus (ISO 8301:1991, IDT)”. (2009). Kyiv: State Standards of Ukraine.
- [17] EN 12667:2001 “Thermal Performance of Building Materials and Products. Determination of Thermal Resistance by Means of Guarded hot Plate and Heat Flow Meter Methods. Products of High and Medium Thermal Resistance”. Kyiv: State Standards of Ukraine.
- [18] ASTM C518-10 “Standard test method for steady-state thermal transmission properties by means of the heat flow meter apparatus”. (2015). Retrieved from <https://www.astm.org/c0518-10.html>.
- [19] Babak, V., Dekusha, O., & Burova, Z. (2021). Hardware-software system for measuring thermophysical characteristics of the materials and products. *CEUR Workshop Proceedings*, 3039, 255-266.
- [20] Zaporozhets, A., Burova, Z., Dekusha, O., Kovtun, S., Dekusha, L., Vorobiov, L., Ivanov, S., & Zaporozhets, A. (Eds.). (2022). Information measurement system for thermal conductivity studying. In *Advanced energy technologies and systems I*. (pp. 1-19). Cham: Springer. doi: 10.1007/978-3-030-85746-2\_1.
- [21] Dekusha, O., Burova, Z., Kovtun, S., Dekusha, H., & Ivanov, S. (2020). Information-measuring technologies in the metrological support of thermal conductivity determination by heat flow meter apparatus. In *Systems, decision and control in energy I*. (pp. 217-230). Cham: Springer. doi: 10.1007/978-3-030-48583-2\_14.
- [22] Babak, V., Dekusha, O., Dekusha, L., Vorobiov L., & Ivanov, S. (2018). System for monitoring thermal resistance of building constructions. *International Journal “NDT Days”*, 1(2), 178-185.
- [23] Systems and solutions guide low-carbon, high-performance building envelopes. (n.d.). Retrieved from <https://www.kingspan.com/meati/en-in/product-groups/insulated-panel-systems/resources/meatca-building-envelope-product-portfolio>.
- [24] Elastopor®(PU): Intelligent sandwich technology for efficient insulation, cooling, storage and transportation. (n.d.). Retrieved from [https://plastics-rubber.basf.com/global/en/performance\\_polymers/industries/pp\\_electronics\\_and\\_electric/products/elastopor.html](https://plastics-rubber.basf.com/global/en/performance_polymers/industries/pp_electronics_and_electric/products/elastopor.html).
- [25] Website of the ISOVER Saint Gobain. (n.d.). Retrieved from <https://www.isover.ua/products/list>.

## Заходи і засоби підвищення енергоефективності харчових виробництв

Зінаїда Андріївна Бурова<sup>1</sup>, Леонід Йосипович Воробйов<sup>2</sup>,  
Сергій Олександрович Іванов<sup>2</sup>, Олег Леонідович Декуша<sup>3</sup>

<sup>1</sup>Національний університет біоресурсів та природокористування України  
03041, вул. Героїв Оборони, 15, м. Київ, Україна

<sup>2</sup>Інститут технічної теплофізики НАН України  
03057, вул. Марії Капніст, 2а, м. Київ, Україна

<sup>3</sup>Інститут загальної енергетики НАН України  
03150, вул. Антоновича, 172, м. Київ, Україна

**Анотація.** Підвищення енергоефективності сучасних підприємств, в тому числі харчової галузі як однієї з пріоритетних для життєзабезпечення населення, має стратегічно важливе значення для України. Метою дослідження є аналіз потенціалу енергозбереження підприємств харчової промисловості та пошук способів зниження енергоємності технологічних процесів, апаратів та обладнання, а також трансмісійних тепловтрат будівель і споруд. Для натурних випробувань промислових та технологічних об'єктів обрано комбіновану тепловізійно-теплометричну методику досліджень, що поєднує тепловізійну зйомку характерних теплових зон для виявлення аномальних ділянок та контактні вимірювання теплофізичних показників в цих зонах. Для проведення тривалого моніторингу теплофізичних параметрів одночасно на різних ділянках об'єктів використано комп'ютеризовану інформаційно-вимірювальну систему, оснащену комплектом первинних сенсорів температури, теплового потоку, вологості та ін. В результаті отримано і опрацьовано масив даних, розраховано параметри складного конвективного та радіаційного теплообміну, визначено опір теплопередачі, що дозволяє адекватно оцінити ступінь небезпеки виявлених теплових аномалій та розробити заходи з термомодернізації об'єктів із застосуванням сучасних теплоізоляційних матеріалів. Зменшення тепловтрат у виробничих процесах також досягають шляхом організації якісної теплової ізоляції технологічних апаратів, трубопроводів, холодильного обладнання. Головним параметром для вибору необхідного матеріалу є його низька теплопровідність в діапазоні робочої температури обладнання. Для коректного вибору ефективних теплоізоляторів проведено дослідження теплопровідності низки популярних матеріалів відомих світових виробників на сертифікованій інформаційно-вимірювальній системі української розробки стаціонарним методом пластини з застосуванням сенсорів теплового потоку та температури. Оцінено теплофізичні показники теплоізоляційних матеріалів в діапазоні 0,02...0,045 Вт/(м·К) та показано, що теплопровідність матеріалів із закритою мікропористою структурою вдвічі менша за волокнисті і не залежить від густини матеріалу, що робить їх найкращим варіантом для спорядження високоякісної ізоляції будівель та обладнання харчових виробництв

**Ключові слова:** енергозбереження, енергоаудит, теплоізоляція, моніторинг, опір теплопередачі, тепловий опір, теплопровідність



UDC 006.022:638.178

DOI: 10.31548/animal.13(2).2022.16-25

## Review of National Regulatory Requirements for Propolis Quality for Compliance with International Standards

Roman Dvykaliuk<sup>1\*</sup>, Leonora Adamchuk<sup>1,2</sup>, Artem Antoniv<sup>1</sup>, Sedat Sevin<sup>3</sup>

<sup>1</sup>National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<sup>2</sup>National Science Center “P.I. Prokopovich Institute of Beekeeping”  
03680, 19 Zabolotnyi Str., Kyiv, Ukraine

<sup>3</sup>Ankara University  
06100, 6A Döğol Caddesi Str., Ankara, Turkey

**Abstract.** Given the growing demand among consumers of the international market for propolis, it is important to review the compliance of national documentation with international, particularly the leading countries in the production and processing of this product. Integration and adaptation of national legislation to the norms of the world community legislation also requires revision of approaches to the quality and safety of propolis. Therefore, the purpose of the study was to analyse the current international and national regulatory legal acts of the leading countries of the world, which play a key role in the international market for the production and sale of propolis in terms of safety and quality of propolis. Authors used the Torracco method to analyse and synthesise scientific and regulatory data; the Springer scientific and metric database and the Google Scholar search. The materials included regulatory documents of Ukraine, EU, Brazil, Argentina, Poland, Mexico, East African region. It was established that the criteria for assessing the quality of propolis in international regulatory and technical documentation are organoleptic (appearance, consistency, colour, smell, taste), physicochemical (dry matter, total ash content, wax, resin) microbiological (yeast, moulds, *Escherichia coli*, *Staphylococcus*, *Candida albicans*, *Paenibacillus*, *Salmonella*) indicators of biological activity (flavonoids, oxidation, phenols, antioxidant activity, ethanol-soluble resins) and contamination (heavy metals, pesticide and antibiotic residues, radionuclides). The study revealed the non-compliance of the current regulatory document in Ukraine with the requirements of international regulations, namely in terms of: phenol content, ethanol and water-soluble resins, dry matter; total ash content; antioxidant activity; colony-forming units. It was determined that in Ukraine propolis is not divided into categories depending on wax impurities; the ambient temperature is not accounted for when determining the consistency index; botanical origin and methods of its selection are also not considered when assessing organoleptic properties. The approach for regulating the propolis market in Ukraine is substantiated as such that will contribute to the formation of added value for raw propolis when grouped by purpose and method of production and processing. The materials of the article are of practical value for the formation of new and harmonization of existing normative and technical regulations on the quality of propolis and can be applied by the working party on beekeeping development under the Ministry of Agrarian Policy of Ukraine

**Keywords:** statutory regulation, bee products, propolis specification, propolis identification, types of propolis

### Suggested Citation:

Dvykaliuk, R., Adamchuk, L., Antoniv, A., & Sevin, S. (2022). Review of national regulatory requirements for propolis quality for compliance with international standards. *Animal Science and Food Technology*, 13(2), 16-25.

\*Corresponding author

## Introduction

Ukraine is not among the leaders in the world market of propolis production. At the same time, the demand for propolis in the world is growing, as evidenced by the results of market research and forecasts based on them. The overall propolis market is expected to grow at an average rate of approximately 6.23% from 2022 to 2030 in monetary terms [1]. Over the past 14 years, the regulatory legal acts regulating the quality and safety of propolis have not been updated. Instead, the international standardisation organisation, which includes 167 member countries, focuses its attention on propolis. Thus, the standard ISO/CD 24381 Bee propolis – Specifications [2] is under development. This standard will contribute to achieving sustainable development goals such as good health, reducing inequality, and responsible consumption.

Raw propolis is used in food [3], pharmaceutical [4] and other industries [5; 6]. The use of propolis in the food industry necessitates its standardisation, which guarantees safety, quality and excludes the use of counterfeit raw materials [7]. Propolis has a very complex and variable set of compounds. Only in propolis collected by honeybees in different geographical regions with *Populus* spp. a total of 344 substances were identified [8; 9]. A total of 8 species of *Populus* spp. serve as sources of propolis in different geographical regions. In the world, 16 plant sources, except *Populus* spp. are known and proven as sources of propolis [10]. Propolis usually contains 40 to 70% balms (flavonoids and phenolic acids), 1-3% essential oils, 20-35% waxes, and 5% other substances [11].

The composition of propolis may include pollen grains from plants that were the sources of propolis and others in the flight zone of bees that produce pollen. Palynological analysis of propolis can serve as one of the methods for determining and confirming its geographical origin [10; 12; 13]. Since propolis is of proven botanical origin and contains fragments of the source plant (trichomes, leaves, buds), their comparison can be used as one of the possible tools to prove the authenticity of the product [14]. While the plants that serve as the source of propolis are not subject to treatment with agrochemicals and pesticides, contamination of propolis with plant protection products does occur and affects the quality of propolis. According to the results of a study of various products made from propolis in Spain, Portugal, Belgium, England, the USA, and Chile, seven acaricides, fungicides and herbicides were found, with triadimefon present in 65% of the samples [15]. Samples of propolis obtained from the Czech Republic, Bulgaria, Slovenia, Serbia, Italy, Greece, and Canada were examined for the content of residues of agrochemicals and pesticides. The presence of acetamiprid, imidacloprid and thiacloprid was detected in seven samples out of thirty samples [16].

One of the equally important factors that affect the quality of propolis is the collection methods and proper observance of sanitary and hygienic requirements for keeping bees. Such methods of propolis collection are distinguished [17]: the use of means that are placed inside the hive (nets, grids, cloth) and do not require modification of hives; collectors that are traditionally used in Latin America and provide for the creation of external holes in the walls of the hive; traditional and much more common

way of obtaining propolis through cleaning the elements of the hive. Studies [18] of Argentine propolis for lead content were conducted. Thus, propolis collected using nets contained 2 mg/kg of lead and collected by the traditional method of cleaning the elements of the hive – 8 mg/kg. The authors [19] note that the use of collectors and collection methods “Propolizador Inteligente”, “De Propóleo Pirassununga”, “Cuadros Colectores de Propóleo”, “Marco Colector de Propóleo”, “Método Propolizador Campechano” have a number of disadvantages that affect the quality of propolis. Among the main ones, the authors distinguish: the openness of the collectors and dust ingress into the propolis; propolis accumulated in the collectors is not protected from sunlight and can melt under high temperatures; loss of volatile substances. According to the results of studies [20], propolis stored in an open container at room temperature of 24°C for seven hours lost weight of  $0.9 \pm 0.3\%$ , which is associated with the evaporation of volatile substances. Cleaning the hive elements as a way to obtain propolis, in addition to its mechanical contamination, is accompanied by an increase in the wax content in the product. Besides, the wax can be contaminated with pesticides and agrochemicals, which additionally contaminate the obtained propolis [21; 22].

Preferably, no more than 0.05 mg/kg of pesticide residues are allowed in food [22]. At the same time, for prohibited organochlorine substances, this indicator is no more than 0.01 mg/kg. And for most agricultural organophosphates, carbamates and pyrethroids, the permissible residues are in the range of 0.01-0.05 mg/kg (kumafos, chlorphenvinfos, boscalide) [23].

In the absence of natural plant sources, honeybees can use substitutes (bitumen, household paints, petroleum products, etc.), which significantly compromises the quality of propolis [24; 25]. In countries with arid climates, and also to obtain monofloral types of propolis, it is practised to roam to plant sources [26; 27]. This approach can be applied in Ukraine to improve the quality of propolis by moving apiaries away from technogenically unfavourable zones to collect product of improved quality.

The quality of propolis in Ukraine is regulated by DSTU 4662:2006 Propolis (bee glue). Technical specifications [28]. This standard applies to propolis, a resinous substance with bactericidal properties that bees collect from tree buds, process, and use as a construction and disinfectant material. In Ukraine, propolis is used for industrial processing in the food and cosmetics industries and the manufacture of pharmaceuticals. However, with the improvement of propolis production technologies, the development of new equipment, loading and contamination of the environment as a source of plant resins, there is a need to review the current regulations and requirements for the safety and quality of this product.

*The purpose of the study* was to analyse the current international and national regulatory legal acts of the leading countries of the world, which play a key role in the international market for the production and sale of propolis in terms of safety and quality of propolis. To achieve this goal, the following *tasks* were identified: 1) to establish the concept of “propolis” and its variations in international legislation; 2) to identify the leading countries producing propolis in the context of the analysis of the world market;

3) to analyse international and national regulatory legal acts regulating the safety and quality of propolis; 4) compare international, national (other countries) regulatory documents and regulations with Ukrainian regulatory documents regulating the safety and quality of propolis; 5) to formulate proposals for improving the legal regulation of propolis quality and safety in Ukraine, based on the latest scientific research.

### Materials and Methods

For the theoretical study of the issue, scientific and regulatory and technical information was analysed, which allowed a systematised and generalised approach to the logical processing of the obtained data to obtain a new interpretation of them. Analysis and synthesis of scientific information was performed by the Torracco method [29] using the Springer scientific metric database and the Google Scholar search tool.

The materials for the study were the requirements of Article 1308 of the Argentine Food Code “Propolis and the Inclusion of Technical Specifications”, Annex VII “On Regulation of Identification and Quality of Propolis Extract” of the regulatory instruction No. 11 of 10/20/2000 [30]. Ministry of Agriculture of Brazil [31], standards “Propolis – kit pszczeli PN-R-78891” [32], NOM-003-SAG/GAN-2017 “Propolis, Production and Specifications for its Processing” [33], DEAS 990: 2019 “Bee Propolis – Specification” [34], DSTU 4662: 2006 “Propolis (bee glue). Technical conditions” [28].

### Results and Discussion

According to Regulation (EU) No 1308/2013, propolis is included in the general term “bee products” along with honey, beeswax, royal jelly, and pollen [35].

According to the Commission Regulation [36], honey, beeswax, royal jelly, propolis or nectar not intended for

human consumption belongs to the category of by-products of beekeeping. Commission Regulation (EU) No. 142/2011 defines import and transit requirements for propolis in particular [36]. Propolis must be exposed to -12 °C or lower temperatures for at least 24 hours and not originate from countries that are subject to a ban related to recorded cases of infection with *Paenibacillus larvae*, *Acarapis woodi* (Rennie), *Aethina tumida*, *Tropilaelaps* spp. At the same time, the Commission Implementing Regulation [37] in Section 5 defines that propolis is classified as edible products of animal origin that are used in the production of pharmaceutical products and food additives and are subject to control at import points into the territory of the EU.

There are no official data on the global production of raw propolis. However, the main producers are China and Brazil. Annual production in China increased from 35 tons in 1984 to 300 tons in 2008 [38]. In 2004, production in Brazil was 250 tons and was estimated to be between 10% and 15% of global production. Most of the propolis produced in Brazil is exported to Japan, and this market is constantly growing [39]. Other major producers of raw propolis in the world include the United States, Spain, Romania, Argentina, and Chile. According to this study, total industrial production ranges from 1,800 to 2,400 tons/year [1].

When raw propolis is converted to processed propolis, its recovery rate in the bee nest is approximately 37-47% at the beginning of the season. During the season, the recovery rate ranges from 15% to 25%, as nectar enters the nest and bees add more wax to the propolis. It is known that one scraping from the hive produces from 30% to 40% pure propolis [40]. But not all commercially produced propolis is processed into pure propolis, some is consumed as raw propolis. The main enterprises operating in the global propolis market are shown in Table 1.

**Table 1.** Main enterprises in the global propolis market

| Company name  | Countries   |
|---|-------------|
| Apis Flora  | Brazil      |
| Wax Green   | Brazil      |
| Comvita   | New Zealand |
| Apiario Polenectar                                    | Brazil      |
| King's Gel Propolis                                   | Brazil      |
| MN Propolis   | Brazil      |
| Ponlee Propolis                                       | Brazil      |
| Manuka Health New Zealand                             | New Zealand |
| Zhifengtang   | China       |
| Beijing Baihua Apiculture Technology Development Corp | China       |

Source: [1]

The prevalence of Brazilian companies among the two companies of China and New Zealand deserves consideration. According to Comvita, in 2017 its annual sales turnover amounted to NZD 156 million and its profit to NZD 9.4 million. In the same year, another company, Manuka Health New Zealand had an annual sales turnover of NZD 80 million and a profit of NZD 3.5 million [1].

According to Annex VII “On the Regulation of the

Identification and Quality of Propolis Extract” of the Normative Instruction No. 11 of 10/20/2000 [31] of the Ministry of Agriculture of Brazil, the main purpose is to establish minimum requirements for the quality of propolis extract. Propolis extract is understood as the product of extracting propolis components in neutral alcohol (food grade) according to the technological process. Quality indicators are determined using sensory and physicochemical properties.

They are characterised by aroma, colour, taste, and appearance, as well as the content of dry substances, wax, phenolic and flavonoid compounds, alcohol, methanol, etc. There is a requirement for the absence of additives and polluting, foreign substances. Also, the product must not contain microscopic foreign substances of any nature. Special attention is paid to the presence of larval spores *Paenibacillus*.

East African Standard (Republic of Uganda) DEAS 990: 2019 “Bee Propolis – Specification” defines general requirements, sampling, and test methods for bee propolis [34]. Bee propolis is a bee glue or resinous mixture that bees produce by mixing bee secretions and beeswax with collected exudate from tree buds, sap flows or other botanical sources. Among the sensory indicators, the appearance, colour, taste, smell, consistency, and presence of foreign inclusions are determined. This standard also provides for specific requirements, including humidity, total ash content, wax and resin content. The content of heavy metals, pesticide residues and veterinary drugs is strictly controlled. Microbiological requirements are also established. Test methods are carried out in accordance with international ISO standards [2], and the limits of indicators correspond to the established indicators of the Codex Alimentarius Commission [41]. The standard provides for labelling requirements and sets out mandatory items that must be indicated on the package. In addition to the above, this standard is constantly aimed at implementation with international standardisation organizations, interested states during use and implementation, the World Trade Organisation, and the Codex Alimentarius Commission [41].

The official Mexican standard NOM-003-SAG/GAN-2017 “Propolis, production and specifications for its processing” [33], in addition to the generally accepted sections (such as scope, literature, definitions, sensory, physicochemical, and antimicrobial requirements, test methods, conformity assessment), additionally contains sections on penalties and compliance with international standards and recommendations. The standard provides for physical (colour, smell, taste, consistency), chemical (flavonoids, common phenols, oxidation index) characteristics and antimicrobial activity. Regarding antimicrobial activity, all samples must be analysed for such microorganisms as *Staphylococcus aureus* (ATCC), *Escherichia coli* (ATCC) and *Candida albicans* (ATCC). Confirmation of

compliance with all requirements must be provided by an official, approved or authorised laboratory indicating the number of the reference strain used in the analysis. In addition, the standard in the section of test methods details the methods of research and all procedures.

Article 1308 bis of the Argentine Food Code refers to the product called “Propolis and the inclusion of technical specifications” [30]. This regulation evaluates the characteristics, properties, and safety limits of propolis. The labelling also indicates allergenic characteristics. Sensory characteristics include aroma, colour, taste, consistency, and appearance. Raw propolis must meet physical and chemical requirements, namely, set limits for the content of ash, phenolic compounds, flavonoids, lead, arsenic, pesticide and antibiotic residues, oxidation rate, etc. It is forbidden to use additives and foreign impurities. In addition to the requirements for raw propolis, this article also establishes requirements for soft propolis extract and indicates where the use of propolis as an ingredient will be allowed. Mild propolis extract semi-finished product, which is obtained by processing propolis raw materials with ethyl alcohol, to extract biologically active components, impurities and wax. The alcohol must be evaporated under a controlled temperature, so as not to affect the bioactive compounds, to produce a purified substance with a paste-like consistency. Raw propolis and mild propolis extract are designed to meet the special nutritional and nutritional needs of certain population groups: food to meet the specific dietary needs of certain groups of healthy people; food to meet the nutritional needs of people with a certain physiological condition; fortified foods; biological supplements; food with propolis.

Polish standard “Propolis – kit pszczeli PN-R-78891” applies to the production and trade of propolis. Following the example of other standards, sensory and physicochemical parameters are monitored. Special requirements apply to batch packaging and individual propolis packaging. A characteristic feature is that in this standard, propolis is divided into two classes I and II [32].

The analysis of the above-mentioned international and national regulatory documents regulating the safety and quality of propolis revealed discrepancies between most indicators. Regulatory documents of countries determine the consistency and appearance of propolis differently (Table 2).

**Table 2.** Description of the appearance and consistency of propolis in different countries of the world

| Countries           | Indicators  |  |
|---------------------|---|--|
|                     | Appearance  | Consistency  |
| Argentina           | Homogeneous or heterogeneous, preferably in uncompressed pieces                   | At room temperature: forged or hard, depending on botanical and/or geographical origin                                     |
| Brazil              | Hard, hard or soft substance of uniform colour, depending on the botanical origin | At room temperature: from plastic to solid, depending on the botanical origin  |
| Poland              | - <sup>1</sup>  | Solid at temperatures up to 20 °C, sticky and plastic at temperatures above 20 °C.   |
| Mexico              | Resinous substance, hard, brittle   | At room temperature, it is pliable or hard, depending on its botanical origin  |
| East African region | Characteristic, depending on the origin   | Lipophilic in nature, with decreasing temperature it becomes brittle, hard, as the temperature rises – soft, pasty, sticky |
| Ukraine             | Lumps, crumbs, or briquettes  | Dense, hard, heterogeneous at fracture   |

**Note:** <sup>1</sup>the standard “Propolis – kit pszczeli PN-R-78891” does not regulate the indicator [32]

**Source:** grouped by authors based on sources [28; 30; 31-34; 42]

The normative document of Ukraine [28] does not account for the ambient temperature when determining the consistency of the tested samples. Given the physicochemical characteristics of propolis and their dependence on temperature, it should be noted that failure to take this into account may lead to erroneous assumptions about these parameters.

When assessing the appearance, the origin of propolis (plant sources) and methods of its selection are not included.

In the regulatory documents of the countries, there is a tendency of similarity of the established requirements for colour, odour, and taste, but there are also characteristic differences (Table 3).

**Table 3.** Sensory characteristics of propolis in different countries of the world

| Countries                  | Indicators  |  |   |
|----------------------------|---|--|---|
|                            | Colour  | Smell  | Taste   |
| <b>Argentina</b>           | Yellow, brown, greenish, reddish, brown and their shades, depending on botanical and/or geographical origin and concentration | Resinous or balsamic, depending on its botanical and/or geographical origin        | Varied, from mild to strong, bitter, and spicy                            |
| <b>Brazil</b>              | It is diverse, depending on the origin and concentration (amber tones, reddish and greenish)                                  | Characteristic, depending on the botanical origin (balsamic and resinous)          | characteristic, mild to strong, bitter, and spicy                         |
| <b>Poland</b>              | Yellow to dark brown, often with a green or red tinge   | Balsamic, pleasant   | - <sup>1</sup>  |
| <b>Mexico</b>              | Red, red-yellow, dark yellow, brown-green, brown, or black, depending on the botanical origin                                 | Resinous (woody smell) or balsamic (waxy smell), depending on its botanical origin | From mild balsamic to strong and spicy, depending on its botanical origin |
| <b>East African region</b> | Characteristic, depending on the origin   | Characteristic, depending on the origin  | Characteristic, depending on the origin                                   |
| <b>Ukraine</b>             | Dark green, brown, greenish-brown, brown, grey with greenish, yellow or brown tint  | Resinous (a mixture of smells of honey, pine needles, and poplar)                  | Bitter, slightly burning  |

**Note:** <sup>1</sup>the standard "Propolis – kit pszczeli PN-R-78891" does not regulate this indicator [32]

**Source:** grouped by authors based on sources [28; 30; 31-34]

The main sensory characteristics of propolis in different regions are primarily determined by different botanical sources of origin. The aetiology of bees during the accumulation of propolis contributes to the polyfloricity of its composition and colour heterogeneity. In addition, the

method of collection and cleaning can affect the main sensory parameters of raw propolis.

Requirements for the content of biologically active substances are contained in most regulatory documents. The indicators almost do not differ among themselves (Table 4).

**Table 4.** Biologically active substances of propolis

| Countries        | Indicators            |                              |                     |                         |                        |
|------------------|-----------------------|------------------------------|---------------------|-------------------------|------------------------|
|                  | Flavonoids            | Oxidation                    | Phenols             | AOA (CA50) <sup>4</sup> | Ethanol-soluble resins |
| <b>Argentina</b> | min 0.5%              | max 22 c                     | min 5% <sup>2</sup> | - <sup>5</sup>          | min 30%                |
| <b>Brazil</b>    | min 0.25%             | max 22 c                     | min 0.5%            | - <sup>6</sup>          | methanol max 0.4 mg/l  |
| <b>Mexico</b>    | min 0.5% <sup>1</sup> | max 22 c                     | min 5% <sup>3</sup> | min 100 mcg/ml          | - <sup>7</sup>         |
| <b>Ukraine</b>   | min 25%               | 0.6 per 1 mg cm <sup>3</sup> |                     | - <sup>8</sup>          |                        |

**Notes:** <sup>1</sup>expressed as quercetin equivalents; <sup>2</sup>expressed as gallic acid; <sup>3</sup>expressed as the equivalent of gallic acid; <sup>4</sup>ability of the substance to absorb free radicals, antioxidant activity; <sup>5</sup> the Article 1308 bis "propolis and inclusion of technical specifications" does not regulate this indicator; <sup>6</sup>in Annex VII "On Regulation of Identification and Quality of Propolis Extract" the indicator is not regulated; <sup>7</sup>in NOM-003-SAG/GAN-2017 "Propolis, Production and Specifications for its Processing" the indicator is not regulated; <sup>8</sup>in DSTU 4662: 2006 "Propolis (bee glue). Technical conditions" does not regulate the indicator

**Source:** grouped by authors based on sources [28; 30; 31; 33]

The regulatory documents of Ukraine should include the definition of the total amount of phenols, AOA (antioxidant activity), the content of ethanol and water-soluble resins, and the methods for determining all indicators should be brought to international standards.

Requirements should be divided according to the purpose of further use (for example, for the food or pharmaceutical industry). The analysed regulatory documents of Poland and the East African region (Uganda) do not regulate the content of biologically active substances of propolis [34].

Regarding physicochemical characteristics, only the standard of the East African region (Uganda) DEAS 990: 2019 “Bee propolis – specification” [34] requires compliance

with all the following indicators. Other countries specify in their regulations certain indicators that, as they believe, have the greatest impact on the quality of propolis (Table 5).

**Table 5.** Physical and chemical characteristics of propolis

| Countries           | Indicators        |  |                          |                            |
|---------------------|-------------------|--|--------------------------|----------------------------|
|                     | Dry substances, % | Total ash content, %, max <sup>1</sup> | Wax, %, max <sup>1</sup> | Resin, %, max <sup>1</sup> |
| Argentina           | 10                | 5                                      |                          | <sup>-2</sup>              |
| Brazil              | 11                | <sup>-3</sup>                          | 1                        | <sup>-3</sup>              |
| East African region | 6                 | 10                                     | 30                       | 50                         |
| Ukraine             |                   | <sup>-4</sup>                          | 15.0                     | <sup>-4</sup>              |

**Notes:** <sup>1</sup>maximum allowed value; <sup>2</sup>Article 1308 bis “Propolis and Inclusion of Technical Specifications” does not regulate indicators; <sup>3</sup>Annex VII “On the Regulation of Identification and Quality of Propolis Extract” does not regulate indicators; <sup>4</sup>DSTU 4662: 2006 “Propolis (Bee Glue). Technical Conditions” does not regulate the indicators

**Source:** grouped by authors based on sources [28; 30; 31; 34]

It is necessary to introduce the parameters of dry matter content and total ash content into the normative documentation of Ukraine. Depending on the collection method, the wax content will vary. It would be necessary to divide propolis into categories depending on the wax content. Propolis of category 1 with a wax content of up to 5%, category 2 up to 10% and category 3 up to 15%. The less wax, the higher the content of plant resins in propolis, and accordingly, the value and cost of propolis should be higher. This approach would encourage the industry to improve the technology for greater benefits, and the market would receive a better product.

The analysed regulatory documents of Poland [32] and Mexico [33] do not regulate the physical and chemical characteristics of propolis.

Contamination is important in developing the quality and safety of both raw materials and finished products. It is important that the most common heavy metals, pesticides, antibiotics, and radionuclides must be controlled by regulatory documents during production. Some countries try to control most of the indicators, and some countries do not regulate these indicators in the analysed regulatory documents (Table 6).

**Table 6.** The normalisation of propolis pollutants, mg/kg

| Countries           | Indicators  |           |               |               |                                   |
|---------------------|-------------|-----------|---------------|---------------|-----------------------------------|
|                     | Arsene (As) | Lead (Pb) | Mercury (Hg)  | Cadmium (Cd)  | Pesticide and antibiotic residues |
| Argentina           | 1.0         | 2.0       |               | <sup>-1</sup> | Not allowed                       |
| East African region | 0.5         | 1.0       | 0.05          | 0.2           | <sup>-2</sup>                     |
| Ukraine             | 0.5         | 1.0       | <sup>-3</sup> | 0.05          | 0.005                             |

**Notes:** <sup>1</sup>Article 1308 bis “Propolis and Inclusion of Technical Specifications” does not regulate this indicator; <sup>2</sup>in DEAS 990: 2019 “Bee Propolis – Specification”, the indicator is not regulated; <sup>3</sup>DSTU 4662: 2006 “Propolis (Bee Glue). Technical Conditions” does not regulate the indicator

**Source:** grouped by authors based on sources [28; 30; 34]

In the analysed regulatory documents of Brazil [31], Poland [32] and Mexico [33] heavy metals, pesticide and antibiotic residues in propolis are not regulated. The content of radionuclides in the analysed regulatory documents is not regulated. According to DSTU 4662:2006 “Propolis (Bee Glue). Technical Conditions” the content of radionuclides is determined by the state hygiene standards GN 6.6.1.1-130-2006. The permissible levels of Cs-137 and Sr-90 radionuclides in food and drinking

water approved by the Ministry of Health of Ukraine on 05/03/2006, in particular, should not exceed the permissible levels of 137Cs any more than 600 Bq/kg, <sup>90</sup>Sr no more than 200 Bq/kg. [28]

The standard “Propolis – kit pszczeli PN-R-78891” [32] does not regulate microbiological indicators. In addition, most of the reviewed regulatory documents do not pay special attention to microbiology, which may adversely affect the safety properties of propolis (Table 7).

Table 7. Regulation of microbiological indicators

| Countries           | Indicators                                       |                         |                       |                         |                      |                                       |
|---------------------|--|-------------------------|-----------------------|-------------------------|----------------------|---------------------------------------|
|                     | Yeast/mould CFU/g                                | <i>Escherichia coli</i> | <i>Staphylococcus</i> | <i>Candida albicans</i> | <i>Paenibacillus</i> | <i>Salmonella</i>                     |
| Argentina           | n = 5<br>c = 2<br>m = 10<br>M = 100 <sup>1</sup> | - <sup>2</sup>          | - <sup>2</sup>        | - <sup>2</sup>          | - <sup>2</sup>       | n = 10<br>c = 0<br>m = 0 <sup>1</sup> |
| Brazil              | - <sup>3</sup>                                   | - <sup>3</sup>          | - <sup>3</sup>        | - <sup>3</sup>          | Prohibited           | - <sup>3</sup>                        |
| Mexico              | - <sup>4</sup>                                   | Prohibited              | Prohibited            | Prohibited              | - <sup>4</sup>       | - <sup>4</sup>                        |
| East African region | 10 CFU/g   | Prohibited              | Prohibited            | - <sup>5</sup>          | - <sup>5</sup>       | - <sup>5</sup>                        |
| Ukraine             | under 100  | Prohibited              | - <sup>6</sup>        | - <sup>6</sup>          | - <sup>6</sup>       | Prohibited                            |

**Notes:** <sup>1</sup>n = number of units that make up the sample, C = number of samples that have values between m and M; <sup>2</sup>Article 1308 bis "Propolis and Inclusion of Technical Specifications" does not regulate indicators; <sup>3</sup>in Annex VII "On Regulation of Identification and Quality of Propolis Extract", indicators are not regulated; <sup>4</sup>the Standard NOM-003-SAG/GAN-2017 "Propolis, Production and Specifications for its Processing" does not regulate the indicators; <sup>5</sup>in DEAS 990: 2019 "Bee Propolis – Specification" indicators are not regulated; <sup>6</sup>DSTU 4662: 2006 "Propolis (Bee Qlue). Technical Conditions" does not regulate the indicators

**Source:** grouped by authors based on sources [28; 30; 31; 33; 34]

It is proved that propolis contains wax of animal and vegetable origin [43; 44]. Bees can transfer old wax during nest rebuilding [44]. Contaminated old wax, together with the remains of veterinary drugs and pesticides, can penetrate into propolis. Thus, cleaning the nest elements from old honeycombs (wax) and propolis improves the quality of the latter.

As a result, the national regulatory legal acts regulating the quality of propolis should be updated in accordance with international market requirements. Adapting regulatory documents to international ones should contain the principles of good beekeeping practice in propolis production, which is currently absent in Ukraine.

The authors also consider it expedient to harmonise the main quality indicators of raw propolis with the requirements of regulations of the leading countries of propolis producers (Brazil). In regulatory documents, it is necessary to divide the methods of determining quality into basic (general) and special, depending on the further use of the batch under study.

There are no requirements in the national regulatory framework on the quality of propolis regarding the quality of imported valuable types of propolis imported to the domestic market. The requirements should also be updated. Particular attention should be paid to the prevention of counterfeit and low-quality propolis in large batches for export. As a result of the analysis and systematisation of scientific information, international and national regulatory documents, it is proposed to elaborate:

1) a normative document regulating the process of obtaining propolis with the use of advanced technology as a preventive approach to obtaining safe and high-quality propolis that will meet the requirements specified in the regulations;

2) regulations for identifying propolis types (the type of propolis is labelled according to the dominant source of plant resin);

3) classification and relevant requirements depending on the further purpose and method of production/processing:

– Group I Raw Propolis is intended for use and processing

in food, pharmaceutical, medical, and veterinary industries in Ukraine and/or for export.

– Group II Raw Propolis is intended for use and processing as technical raw materials in Ukraine and/or for export.

– Group III Raw Propolis obtained in an organic apiary.

– Group IV propolis, which is imported to Ukraine.

4) list of the most common agrochemicals and veterinary drugs that need to be identified in organic propolis, and the procedure for its mandatory review every 10 years;

5) methodology for determining the main substances of markers to identify the regional and botanical origin of propolis (plant fibres, palynology).

The proposed approach will regulate the propolis market in Ukraine and will contribute to the formation of added value for raw propolis in the case of its grouping by purpose and method of production and processing; will allow exporting propolis as raw materials or finished products.

## Conclusions

The main producer in the world market of propolis is Brazil, the second place is shared by New Zealand and China. The norms of the national standard were analysed for compliance with some foreign regulatory documents that contain the most criteria for assessing the quality of propolis, namely: Brazil, Argentina, Poland, Mexico, East African region. European requirements for regulating the international propolis market are also given.

The regulatory document of Ukraine does not account for: ambient temperature when determining the consistency of propolis origin (plant sources) and the methods of its selection when assessing the appearance; total phenols, antioxidant activity, the content of ethanol and water-soluble resins; dry matter content; total ash content; categorisation depending on the impurity of wax; microbiological indicators. Regulations on the content of residues of veterinary drugs and pesticides should be expanded to reflect the modern drugs used.

Significant differences in national and international standards make it impossible to realise the export potential

of Ukraine. It is recommended to develop new regulatory documentation for regulating the production, processing, and quality assessment of propolis.

Prospects for further research are to develop technologies for obtaining and identifying various types of propolis.

## References

- [1] Market Research Future. (2018). *Propolis market report – Forecast to 2030*. Retrieved from <https://www.marketresearchfuture.com/reports/propolis-market-782>.
- [2] ISO/CD 24381 “Bee Propolis – Specifications”. Retrieved from <https://www.iso.org/standard/78543.html>.
- [3] Özer, E.D. (2020). Propolis and potential use in food products. *Turkish Journal of Agriculture-Food Science and Technology*, 8(5), 1139-1144. doi: 10.24925/turjaf.v8i5.1139-1144.3324.
- [4] Safaei, M., & Azad, R.R. (2020). Preparation and characterization of poly-lactic acid based films containing propolis ethanolic extract to be used in dry meat sausage packaging. *Journal of Food Science and Technology*, 57(4), 1242-1250. doi: 10.1007/s13197-019-04156-z.
- [5] Sahlan, M., Fadhullah, H., Pratami, D.K., & Lischer, K. (2020). Physical and chemical characterization of dry mud propolis for natural scrub cosmetic. *AIP Conference Proceedings*, 2230(1). doi: 10.1063/5.0002437.
- [6] Karabaş Kılıç, Z., Erdem, S., Kabakçı, D., & Akdeniz, G. (2020). Recent studies in the use of propolis as a traditional medicine: A review. *Bee Studies*, 12(1), 12-16. doi: 10.51458/BSTD.2021.3.
- [7] Bankova, V. (2005). Chemical diversity of propolis and the problem of standardization. *Journal of Ethnopharmacology*, 100, 114-117. doi: 10.1016/j.jep.2005.05.004.
- [8] Kuropatnicki, A.K., Szliszka, E., & Krol, W. (2013). Historical aspects of propolis research in modern times. *Evidence-Based Complementary and Alternative Medicine*, article number 964149. doi: 10.1155/2013/964149.
- [9] De Groot, A.C., Popova, M.P., & Bankova, V.S. (2014). *An update on the constituents of poplar-type propolis*. Wapserveen: Acdegroot Publishing. Retrieved from <https://www.patchtesting.info/wp-content/uploads/2019/05/4-Update-on-the-constituents-of-poplar-type-propolis-De-Groot-Popova-Bankova.pdf>.
- [10] Bankova, V., Popova, M., & Trusheva, B. (2008). The phytochemistry of the honeybee. *Phytochemistry*, 155, 1-11. doi: 10.1016/j.phytochem.2018.07.007.
- [11] Osés, S.M., Marcos, P., Azofra, P., de Pablo, A., Fernández-Muñoz, M.Á., & Sancho, M.T. (2020). Phenolic profile, antioxidant capacities and enzymatic inhibitory activities of propolis from different geographical areas: Needs for analytical harmonization. *Antioxidants*, 9(1), article number 75. doi: 10.3390/antiox9010075.
- [12] Guzelmeric, E., Ristivojević, P., Trifković, J., Dastan, T., Yilmaz, O., Cengiz, O., & Yesilada, E. (2018). Authentication of Turkish propolis through HPTLC fingerprints combined with multivariate analysis and palynological data and their comparative antioxidant activity. *LWT-Food Science and Technology*, 87, 23-32. doi: 10.1016/j.lwt.2017.08.060.
- [13] Matos, V.R., & dos Santos, F. de A.R. (2016). The pollen spectrum of the propolis of *Apis mellifera* L. (Apidae) from the Atlantic Rainforest of Bahia, Brazil. *Palynology*, 41(2), 207-215. doi: 10.1080/01916122.2016.1146175.
- [14] Teixeira, É.W., Message, D., & Meira, R.M. (2019). Methacrylate: An alternative fixing agent for identifying the botanical origin of propolis. *Applications in Plant Sciences*, 7(12), article number 11309. doi: 10.1002/aps3.11309.
- [15] González-Martín, M.I., Revilla, I., Betances-Salcedo, E.V., & Vivar-Quintana, A.M. (2018). Pesticide residues and heavy metals in commercially processed propolis. *Microchemical Journal*, 143, 423-429. doi: 10.1016/j.microc.2018.08.040.
- [16] Tomšič, R., Heath, D., Heath, E., Markelj, J., Kandolf Borovšak, A., & Prosen, H. (2020). Determination of neonicotinoid pesticides in propolis with liquid chromatography coupled to tandem mass spectrometry. *Molecules*, 25(24), article number 5870. doi: 10.3390/molecules25245870.
- [17] Bankova, V., Bertelli, D., Borba, R., Conti, B.J., da Silva Cunha, I.B., Danert, C., Eberlin, M.N., Falcão, S.I., Isla, M.I., Moreno, M.I.N., Papotti, G., Popova, M., Santiago, K.B., Salas, A., Sawaya, A.C.H.F., Schwab, N.V., Sforcin, J.M., Simone-Finstrom, M., Spivak, M., Trusheva, B., Vilas-Boas, M., Wilson, M., & Zampini, C. (2016). Standard methods for *Apis mellifera* propolis research. *Journal of Apicultural Research*, 58(2), 1-49. doi: 10.1080/00218839.2016.1222661.
- [18] Sales, A., Alvarez, A., Areal, M.R., Maldonado, L., Marchisio, P., Rodríguez, M., & Bedascarrasbure, E. (2006). The effect of different propolis harvest methods on its lead contents determined by ET AAS and UV-visS. *Journal of Hazardous Materials*, 137(3). doi: 10.1016/j.jhazmat.2006.05.026.
- [19] De Ayala, L.M.P., Tucuch-Tun, J.R., Cruz-Sánchez, T.A., Canales-Martínez, M.M., Penieres-Castillo, J.G., & Rodríguez-Pérez, B. (2019). Analysis of different techniques for propolis collection adhering to NOM-003-SAG/GAN-2017. *Tropical Agroecosystems*, 15-23.
- [20] Saccardi, L., Schiebl, J., Schwarz, O., Gorb, S.N., Kovalev, A., & Weber, K. (2021). Adhesive behavior of propolis on different substrates. *Frontiers in Mechanical Engineering*. doi: 10.3389/fmech.2021.660517.
- [21] Wilmart, O., Legrève, A., Scippo, M.-L., Reybroeck, W., Urbain, B., de Graaf, D.C., & Saegerman, C. (2021). Honey bee exposure scenarios to selected residues through contaminated beeswax. *Science of the Total Environment*, 772, article number 145533. doi: 10.1016/j.scitotenv.2021.145533.
- [22] Murcia-Morales, M., Heinzen, H., Parrilla-Vázquez, P., del Mar Gómez-Ramos, M., & Fernández-Alba, A.R. (2022). Presence and distribution of pesticides in apicultural products: A critical appraisal. *TrAC Trends in Analytical Chemistry*, 146, article number 116506. doi: 10.1016/j.trac.2021.116506.
- [23] Regulation (EC) of the European Parliament and of the Council No. 396/2005 “On Maximum Residue Levels of Pesticides in or on Food and Feed of Plant and Animal Origin and Amending Council Directive 91/414/EEC”. (2005, February). Retrieved from <http://data.europa.eu/eli/reg/2005/396/2016-05-13>.

- [24] Alqarni, A.S., Rushdi, A.I., Owayss, A.A., Raweh, H.S., El-Mubarak, A.H., & Simoneit, B.R. (2015). Organic tracers from asphalt in propolis produced by urban honey bees, *Apis mellifera* Linn. *PLoS One*, 10(6), article number 0128311. doi: 10.1371/journal.pone.0128311.
- [25] Özenirler, Ç., Çelemlı, Ö.G., Mayda, N., & Sorkun, K.A. (2018). New record for propolis substitute: Pruning sealer. *Mellifera*, 18(1), 36-39. Retrieved from <https://dergipark.org.tr/en/pub/mellifera/issue/40742/491041>.
- [26] Breyer, E.D., Breyer, H.F., & Cella, I. (2016). Production and processing of propolis. *Didactic Bulletin*, 1, 30. Retrieved from <https://publicacoes.epagri.sc.gov.br/BD/article/view/405>.
- [27] Abou-Shaara, H.F., & Eid, K.S. (2019). Increasing the profitability of propolis production in honey bee colonies by utilizing remote sensing techniques to spot locations of trees as potential sources of resin. *Remote Sensing Letters*, 10(9), 922-927. doi: 10.1080/2150704X.2019.1633488.
- [28] DSTU 4662:2006 "Propolis (Bee Glue). Specifications". (2007). Kyiv: State Standards of Ukraine.
- [29] Torraco, R.J. (2005). Writing integrative literature reviews: Guidelines and examples. *Human Resource Development Review*, 4(3), 356-367. doi: 10.1177/1534484305278283.
- [30] Article 1308 bis Argentine food code. Propolis and the inclusion of technical specifications. File No. 1-2002-7014-96-3. Buenos Aires, 05.05.2008.
- [31] Normative Instruction No. 11 Annex VII. Regulation of Identity and Quality of Propolis Extract. (2000, October). *Official Gazette of 10/23/00*, 16-17. Department of Inspection of Products of Animal Origin – DIPOA.
- [32] Polish standard "Propolis – kit pszczeli PN-R-78891". (1996). Polish Committee for Standardisation. SKN 1552 ICS 65.140.10.
- [33] NORMA Oficial Mexicana NOM-003-SAG/GAN-2017. Propóleos, producción y especificaciones para su procesamiento. Secretaria de agricultura, ganaderia, desarrollo rural, pesca y alimentacion. Retrieved from [https://www.dof.gob.mx/nota\\_detalle.php?codigo=5500103&fecha=06/10/2017#gsc.tab=0](https://www.dof.gob.mx/nota_detalle.php?codigo=5500103&fecha=06/10/2017#gsc.tab=0).
- [34] Official Mexican Standard NOM-003-SAG/GAN-2017 "Propolis, production and specifications for its processing. Secretary of agriculture, livestock, rural development, fishing and food". (2017, October).
- [35] DEAS 990:2019 "Bee propolis – Specification". ICS 67.180.20. East African Community.
- [36] Regulation (EU) No. 1308/2013 of the European Parliament and of the Council of establishing a common organisation of the markets in agricultural products and repealing Council Regulations (EEC) No. 922/72, (EEC) No. 234/79, (EC) No. 1037/2001 and (EC) No. 1234/2007. (2013, December). Retrieved from <http://data.europa.eu/eli/reg/2013/1308/oj>.
- [37] Commission Regulation (EU) No. 142/2011 implementing Regulation (EC) No. 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive Text with EEA relevance. (2011, February). Retrieved from <http://data.europa.eu/eli/reg/2011/142/oj>.
- [38] Commission Implementing Regulation (EU) 2021/632 of laying down rules for the application of Regulation (EU) 2017/625 of the European Parliament and of the Council as regards the lists of animals, products of animal origin, germinal products, animal by-products and derived products, composite products, and hay and straw subject to official controls at border control posts, and repealing Commission Implementing Regulation (EU) 2019/2007 and Commission Decision 2007/275/EC. (2021, April). Retrieved from [http://data.europa.eu/eli/reg\\_impl/2021/632/oj](http://data.europa.eu/eli/reg_impl/2021/632/oj).
- [39] Crane, E. (2009). Bee Products. In *Encyclopaedia of insects* (2<sup>nd</sup> ed., pp. 71-75). Cambridge: Academic Press.
- [40] Miguel, M.G., & Antunes, M.D. (2011). Is propolis safe as an alternative medicine. *Journal of Pharmacy and Bioallied Sciences*, 3(4), 479-495. doi: 10.4103/0975-7406.90101.
- [41] Ministry of Agriculture New Zealand. (2016). *Apiculture monitoring programme report*. Retrieved from <https://www.mpi.govt.nz/dmsdocument/16621/LoggedIn>.
- [42] Codex Alimentarius Commission. (2001). Revised Codex Standard for honey. Codex STAN 12-1981.
- [43] Negri, G., Marcucci, C., Salatino, A., Salatino, M.L.F. (2000). Comb and propolis waxes from Brazil (States of São Paulo and Paraná). *Journal of the Brazilian Chemical Society*, 11(5), 453-457. doi: 10.1590/S0103-5053200000050000.
- [44] Pobiega, K., Gniewosz, M., Kraśniewska, K. (2017). Antimicrobial and antiviral properties of different types of propolis. *Progress Problem Journals Agricultural Sciences*, 589, 69-79. doi: 10.22630/ZPPNR.2017.589.22.
- [45] Örsi-Pal, Z. (1957). The role of the mandibular glands of the honeybee. *Bee World*, 38(3), 70-73. doi: 10.1080/0005772X.1957.11094979.

## Перегляд національних нормативних вимог до якості прополісу на відповідність міжнародним стандартам

Роман Мар'янович Двикалюк<sup>1</sup>, Леонора Олександрівна Адамчук<sup>1, 2</sup>,  
Артем Дмитрович Антонів<sup>1</sup>, Седат Севин<sup>3</sup>

<sup>1</sup>Національний університет біоресурсів та природокористування України  
03041, вул. Героїв Оборони, 15, м. Київ, Україна

<sup>2</sup>Національний науковий центр «Інститут бджільництва імені П. І. Прокоповича»  
03680, вул. Заболотного, 19, м. Київ, Україна

<sup>3</sup>Університет Анкари  
06100, вул. Доголь Каддесі, 6А, м. Анкара, Туреччина

**Анотація.** Зважаючи на зростання попиту серед споживачів міжнародного ринку на прополіс, є актуальним переглянути відповідність національної документації до міжнародної, зокрема країн які є лідерами з виробництва й перероблення цього продукту. Інтеграція та адаптація національного законодавства до норм законодавства світової спільноти вимагає також перегляду підходів до якості та безпечності прополісу. Тому, метою дослідження було проведення аналізу чинних міжнародних та національних нормативно-правових актів провідних країн світу, котрі відіграють ключову роль на міжнародному ринку виробництва та реалізації прополісу за показниками безпечності та якості прополісу. Використовували метод Торрако для аналізу та синтезу наукової й нормативно-технічної інформації; користувалися науково-метричною базою Springer та пошуковим інструментом Google Scholar. Матеріалами слугували нормативні документи України, ЄС, Бразилії, Аргентини, Польщі, Мексики, Східно-Африканського регіону. З'ясували, що критеріями для оцінювання якості прополісу у міжнародній нормативно-технічній документації слугують органолептичні (зовнішній вигляд, консистенція, колір, запах, смак), фізико-хімічні (сухі речовини, загальна зольність, віск, смоли) мікробіологічних (дріжджі, плісняви, *Escherichia coli*, *Staphylococcus*, *Candida albicans*, *Paenibacillus*, *Salmonella*) показники біологічної активності (флавоноїди, окислення, феноли, антиоксидантна активність, етанол-розчинні смоли) та контамінації (важкі метали, залишки пестицидів і антибіотиків, радіонукліди). Встановлено невідповідність діючого в Україні нормативного документа до вимог міжнародних регламентів, а саме за показниками: вмісту фенолів, етанольно- та водорозчинних смол, сухих речовин; загальної зольності; антиоксидантної активності; колонієутворюючі одиниці. Визначено, що в Україні прополіс не розділено за категоріями залежно від домішок воску; не враховано температуру зовнішнього середовища під час визначення показника консистенції; не береться до уваги ботанічне походження та способи його відбору під час оцінювання органолептичних властивостей. Обґрунтовано підхід для урегулювання ринку прополісу в Україні, що сприятиме формуванню доданої вартості на прополіс-сирець у разі його групування за призначенням та способу виробництва і перероблення. Матеріали статті становлять практичну цінність для формування нових та гармонізації існуючих нормативно-технічних регламентів щодо якості прополісу, та можуть бути використані у робочій групі з розвитку бджільництва при Мінагрополітики України

**Ключові слова:** нормативне регулювання, продукти бджільництва, специфікація прополісу, ідентифікація прополісу, типи прополісу



UDC 636.4.033.085:579.8

DOI: 10.31548/animal.13(2).2022.26-34

## The Effect of a New Complex Sorbent of Mycotoxins in Pigs Diets on Their Growth Performance, Fattening and Meat Traits

Vadym Lykhach<sup>1\*</sup>, Anna Lykhach<sup>1</sup>, Rostyslav Faustov<sup>2</sup>, Yevhen Barkar<sup>2</sup>, Leonid Lenkov<sup>3</sup>

<sup>1</sup>National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<sup>2</sup>Mykolaiv National Agrarian University  
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine

<sup>3</sup>“VetServiceProduct” LLC  
08132, 6-H Kyivska Str., Vyshneve, Kyiv region, Ukraine

**Abstract.** Compliance with feed safety in livestock production requires pork producers to add mycotoxin-binding adsorbents to pig diets. Therefore, the purpose of the study was to evaluate the effect of two complex sorbents added to the diet of fattening pigs on their performance. The experiment included 90 pigs, which were kept in LLC “Tavriyski svyni” in the Kherson region. According to the principle of analogues, experimental animals were divided into three groups of 30 animals each: I – the control group of pigs consumed the basic diet “Grower”, and “Finisher”; pigs of experimental group II consumed the basic diet “Grower”, “Finisher” with the addition of 0.15% by weight of feed of a commercial analogue of mycotoxin adsorbent; animals of experimental group III received the basic diet “Grower”, “Finisher” with the addition of 0.15% by weight of feed of the complex preparation “Hepasorbex”. Animals that consumed feed containing adsorbents of mycotoxins had a higher live body weight, and average daily weight gain, reaching weights of 100 and 120 kg with lower feed conversion earlier compared to analogues of a control group. It was found that the introduction of “Gepasorbex” in the diet of store pigs of experimental group III at a pre-slaughter weight of 100 and 120 kg resulted in an increase in: slaughter yield, half-carcass length, muscle eye area, the weight of the hind third of the half-carcass and a decrease in the thickness of the fat compared to the control group. In terms of chemical composition, the meat of animals of experimental groups, both at slaughter in 100 kg and in 120 kg, met the requirements for pork of normal quality (NORMAL). At a live weight of 100 and 120 kg, pigs of experimental group III had significantly lower moisture content, higher protein, fat and ash content in meat. Due to the complex composition of “Gepasorbex” ingredients, the nutrients in the feed remained and were absorbed by the pig’s body, which is confirmed by higher productivity indicators and significantly reduces the cost of the main expense item of pig farms in pig production technologies – “Feed”. Therefore, this research is useful for specialists in pork production and processing in developing strategies for feeding pigs and obtaining quality raw materials for processing enterprises, which opens up ways to ensure food security in the country

**Keywords:** weight condition, feeding, feed sorbents, productivity, pig breeding

### **Suggested Citation:**

Lykhach, V., Lykhach, A., Faustov, R., Barkar, Ye., & Lenkov, L. (2022). The effect of a new complex sorbent of mycotoxins in pigs diets on their growth performance, fattening and meat traits. *Animal Science and Food Technology*, 13(2), 26-34.

\*Corresponding author

## Introduction

To eliminate the negative effects of mycotoxicosis on the body of animals (decrease in productivity, reproductive qualities, weakening of the immune system of animals, disruption of the gastrointestinal tract, kidneys, a hepatoprotective function of the liver, deterioration of the quality of meat raw materials, etc.) it is necessary to strictly control the content of mycotoxins in feed fed to pigs, which further ensures the preservation of not only animal health, but also the end consumers of livestock products [1].

Neutralisation of mycotoxins in feed using sorbents is a common and virtually the only method in systematic measures to combat mycotoxicosis in pigs [2; 3]. The use of intensively innovative technologies and pigs of high genetic potential to ensure productivity through the efficient use of feed resources, maximum preservation of animals and prevention of various diseases is a feature of the modern pig industry. This fact puts forward significant requirements for scientists and practitioners in providing high-quality and environmentally friendly feed, which is associated with their contamination with various toxins, heavy metals, pesticides, nitrates, etc. [4-6].

With sufficient and balanced feeding, the share of transformation of nutrients of the consumed feed into the substances of the product when growing pigs is 45-50%. An important aspect in solving this is the organisation of a full, balanced feeding of animals, that is, the use of diets that best meet the needs of pigs in terms of the content of basic nutrients and biologically active substances [7; 8]. Therefore, a number of studies are currently being conducted [9-11] to find the most effective sorbents that will get rid of mycotoxins and maximise the preservation of biologically active substances in the body of animals.

Despite the fact that the issue of mycotoxins has been known for more than 50 years [12-14], and the vast majority of pork producers have experienced their presence in feed, yet farms do not apply a full range of preventive measures against mycotoxicosis, which is the reason for low profitability of pork production [15-17].

Feed mycotoxins are products of fungal metabolism (*Aspergillus*, *Mucoraceae*, *Fusarium* etc.), which form stable compounds and disrupt various types of metabolism of the animal body, and, as a result, diseases of animals with a severe course that occur when feeding feed affected by toxic fungi: reduce the productivity of biological objects and the efficiency of using feed for the production of a unit of production; disrupt reproductive functions; weaken the immune system of animals and poultry; increase sensitivity to diseases; increase the cost of treatment and preventive measures, reducing the effectiveness of vaccines and medicines [18-21].

It should be noted that adsorbents of mycotoxins differ from one another by the nature of origin, composition, adsorption capacity, rate of endogenous detoxification, bioavailability, and from generation to generation due to technological developments they become more and more perfect and diverse in terms of adsorption properties, and also have an indirect therapeutic effect. Feed sorbents have the ability to quickly bind a wide range of toxicants. Sorbents are stable at different pH values, thermostable during feed granulation. The use of mycotoxin adsorbents as feed additives is beneficial to reduce the toxic effects of mycotoxins in pigs, which ensures more sustainable use of feed [8; 12; 20].

However, as noted by A. Kihal *et al.* [21], many feed additives with sorption properties bind vitamins, macro- and microelements. According to the findings of other authors, it was proved that the prolonged use of sorbents caused a decrease in the content of vitamins A, D and E and other elements in the blood of animals and poultry. Thus, T. C. Schell *et al.* [22]; K. E. Reddy *et al.* [23]; A. C. Weaver *et al.* [24] proved that aflatoxin B<sub>1</sub> had a detrimental effect on liver health and electrolytic balance in pigs, which led to a deterioration of functions and changes in the structure of the liver and kidney architecture. Productivity and resistance of pigs depends on providing them with sufficient nutrients and biologically active substances [21]. Thus, there is an important scientific and practical task to study the effect of different feed sorbents when used in diets with an average level of contamination with mycotoxins on the productivity of fattening pigs.

*The purpose of the study* is to identify the effect of a new complex sorbent of mycotoxins in the diets of store pigs on their growth performance, fattening, quantitative and qualitative meat traits in industrial technology.

## Materials and Methods

Overall in the experiment, which lasted during 2021, 90 heads of fattening store pigs were used in the ratio: 50% – castrated boars and 50% – piglets, where the maternal form was a combination of breeds Large White × Landrace, and the paternal form was boars of the terminal line “Maxter”, which were kept on the farm of LLC “Tavriyski svyni”, Kherson region.

Fattening was divided into two periods: I period of fattening (“Grower”) – animals with a live weight of 30-60 kg (12-17 weeks) consumed feed 2.4-2.6 kg per head per day using feed of the “Grower” type by nutritional value: crude protein – 180.25 g/kg; metabolisable energy – 13.04 MJ/kg, pigs were placed on a concrete slotted floor with an area of 0.65 m<sup>2</sup>/head according to DNTD-IAC-02.05 “Pig enterprises (complexes, farms, small farms)” [25]; II period of fattening (“Finisher”) – animals with a live weight of 61-120 kg (17-26 weeks) consumed 2.8-3.2 kg per head per day using a feed of the “Finisher” type with nutritional value: crude protein – 140.88-153.08 g/kg; metabolizable energy – 12.90-13.14 MJ/kg, pigs were placed on a concrete slotted floor with an area of 0.85 m<sup>2</sup>/head according to DNTD-02.05 “Pig enterprises (complexes, farms, small farms)” [25]. As the basic diet (BD) was used a feed of domestic production with the use of premixes produced by the company “PC Alternative” (Ukraine) in the corresponding composition of “Grower” (%): wheat – 32; barley – 12.1; corn – 17.38; bran (wheat) – 8; soybean cake – 24.3; sunflower cake – 3.22; premix – 3; “Finisher” (%): wheat – 24; barley – 24; corn – 19; bran (wheat) – 12; soybean cake – 11.6; sunflower cake – 6.9; premix – 2.5.

When transferring pigs from the rearing unit to the fattening unit of the first period, to equalise the animals and the purity of the research in the period from 11-12 weeks, the equalisation period (EP) started. Further, all experimental animals were divided into three groups (according to the principle of analogues) based on generally accepted methods [26; 27], 30 animals in each group: I control group of pigs consumed the basic diet “Grower”, “Finisher”; pigs of II experimental group consumed the basic diet “Grower”,

“Finisher” with the addition of 0.15% by weight of feed of a commercial analogue of mycotoxin adsorbent; animals of III experimental group were fed the basic diet

“Grower”, “Finisher” with the addition of 0.15% by weight of feed of the complex preparation “Hepasorbex” (Table 1).

**Table 1.** Scheme of using a feed additive in the experiment

| No.  | Group        | Feeding conditions   |
|--|--------------|--|
| Age 11-12 weeks – equalisation period (EP) |              |  |
| Age 12-17 weeks                            |              |  |
| I  | Control      | “Grower”   |
| II   | Experimental | “Grower” + 0.15% by weight of feed “Commercial analogue”   |
| III  | Experimental | “Grower” + 0.15% by weight of feed “Gepasorbex”            |
| Age 17-26 weeks                            |              |  |
| I  | Control      | “Finisher”   |
| II   | Experimental | “Finisher” + 0.15% by weight of feed “Commercial analogue” |
| III  | Experimental | “Finisher” + 0.15% by weight of feed “Gepasorbex”          |

The composition of 1 kg of feed additive “Gepasorbex” (LLC “Vetservisprodukt”, Ukraine) contains the following active components (%): silicon dioxide – 60.2-70.8; aluminium oxide – 8-12; magnesium carbonate – 1.0-2.5; titanium dioxide – 0.8-0.15; selenium – 0.32-0.35; clinoptilolite – 4.2-4.5; active feed yeast – 8-10; milk thistle spotted – 18-20%.

Composition of the feed additive “Commercial analogue”: silicon dioxide (SiO<sub>2</sub>), kaolinite clay, magnesium silicate, inactivated yeast (*Saccharomyces Cerevisiae*), Sugar kelp, extracts of Wild Chicory and Calendula officinalis, dry matter – 954.0 g.

The main feed used for feeding pigs of experimental groups according to laboratory studies was recognized as slightly toxic for aflatoxin, ochratoxin and zearalenone, contract No. 837 of 07/06/2021 (Expert Centre “Biolights” LLC, Kyiv) [28].

At the age of 12-26 weeks, live weight (kg) and average daily gain (G) were determined. The following fattening traits of pigs were evaluated, in particular: age of reaching live weight (days), average daily gain (g), and feed conversion (kg) were determined in experimental groups of pigs when reaching a live weight of 100 and 120 kg, according to conventional methods [26; 27].

Slaughter qualities of experimental animals were studied according to the relevant methodological recommendations of the Institute of Pig Breeding and Agroindustrial Production of the National Academy of Agrarian Sciences of Ukraine [7; 27]. To assess the slaughter qualities, store pigs were selected for slaughter from groups of fattening pigs when they reached a live weight of 100 and 120 kg in the amount of 10 heads of each weight condition in the conditions of LLC “Tavriyski svyni”. Control slaughter

with subsequent determination of the slaughter qualities of experimental groups of animals was carried out by rolling carcasses according to generally accepted methods [27].

The effect of the complex additive “Hepasorbex” on the chemical properties of the longest back muscle of pigs of experimental groups was determined and analysed, for this purpose 10 samples of the longest back muscle (400 g) between 9-12 thoracic vertebrae were taken from the carcasses of slaughtered animals of each of the three groups using conventional methods [27; 29; 30]. To determine the chemical composition of the longest back muscle (*m. longissimus dorsi*) the obtained samples in the independent laboratory of LLC “Expert Centre “Biolights” were examined by a mass fraction, %: moisture, protein, fat, ash according to DSTU ISO 936:2008” meat and meat products. Method for determining the mass fraction of total ash” [31]. The performed methodology of scientific research is included in the accreditation for compliance with DSTU ISO/IEC 17025:2017 [28].

The rules for the treatment of animals in experiments are in accordance with European legislation on the protection and welfare of animals kept on farms (Directive 95/58 EC “On the Protection of Farm Animals” of the Council of the European Union of 07/20/1998 [32] as amended by Regulation (EC) No. 806/2003 of 14.04.2003 [33], No. 91/630 EC “Minimum Standards for the Protection of Pigs” of 11/19/1991 [34] as amended by Regulation (EC) No. 35.

## Results and Discussion

A significant difference was found in the productive characteristics (live weight and average daily growth) of pigs of control and experimental groups at the age of 98 days, or at 14 weeks (Table 2).

**Table 2.** Productive traits of experimental groups of pigs, (n = 30),  $\bar{X} \pm S_{\bar{X}}$

| Trait           | Group/Age     |                   |                    |
|-----------------|---------------|-------------------|--------------------|
|                 | I – control   | II – experimental | III – experimental |
| 12 weeks        |               |                   |                    |
| Live weight, kg | 35.50 ± 0.717 | 35.03 ± 0.812     | 35.83 ± 0.649      |

Table 2, Continued

| Trait                   | Group/Age      |                               |                                |
|-------------------------|----------------|-------------------------------|--------------------------------|
|                         | I – control    | II – experimental             | III – experimental             |
| 14 weeks                |                |                               |                                |
| Live weight, kg         | 45.80 ± 0.637  | 46.23 ± 0.768                 | 47.73 ± 0.629 <sup>c</sup>     |
| Average daily growth, g | 735.7 ± 15.75  | 800.0 ± 19.19 <sup>**</sup>   | 850.0 ± 12.04 <sup>***a</sup>  |
| 17 weeks                |                |                               |                                |
| Live weight, kg         | 62.87 ± 0.610  | 64.20 ± 0.791                 | 66.50 ± 0.645 <sup>***a</sup>  |
| Average daily growth, g | 812.7 ± 15.64  | 855.6 ± 10.33 <sup>*</sup>    | 893.7 ± 8.45 <sup>***b</sup>   |
| 22 weeks                |                |                               |                                |
| Live weight, kg         | 93.33 ± 0.471  | 95.80 ± 0.720 <sup>**</sup>   | 98.43 ± 0.544 <sup>***b</sup>  |
| Average daily growth, g | 870.5 ± 11.92  | 902.86 ± 9.55 <sup>*</sup>    | 912.40 ± 8.55 <sup>**</sup>    |
| 26 weeks                |                |                               |                                |
| Live weight, kg         | 113.97 ± 0.367 | 118.13 ± 0.412 <sup>***</sup> | 120.97 ± 0.256 <sup>***b</sup> |
| Average daily growth, g | 736.9 ± 9.45   | 797.6 ± 15.35 <sup>**</sup>   | 804.8 ± 13.23 <sup>***</sup>   |

Notes: (hereafter): \* –  $R < 0,05$ ; \*\* –  $R < 0,01$ ; \*\*\* –  $R < 0,001$  (compared to animals of control group – group I); a –  $R < 0,05$ ; b –  $R < 0,01$  (compared to the animals of experimental group III with analogues of experimental group II)

When starting fattening, all piglets had a live weight of 33–34 kg. For 14 weeks, pigs of experimental group III who consumed the complex preparation “Gepasorbex” significantly exceeded the live weight of animals of control group by 1.93 kg ( $p < 0.05$ ), and in terms of average daily growth, the advantage was observed in relation to animals as a control group by 114.3 g ( $p < 0.001$ ), and the experimental group II, which consumed a commercial analogue of mycotoxin adsorbent by 50 g ( $p < 0,05$ ).

At 17 weeks of age, the animals of experimental group III significantly prevailed in terms of live weight over the analogues of experimental group II by 2.3 kg ( $p < 0.05$ ) and the peers of control group I by 3.63 kg ( $p < 0.001$ ). The highest average daily increase was recorded in pigs that consumed the complex supplement “Gepasorbex” and significantly exceeded the studied indicator in pigs of control I and the experimental group I by 9.1% ( $p < 0.001$ ) and 5.9% ( $p < 0.05$ ), respectively.

In the period of 22 weeks of life of fattening store pigs, a significant advantage of animals of II and III experimental groups in terms of live weight and average daily weight gain by 2.47 kg ( $p < 0.01$ ), 32.36 g ( $p < 0.05$ ) and 5.1 kg ( $p < 0.001$ ), 41.9 g ( $r < 0.01$ ) respectively was established.

In the age period of 26 weeks, according to the live weight indicator, animals of experimental group III who consumed the complex feed additive “Gepasorbex” outnumbered the peers of both the II experimental and I control groups by 2.67 kg, respectively ( $p < 0.01$ ) and 7.00 kg ( $p < 0,001$ ). In terms of average daily weight gain, pigs of experimental groups II and III that consumed mycotoxin

entersorbents had higher values by 60.7 g ( $p < 0.001$ ) and 67.9 g ( $p < 0.001$ ), respectively, than the control group.

Thus, piglets from experimental groups II and III had a higher growth rate and significantly exceeded the control group analogues in live weight and average daily gain at all ages. Thus, pigs that received mycotoxin adsorbent in the main diet (experimental groups II, III) had higher growth rates.

However, the experimental studies conducted by a group of scientists [11] did not reveal a significant superiority in live weight and average daily weight gain between the control and experimental groups of pigs receiving the main diet with the addition of purified bentonite. However, according to the conclusive opinion of M.D. Subramaniam, I.H. Kim [36], higher growth rates in pigs are explained by an increase in the absorption of certain nutrients in the case of using clay as an adsorbent of mycotoxins by an experimental group of animals, which is consistent with this study. J.H. Li, I.H. Kim [37] reported that growing pigs fed a basic diet with the addition of 0.5% sercite had 6.6% higher live weight gain and 5.1% better feed conversion rate compared to pigs fed a diet without additives. According to D.S. Alexopoulos *et al.* [38], a higher increase of 5.3% was observed in pigs from 25 to 110 kg, which were provided with clay supplementation in the main diet. These results are also consistent with the current study.

It was found that animals fed complex supplements with entersorbents of mycotoxins: experimental groups II and III, respectively, reached a live weight of 100 kg 3.0 ( $p < 0.01$ ) and 6.0 ( $p < 0.001$ ) days earlier compared to the peers of control group I (Table 3).

Table 3. Fattening traits of store pigs, ( $n = 30$ ),  $\bar{X} \pm S_{\bar{x}}$ 

| Group                 | Age of reaching a live weight of 100 kg, days | Average daily gain during fattening, g | Feed conversion, kg |
|-----------------------|---|--|---------------------|
| live weight of 100 kg |   |  |                     |
| I – control           | 161.7 ± 0.56                                  | 826.6 ± 7.66                           | 3.39                |
| II – experimental     | 158.7 ± 0.80                                  | 868.1 ± 5.96                           | 2.94                |
| III – experimental    | 155.7 ± 0.58                                  | 894.3 ± 5.88                           | 2.85                |
| +/- II to I           | -3.0 <sup>**</sup>                            | +41.5 <sup>***</sup>                   | -0.45               |

Table 3, Continued

| Group                 | Age of reaching a live weight of 100 kg, days | Average daily gain during fattening, g | Feed conversion, kg |
|-----------------------|---|--|---------------------|
| +/- III to I          | -6.0***                                       | +67.7***                               | -0.54               |
| live weight of 120 kg |   |  |                     |
| I - control           | 190.2 ± 0.49                                  | 800.7 ± 5.46                           | 3.50                |
| II - experimental     | 184.2 ± 0.48                                  | 848.0 ± 6.21                           | 3.30                |
| III - experimental    | 180.7 ± 0.32                                  | 868.7 ± 5.26                           | 3.22                |
| +/- II to I           | -6.0***                                       | +47.3***                               | -0.20               |
| +/- III to I          | -9.5***                                       | +68.0***                               | -0.28               |

The values of average daily gains in pigs of experimental groups II and III, which used a commercial analogue of the adsorbent of mycotoxins and, in fact, the feed additive "Hepasorbex" were significantly higher ( $p < 0.001$ ) by 41.5 g and 67.7 g, respectively; for feed conversion for the experimental group II the index reached 2.94 kg, and for the experimental group III – 2.85 kg, than the same index of animals of control group I, where the feed conversion was 3.39 kg.

The study of fattening indices at reaching 120 kg of live weight by experimental animals showed a significant excess ( $p < 0.001$ ) in animals of experimental groups II and III in terms of average daily weight gain and amounted to 47.3 g and 68.0 g relative to store pigs that did not use mycotoxin enterosorbent supplements in the main diet.

Similarly, the animals of experimental groups II and III reached the expected live weight (120 kg) 6.0 and 9.5 days earlier than the peers of the control group. At the same time, they have significantly higher average daily

gains compared to the control group by 47.3 g ( $p < 0.001$ ) and 68.0 g ( $p < 0.001$ ), respectively. The lowest rate of feed conversion was recorded in the pigs of experimental group III – 3.22 kg, which is 0.28 kg less than the same value in the pigs of control group I – 3.50 kg.

The conducted experiments [39; 40] also confirmed the positive effect of the use of sorbents in the diet of fattening pigs, which, in turn, improved the average daily gain, feed utilisation and feed conversion rate in crossbred animals (Duroc × Landrace × Yorkshire).

Based on the evaluation of the slaughter qualities of experimental groups of pigs (Table 4), it was found that the pigs of experimental group III dominated the slaughter yield over the peers of the I control group by 4.1% ( $p < 0.001$ ) at slaughter with a live weight of 100 kg and 0.5% – 120 kg. By the length of the half-carcass at the slaughter at 100 kg of weight, store pigs of experimental groups II and III showed a maximum length – 96.7 cm, which is 2.1 cm more than the same indicator of animals of control group I ( $p < 0.05$ ).

Table 4. Slaughter qualities of young pigs, ( $n = 10$ ),  $\bar{X} \pm S_{\bar{X}}$ 

| Group                               | Slaughter yield, % | Half-carcass length, cm | Lard thickness, mm | Loin-eye area, cm <sup>2</sup> | Weight of the back third of the half-carcass, kg |
|-------------------------------------|--------------------|-------------------------|--------------------|--------------------------------|--|
| Pre-slaughter live weight of 100 kg |                    |                         |                    |                                |  |
| I – control                         | 71.1 ± 0.76        | 94.6 ± 0.58             | 18.2 ± 0.89        | 36.8 ± 0.34                    | 10.9 ± 0.32                                      |
| II – experimental                   | 75.0 ± 0.62        | 96.7 ± 0.69             | 15.2 ± 0.51        | 39.2 ± 0.29                    | 11.4 ± 0.17                                      |
| III – experimental                  | 75.2 ± 0.58        | 96.7 ± 0.62             | 14.0 ± 0.54        | 39.8 ± 0.28                    | 11.6 ± 0.21                                      |
| +/- II to I                         | +3.9***            | +2.1*                   | -3.0**             | +2.4***                        | +0.5   |
| +/- III to I                        | +4.1***            | +2.1*                   | -4.2***            | +3.0***                        | +0.7   |
| Pre-slaughter live weight of 120 kg |                    |                         |                    |                                |  |
| I – control                         | 75.8 ± 0.52        | 102.6 ± 1.07            | 26.2 ± 0.74        | 42.9 ± 1.02                    | 14.3 ± 0.14                                      |
| II – experimental                   | 76.2 ± 0.58        | 103.1 ± 1.25            | 19.1 ± 0.62        | 43.4 ± 0.98                    | 14.7 ± 0.16                                      |
| III – experimental                  | 76.3 ± 0.56        | 103.6 ± 1.49            | 18.0 ± 0.55        | 44.1 ± 1.03                    | 14.8 ± 0.17                                      |
| +/- II to I                         | +0.4               | +0.5                    | -7.1***            | +0.5                           | +0.4   |
| +/- III to I                        | +0.5               | +1.0                    | -8.2***            | +1.2                           | +0.5*  |

It was found that at a pre-slaughter live weight of 120 kg the animals of experimental group III prevailed over the animal in the control group by 1.0 cm, but the difference is statistically insignificant.

The animals of group III both at slaughter with a live weight of 100 kg and 120 kg had a thinner carcass by 4.2 cm and 8.2 mm, respectively, compared to the animals of control group I ( $p < 0.001$ ).

The dynamics of changes in muscle and adipose tissue is manifested by different size of the "lion eye"

area, which positively correlates with the yield of meat in pig carcasses and is the main criterion for assessing their meat content [16; 17]. It was found that the area of the loin eye in experimental groups ranged from 36.8-39.8 cm<sup>2</sup> when pigs reach a live weight of 100 kg and 42.9-44.1 cm<sup>2</sup> – 120 kg, respectively. The animals of experimental group III exceeded the store pigs of control group I in terms of the lion eye area by 3.0 cm<sup>2</sup> (for pre-slaughter live weight of 100 kg), at  $p < 0.001$  and 1.2 cm<sup>2</sup> (for pre-slaughter live weight of 120 kg).

In terms of the weight of half-carcass hind third, there was an increase in the weight of hock in animals of experimental groups II and III, which during the fattening period were fed with adsorbents of mycotoxins both “hepasorbex” and commercial analogue, but no significant differences between groups of animals were found. Thus, the use of mycotoxin adsorbent “gepasorbex” in the diet of store pigs of experimental group III contributed to the improvement of slaughter qualities both with a live weight of 100 kg and 120 kg.

Currently, the pig breeding industry shows a tendency towards increasing meat content while improving the quality of pork. However, most animals with a high yield of meat have an increased moisture content in it and, as a result, flabbiness is recorded and the intensity of the colour of meat raw materials decreases, which causes unprofitability of the entire meat processing industry of the country [16].

The evaluation of slaughter products revealed that the chemical properties of meat depend on the assigned purpose of the group in the experiment. The mass fraction of moisture in the meat of animals of all experimental groups was in the range of 63.75-68.25% at a pre-slaughter weight of 100 kg and 63.21-67.70% – slaughtered at 120 kg (Table 5).

The value of the mass fraction of moisture was within the physiological norm, but there was a significant difference between the groups on this indicator. It should be noted that at a pre-slaughter weight of 100 and 120 kg, animals of both experimental groups II and III had a significantly lower moisture content in meat – 65.43% and 63.75%, 65.12% and 63.21%, respectively, than store pigs of control group I – 68.25% slaughtered at 100 kg and 67.70% – 120 kg, where the differences are statistically significant ( $p < 0.001$ ).

**Table 5.** Chemical composition of the longest back muscle of pigs (*m. longissimus dorsi*), ( $n = 10$ ),  $\bar{X} \pm S_{\bar{X}}$

| Group                               | Mass fraction, % |               |               |              |
|-------------------------------------|------------------|---------------|---------------|--------------|
|                                     | Moisture content | Protein       | Fat           | Ash          |
| Pre-slaughter live weight of 100 kg |                  |               |               |              |
| I – control                         | 68.25 ± 0.389    | 19.08 ± 0.331 | 11.65 ± 0.473 | 1.02 ± 0.029 |
| II – experimental                   | 65.43 ± 0.291    | 19.36 ± 0.326 | 14.09 ± 0.494 | 1.12 ± 0.037 |
| III – experimental                  | 63.75 ± 0.382    | 21.92 ± 0.390 | 13.05 ± 0.362 | 1.28 ± 0.022 |
| +/- II to I                         | -2.82***         | +0.28         | +2.44***      | +0.10*       |
| +/- III to I                        | -4.50***         | +2.84***      | +1.40*        | +0.26***     |
| Pre-slaughter live weight of 120 kg |                  |               |               |              |
| I – control                         | 67.70 ± 0.504    | 18.90 ± 0.327 | 12.22 ± 0.272 | 1.18 ± 0.033 |
| II – experimental                   | 65.12 ± 0.419    | 19.00 ± 0.368 | 14.72 ± 0.312 | 1.16 ± 0.029 |
| III – experimental                  | 63.21 ± 0.480    | 21.75 ± 0.340 | 13.65 ± 0.278 | 1.39 ± 0.027 |
| +/- II to I                         | -2.58***         | +0.10         | +2.5***       | -0.02        |
| +/- III to I                        | -4.49***         | +2.85***      | +1.43***      | +0.21***     |

The presence of adipose tissue in meat is known to increase its caloric content, contribute to its tenderness and flavour, and, in contrast, excessive fat decreases the protein content, as the nutritional value decreases [16; 29; 30].

In terms of the chemical composition of the muscle tissue – at a pre-slaughter live weight of 100 kg, the highest fat content in meat was found in pigs of experimental group II at the level of 14.09%, which significantly exceeded the value of the identical indicator of control group I by 2.44% ( $p < 0.001$ ). At a pre-slaughter live weight of 120 kg, pigs of experimental group II also had the highest mass fraction of fat – 14.72%, which significantly exceeded those of control group I by 2.5% ( $p < 0.001$ ). As for the mass fraction of fat in meat, the animals of experimental group III, which consumed the complex additive of mycotoxin adsorbent “Hepasorbex”, have intermediate position and the value of this indicator at a pre-slaughter live weight of 100 kg, and 120 kg at the level of 13.05% and 13.65%, which evidences the obvious caloric content and tenderness of meat raw materials obtained from animals of this group while maintaining the mass fraction of protein, which affects the nutritional value of meat.

An essential component of meat is proteins, consisting of essential and nonessential amino acids [29]. Thus, in slaughtered animals with a live weight of 100 kg, the store pigs of experimental group III had the greater content of the mass fraction of protein – 21.92% ± 0.390, which ( $p < 0.001$ ) exceeded the same indicator of animals in the control group I. Similarly, the likely prevalence of pigs of experimental group III by the value of this indicator was established in slaughtered store pigs with a live weight of 120 kg – by 2.85% ( $p < 0.001$ ) compared to control animals.

The mass fraction of ash in the meat of pigs of the experimental groups ranged from 1.02% to 1.28% slaughtered at 100 kg of weight and from 1.16% to 1.39% – at 120 kg. A significant difference was found between animals at a pre-slaughter weight of 100 kg: 0.10% ( $p < 0.05$ ) – experimental group II, 0.26% ( $p < 0.001$ ) – experimental group III. At a pre-slaughter weight of 120 kg, a significant difference was observed only in animals of experimental group III – 0.21% ( $p < 0.001$ ), while pigs of experimental group II were by 0.02% inferior to control analogues, although the difference was not statistically significant. Thus, given the increased moisture content and a lower percentage of dry matter in

meat obtained from pigs of control group I slaughtered at 100 kg of weight, a lower ash content of  $1.02\% \pm 0.029$  was detected. The lowest ash content –  $1.16\% \pm 0.029$  is found in animals of experimental group II slaughtered at 120 kg.

A similar study on the effect of sorbents on the slaughter performance of pig carcasses was conducted by M. Ossowski, Ł. Wlazło, B. Nowakowicz-Dębek, M. Florek, in their manuscript “Effect of natural sorbents in the diet of fattening pigs on meat quality and suitability for processing” [41] investigated and evaluated the effect of sorbents, mainly on the physicochemical properties of pork. Results showed that the addition of 0.5% zeolite to the feed for crossbred pigs (Landrace × Yorkshire × Duroc) had no significant effect on the approximate chemical composition of the long muscle (loin), but lower moisture (70.23%) and ash (1.16%), but higher protein (26.06%) and fat (2.55%) were recorded, which is consistent with the studies conducted.

### Conclusions

Based on the results of the experiment, it was determined that animals that received a complex additive of mycotoxin adsorbent “Gepasorbex” LLC “Vetservisproduct” had higher performance.

1. Pigs of experimental groups II and III, which consumed feed containing adsorbents of mycotoxins had a significant ( $p < 0.001$ ) increase in live body weight by 2.3-4.2 kg and

3.6-7.0 kg; average daily gains – 41.5-47.3 g, 67.7-68.0 g; reached weight standards of 100 kg (by 3 and 6 days) and 120 kg (by 6 and 9.5 days) earlier with a lower feed conversion by 0.2-0.45 and 0.28-0.54 kg, respectively, compared to animals of the control group.

2. When using mycotoxin adsorbent “Gepasorbex” in the diet of store pigs of experimental group III with a pre-slaughter weight of 100 and 120 kg increased: the slaughter yield – by 0.5-4.1% ( $p < 0.001$ ); the length of the half carcass – by 1.0-2.1 cm ( $p < 0.05$ ); lion eye area – by 1.2-3.0 cm<sup>2</sup> ( $p < 0.001$ ); the weight of the hind third of the half carcass – by 0.5-0.7 kg ( $p < 0.05$ ) and the lard thickness index decreased by 4.2-8.2 mm ( $p < 0.001$ ), respectively, compared to pigs of control group I.

3. The chemical composition of the meat of the animals of the experimental groups, both when slaughtered at 100 kg and 120 kg, met the requirements for pork of normal quality (NORMAL). At a live weight of 100 and 120 kg, pigs of experimental group III with the use of “Hepasorbex” in meat had significantly ( $p < 0.001$ ), %: lower moisture content by 4.49-4.50; higher protein content – by 2.84-2.85, fat – by 1.40-1.43, ash – by 0.2-0.26.

The obtained results determine the prospects for further research in continuing to study the effect of feed sorbents on the productive traits of other technological groups of pigs.

### References

- [1] Kępińska-Pacelik, J., & Biel, W. (2021). Alimentary risk of mycotoxins for humans and animals. *Toxins*, 13(11), article number 822. doi: 10.3390/toxins13110822.
- [2] Piotrowska, M. (2021). Microbiological decontamination of mycotoxins: Opportunities and limitations. *Toxins*, 13(11), article number 819. doi: 10.3390/toxins13110819.
- [3] Stoycho, D.S. (2013). Food Safety and increasing hazard of mycotoxin occurrence in foods and feeds. *Critical Reviews in Food Science and Nutrition*, 53(9), 887-901. doi: 10.1080/10408398.2011.571800.
- [4] Bryden, W.L. (2012). Mycotoxin contamination of the feed supply chain: Implication of animal productivity and feed security. *Animal Feed Science and Technology*, 173(1-2), 134-158. doi: 10.1016/j.anifeedsci.2011.12.014.
- [5] Caisin, L., Harea, V., & Bivol, L. (2011). Using enterosorbent Praimix Alfasob in feeding growing piglets. In *Scientific Papers, UASVM of Bucharest. Series D: Animal science, LIV* (pp. 25-30). Retrieved from [http://dspace.uasm.md/bitstream/handle/123456789/4504/07\\_caisin\\_25-30.pdf?sequence=1&isAllowed=y](http://dspace.uasm.md/bitstream/handle/123456789/4504/07_caisin_25-30.pdf?sequence=1&isAllowed=y).
- [6] Holanda, D.M., & Kim, S.W. (2020). Efficacy of mycotoxin detoxifiers on health and growth of newly-weaned pigs under chronic dietary challenge of deoxynivalenol. *Toxins*, 12(5), article number 311. doi: 10.3390/toxins12050311.
- [7] Remyzova, Yu.A. (2019). *The influence of microclimate on the homeostasis of the pig body, productivity and quality of pork* (Doctoral thesis, Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Sciences, Poltava, Ukraine).
- [8] Faustov, R., Lykhach, V., Lykhach, A., Shpetny, M., & Lenkov, L. (2022). Effect of a new complex mycotoxin adsorbent on growth performance, and serum levels of retinol, tocopherol and 25-hydroxycholecalciferol in pigs fed on mycotoxin-contaminated feed. *Online Journal of Animal and Feed Research*, 12(1), 107-113. doi: 10.51227/ojafr.2022.2.
- [9] Elliott, C.T., Connolly, L., & Kolawole, O. (2020). Potential adverse effects on animal health and performance caused by the addition of mineral adsorbents to feeds to reduce mycotoxin exposure. *Mycotoxin Research*, 36, 115-126. doi: 10.1007/s12550-019-00375-7.
- [10] Gregorio, M.C.D., Neeff, D.V., Jager, A.V., Corassin, C.H., Pinho Carão, Á.C., Albuquerque, R., Azevedo, A.C., & Oliveira, C.A.F. (2014). Mineral adsorbents for prevention of mycotoxins in animal feed. *Toxin Reviews*, 33(3), 125-135. doi: 10.3109/15569543.2014.905604.
- [11] Horky, P., Nevrlka, P., Kopec, T., Bano, I., Skradanka, J., & Skalickova, S. (2022). Is a new generation of mycotoxin clay adsorbents safe in a pig's diet? *Porcine Health Management*, 8, article number 31. doi: 10.1186/s40813-022-00275-w.
- [12] Lykhach, A.V., Lykhach, V.Ya., Faustov, R.V., & Lenkov, L.G. (2018). “Gepasorbex” – solving the problem of mycotoxins in industrial pig farming. *Taurian Scientific Bulletin*, 1(100), 172-176.
- [13] Mycotoxins. Effects on animals. (2017). *Globus*. Retrieved from <http://globusp.com/uk/mikotoksini-vpliv-na-tvarin.html>.
- [14] Popsuy, V. (2012). Safety of feed for pigs. *Offer*. Retrieved from <http://propozitsiya.com/ua/bezpechnist-kombikormiv-dlya-sviney>.
- [15] Nutriecconomics in pig farming – in search of sources of additional profit. (n.d.). *Agrarian Week, Ukraine*. Retrieved from <http://a7d.com.ua/analtika/tehnology/2216-nutriekonomika-u-svinarstvi-u-poshukax-dzherel.html>.

- [16] Voloshchuk, V.M., Zhukorskyi, O.M., Bankovska, I.B., & Semenov, S.O. (2020). *Assessment, forecasting and production of high-quality pig products*. Kyiv: Agrarian Science.
- [17] Topikha, V.S. (Ed.). (2012). *Technology of pig production*. Mykolaiv: MNAU.
- [18] Povod, M.G. (2021). *Technology of pig production*. Kyiv: Scientific and Methodological Center of VFPO.
- [19] Tsereniuk, O.M., & Timofienko, I.M. (2013). Veterinary support in pig farming. *Agribusiness Today*. Retrieved from <http://agro-business.com.ua/agro/suchasne-tvarynnytstvo/item/8073-veterynarne-zabezpechennia-u-svynarstvi.html>.
- [20] Holanda, D.M., & Kim, S.W. (2021). Mycotoxin occurrence, toxicity, and detoxifying agents in pig production with an emphasis on deoxynivalenol. *Toxins*, 13, article number 171. doi: 10.3390/toxins13020171.
- [21] Kihal, A., Margues, C., Rodrigues-Prado, M., Jose-Cunileras, E., & Calsamiglia, S. (2022). Effect of diet supplementation with the mycotoxin binder montmorillonite on the bioavailability of vitamins in dairy cows. *Toxins*, 14(1), article number 26. doi: 10.3390/toxins14010026.
- [22] Schell, T.C., Lindemann, M.D., Kornegay, E.T., & Blodgett, D.J. (1993). Effects of feeding aflatoxin-contaminated diets with and without clay to weanling and growing pigs on performance, liver function, and mineral metabolism. *Journal of Animal Science*, 71(5), 1209-1218. doi: 10.2527/1993.7151209x.
- [23] Reddy, K.E., Song, J., Lee, H.J., Kim, M., Kim, D.W., Jung, H.J., Kim, B., Lee, Y., Yu, D., Oh, Y.K., & Lee, S.D. (2018). Effects of high levels of deoxynivalenol and zearalenone on growth performance, and hematological and immunological parameters in pigs. *Toxins*, 10(3), article number 114. doi: 10.3390/toxins10030114.
- [24] Weaver, A.C., See, M.T., & Kim, S.W. (2014). Protective effect of two yeast-based feed additives on pigs chronically exposed to Deoxynivalenol and Zearalenone. *Toxins*, 6(12), 3336-3353. doi: 10.3390/toxins6123336.
- [25] VNTP-APK-02.05 "Departmental norms of technological design Pig enterprises (complexes, farms, small farms)". (2005). Kyiv: Ministry of Agricultural Policy of Ukraine. Retrieved from [https://lugdpss.gov.ua/images/bezpechnist\\_veterynariya/Svynarski-pidpryyemstva-VNTP-APK-02.05.pdf](https://lugdpss.gov.ua/images/bezpechnist_veterynariya/Svynarski-pidpryyemstva-VNTP-APK-02.05.pdf).
- [26] Ibatulin, I.I., & Zhukorskyi, O.M. (2017). *Methodology and organization of scientific research in animal husbandry*. Kyiv: Ahrarna nauka.
- [27] Modern methods of research in pig breeding. (2005). Poltava: Institute of Pig Breeding of the Ukrainian Academy of Sciences.
- [28] Maletska, O.E. (2022). *Analysis of the requirements of DSTU EN ISO/IEC 17025:2019. Requirements for measurement and test methods*. Retrieved from <https://www.ipkm.org.ua/analiz-vimog-2-dstu-iso-iec-17025-2>.
- [29] Baranova, G.S. (2014). Meat and fat productivity and physicochemical properties of pig meat of different genotypes. *Bulletin of the Poltava State Agrarian Academy*, 2, 169-172.
- [30] Ponomarenko, V.M., & Voytenko, S.L. (2012). Amino acid composition of pig meat of different genotypes. *Animal Husbandry of Ukraine*, 10, 7-9.
- [31] DSTU ISO 936:2008 "Meat and meat products. Method for determining the mass fraction of total ash (ISO 936:1998, IDT)". (2008). Kyiv: State Standards of Ukraine.
- [32] Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. *Official Journal of the European Union*, 221, 23-27.
- [33] Regulation (EC) No. 806/2003 of 14 April 2003 adapting to Decision 1999/468/EC the provisions relating to committees which assist the Commission in the exercise of its implementing powers laid down in Council instruments adopted in accordance with the consultation procedure. *Official Journal of the European Union*, 122, 1-35.
- [34] Council Directive 91/630/EEC of 19 November 1991 laying down minimum standards for the protection of pigs. *Official Journal of the European Union*, 340, 33-38.
- [35] Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs (Codified version). *Official Journal of the European Union*, 47, 5-13.
- [36] Subramaniam, M.D., & Kim, I.H. (2015). Clays as dietary supplements for swine: A review. *Journal of Animal Science and Biotechnology*, 6, 1-9. doi: 10.1186/s40104-015-0037-9.
- [37] Li, J.H., & Kim, I.H. (2013). Effects of dietary supplementation of sericite on growth performance, nutrient digestibility, blood profiles and fecal microflora shedding in growing pigs. *Animal Feed Science and Technology*, 184(1-4), 100-104. doi: 10.1016/j.anifeedsci.2013.04.010.
- [38] Alexopoulos, C., Papaioannou, D.S., Fortomaris, P., Kyriakis, C.S., Tserveni-Goussi, A., Yannakopoulos, A., & Kyriakis, S.C. (2007). Experimental study on the effect of in-feed administration of a clinoptilolite-rich tuff on certain biochemical and hematological parameters of growing and fattening pigs. *Livestock Science*, 111(3), 230-241. doi: 10.1016/j.livsci.2007.01.152.
- [39] Kim, J.H., Kim, S.C., & Ko, Y.D. (2005). Effect of dietary zeolite treated on the performance and carcass characteristics in finishing pigs. *Journal of Animal Science and Technology*, 47, 555-564.
- [40] Yu, D.Y., Li, X.L., & Li, W.F. (2008). Effect of montmorillonite superfine composite on growth performance and tissue lead level in pigs. *Biological Trace Element Research*, 125, 229-235. doi: 10.1007/s12011-008-8173-0.
- [41] Ossowski, M., Wlazło, Ł., Nowakowicz-Dębek, B., & Florek, M. (2021). Effect of natural sorbents in the diet of fattening pigs on meat quality and suitability for processing. *Animals*, 11(10), article number 2930. doi: 10.3390/ani11102930.

## **Вплив нового комплексного сорбенту мікотоксинів у раціонах свиней на їхні показники росту, відгодівельні та м'ясні ознаки**

**Вадим Ярославович Лихач<sup>1</sup>, Анна Василівна Лихач<sup>1</sup>, Ростислав Вікторович Фаустов<sup>2</sup>, Євген Володимирович Баркар<sup>2</sup>, Леонід Григорович Леньков<sup>3</sup>**

<sup>1</sup>Національний університет біоресурсів і природокористування України  
03041, вул. Героїв Оборони, 15, м. Київ, Україна

<sup>2</sup>Миколаївський національний аграрний університет  
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна

<sup>3</sup>ТОВ «ВетСервісПродукт»  
08132, вул. Київська, 6-Г, м. Вишневе, Київська область, Україна

**Анотація.** Дотримання безпеки кормів у тваринництві вимагає від виробників свинини додавання до раціонів свиней адсорбенти, що зв'язують мікотоксини. З цієї причини, мета дослідження полягала в оцінці дії двох комплексних сорбентів, що додані до раціону відгодівельних свиней на їх продуктивність. В експерименті використано 90 голів свиней, які утримувались у ТОВ «Таврійські свині» Херсонської області. Дослідні тварини, за принципом аналогів поділені на три групи по 30 голів у кожній: I контрольна група свиней використовували основний раціон «Гроуер», «Фінішер»; свині II дослідної групи споживали основний раціон «Гроуер», «Фінішер» з додаванням 0,15 % за масою корму комерційного аналогу адсорбенту мікотоксинів; тваринам III дослідної групи застосовували основний раціон «Гроуер», «Фінішер» з додаванням 0,15 % за масою корму комплексного препарату «Гепасорбекс». Тварини, які споживали комбікорм, що містив адсорбенти мікотоксинів мали більшу живу масу тіла, середньодобові прирости, раніше досягали вагових кондицій 100 і 120 кг із нижчою конверсією корму, порівняно з аналогами контрольної групи. Встановлено, що за використання «Гепасорбекс» у раціоні молодняка свиней III дослідної групи за передзабійної маси 100 і 120 кг збільшилися: забійний вихід, довжина напівтуші, площа «м'язового вічка», маса задньої третини напівтуші та знизився показник товщини шпиків, порівняно з аналогами контрольної групи. За хімічним складом м'ясо тварин піддослідних груп як при забої у 100 кг, так і у 120 кг, відповідало вимогам щодо свинини нормальної якості (NORMAL). За живої маси 100 і 120 кг свині III дослідної групи у м'ясі мали вірогідно нижчий вміст вологи, більший вміст білка, жиру і золи. За рахунок комплексного складу компонентів «Гепасорбекс» поживні речовини у складі комбікорму залишалися і засвоювалися організмом свиней, що підтверджується вищими показниками продуктивності та суттєво здешевлює основну витратну статтю господарств із технологій виробництва продукції свинарства – «Корми». Тому, корисними дані дослідження є для фахівців з виробництва і переробки свинини у розробці стратегій годівлі свиней та отримання якісної сировини для переробних підприємств, що відкриває шляхи для забезпечення продовольчої безпеки країни

**Ключові слова:** вагова кондиція, годівля, кормові сорбенти, продуктивність, свинарство



UDC 664.643.1

DOI: 10.31548/animal.13(2).2022.35-43

## Technical and Economic Substantiation of the Process of Semi-Fluidisation Treatment of Fruit and Berry Products

Ihor Palamarchuk<sup>1\*</sup>, Vladyslav Palamarchuk<sup>2</sup>, Viktor Sarana<sup>1</sup>, Yaroslava Heipel<sup>1</sup>, Bohdan Borodych<sup>1</sup>

<sup>1</sup>National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<sup>2</sup>Vinnitsia Institute of Trade and Economics of Kyiv National University of Trade and Economics  
21050, 87 Soborna Str., Vinnitsia, Ukraine

**Abstract.** The search for effective patterns for implementing the semi-fluidisation process for freezing and partial freezing of fruit and berry products under the condition of minimising energy consumption and high productivity of the process constitutes the relevance of the research. The purpose of the study is to develop energy-efficient and reliable technological solutions for the implementation of vibro-wave refrigeration processing of fruit and berry products based on the development of a vibration transport and technological fluidisation machine; determination of power and energy characteristics of the semi-fluidisation process; substantiation of rational speed modes of raw material movement in the processing zone. Based on a comparative analysis of the design and technological characteristics of wave, conveyor and vibration machines, the main trends in their development were substantiated; the main power and energy parameters of the developed oscillatory system were determined. A comparative analysis of the technological schemes of semi-fluidisation using the transport movement of products by belt and vibrating wave conveyor was carried out, which allowed substantiating the effectiveness of the use of the corresponding drive mechanisms of the studied machine. Graph-analytical analysis of the speed and energy parameters of the studied semi-fluidisation process on the basis of the obtained theoretical and experimental data allowed to verify the adequacy of the developed mathematical model and to substantiate the main parameters of the operating mode of the technological load advancement along the processing zone. The conducted research using the developed experimental model and the classical belt conveyor showed an increase in the speed of transportation of raw materials by almost 2 times with a decrease in energy consumption for the process by 1.4 times for the vibro-wave scheme. In the developed vibrating transport-technological semi-fluidisation machine, the vibration effect provides a decrease in technological resistance in the mass of products, significantly reducing the force effect on it, as a result of the generated travelling wave on the surface of the load-carrying body, the movement of the processed material along the belt and continuous mixing or renewal of product layers are provided. The practical value of the study includes the use of a combined scheme for creating a fluidised layer of products due to the oscillation of the belt and bubbling with the flow of coolant; the use of the belt wave to create the movement of products in the production area

**Keywords:** vibration, wave conveyor, small-scale raw materials, unbalanced oscillation system, low-temperature processing, unbalanced vibration exciter

### **Suggested Citation:**

Palamarchuk, I., Palamarchuk, V., Sarana, V., Heipel, Ya., & Borodych, B. (2022). Technical and economic substantiation of the process of semi-fluidisation treatment of fruit and berry products. *Animal Science and Food Technology*, 13(2), 35-43.

\*Corresponding author

## Introduction

The search for favourable conditions for the intensification of the production process with effective action on the object of the processing; implementation of technological movement in a continuous mode; maximum reduction of unproductive labour when performing auxiliary functions by the system; mutual coordination of technological influences in controlling the dynamic state of the system, in particular, with the multifunctionality of the components of the technological system and their harmonious application are the main trends in the development of processes and equipment, in particular in the processing and food industries. Among the machines that meet these properties, one can distinguish vibrating transport and technological machines, which include semi-fluidisation devices. During the operation of these machines, technological and transport movement are realised in one unit and two quite common technological actions are combined: the use of advanced technologies with the involvement of low-frequency oscillations in the conveyor form of the organisation of the treatment process.

The technical term “conveyor” comes from the English “convey”, which defines the equipment for the transportation or continuous movement of certain goods, which are divided into bulk, lumpy, elastic, viscous or bound [1; 2]. The current or technologically continuous method of implementation of technologies makes it possible to realise such production factors as proportionality, dynamism and direction of the technological process, which is the potential for increasing productivity, reducing the labour intensity of manufacturing products and allows processing on automated production lines. Such lines in automated or complex mechanised operating modes practically eliminate contradictions between transport and technological movements, creating conditions for harmonious and rational use of technological equipment.

The use of low-frequency oscillations in the processing of products provides an increase in the intensity of processing by increasing the surface of heat and mass transfer, softening the force action on the particles of raw materials, reducing the internal coefficient of friction and viscosity, which reduces energy consumption for the process and in aggregate allows realising new technological possibilities. The latter are often unique, allowing to significantly increase the efficiency of the implementation of such common operations in food technology as separation, mixing, movement of products with specific properties, homogenisation, filtering, grinding, dehydration and drying, a saturation of technological masses with specific ingredients and media under conditions of mechanical and heat and mass exchange processes [3; 4].

The complex application of vibration impact in conveyor technology, which takes place during the operation of conveyor semi-fluidisation machines, corresponds to the highest form of interaction of technological and transport movements in the implementation of low-temperature processes, namely, the implementation of technological action during transport movement, which allows automating the production process, determines the optimal functioning of the main structural components of the technical system, increases the efficiency of volumetric action on technological masses, which determines the relevance of this study.

Semi-fluidisation apparatuses are transport and technological machines in which such low-temperature operations as freezing and partial freezing are implemented, carried out in the conditions of a fluidised layer of products, which at the same time is moved by a conveyor with a flexible load-carrying body. Among the machines, the structure of which combines the above-mentioned technological factors of increasing the efficiency of technological equipment, it is possible to note vibrating transport and technological machines.

In terms of technical and economic efficiency of the studied technical system, conveyor machines perform not only a purely transport function, but are also used as transfer devices in technological automated lines for certain product processing. The focus of technological and transport action, and the simplicity of automation of conveyor control determine them as an integral part of modern production processes and devices, regulating the pace of production and realising its rhythmicity. This can significantly improve the technical and economic parameters of production, increasing labour productivity and output tenfold, to ensure synchronisation and proportionality between transport and technological movements, between the main and auxiliary operations, expanding the functionality of the equipment; complex mechanisation and automation of production processes, which is systematised in the studies by V.N. Poturaev [5], O.V. Tsurkan [6], I.P. Palamarchuk [7].

An essential feature of the conveyor vibration technological machine under study is the possibility of using low-frequency vibrations to create a fluidised layer of products with the current method of organising low-temperature processing. The transport process under such conditions can be defined as an integral and auxiliary part of the technological movement. Vibration action is the main dynamic factor in the processing of products, usually loose or small pieces, which include fruits, berries and small vegetables, as expressed in studies by R. Leruk [8], G. Semenov [9], I. Chang [10], H. Yang [11], L. Wei [12]. At the same time, depending on the design of conveyor-type equipment, the implementation of transport and technological movements may differ in time and functional content. Therefore, the performance of production tasks in the process of moving the masses of products or technological media eliminates the contradiction between transport and technological movement, which brings the design perfection of this equipment closer to its highest forms.

Unlike vibrating conveyor machines, which move products in different horizontal directions and altitude levels, transport and technological machines are of a higher level of perfection, carrying out in the process of transportation and technological processing of the bulk product being moved, in particular, drying, extraction, crystallisation and other heat and mass transfer processes. The multifunctional nature of such technical systems is characterised by the complication of the design of their elements, and the establishment of practically separate transporting elements, which are often quite complex, eliminating the advantages of the current structure of production. At the same time, the challenge of increasing the level of mechanisation and automation of production causes difficulties in the mutually coordinated functioning of transport and technological links. Obviously, the implementation

of effective conveyor technical systems in the conditions of low-frequency oscillations in the processes of low-temperature processing is relevant and widespread.

Semi-fluidisation or semi-fluidisation is realised in common devices by ventilation with a jet of cold air in the direction from bottom to top through perforations on the moving belt at a speed not exceeding the critical value. The intensive heat and mass exchange effect on the surface layer of the raw material creates issues of its overcooling and unevenness of layer-by-layer processing; there is relatively high energy consumption when creating a fluidised layer due to significant resistance when bubbling the product with a flow of coolant. In addition, the disadvantages of these machines are the complex design, the creation of an uneven vertical movement of the product layer in the device, low heat exchange intensity and relatively low process productivity.

Harmonious in constructive and technical and economic terms, the combination of the directions of vibration processing and transportation systems is a high potential and prospects for the development of production processes were traced in the scientific works of both well-known vibration technologists and designers of the food technology industry, namely, O. Avci [13], as one of the first founders of the development of vibration technological machines; P.S. Bernyk and I.P. Palamarchuk, who in their designs combined vibromechanical, pneumodynamic and electromagnetic technological influences specifically for the processes of processing and food technologies [14]; J. Rapur and R. Tiwari [15], who initiated the broad application of vibrating machines in food production; O. Spivakovskiy and A. Chervonenko [16], the pioneers of the conveyor machines development and use; and recognised founders of technologies and equipment of food and processing agricultural production, O.G. Burdo [17], V.D. Popova [18], V.N. Stabnikov [19] and other prominent scientists.

*The purpose of this study* is to reduce energy consumption during intensive refrigeration processing of fruit and berry products by developing a structural and technological scheme of a vibrating wave fluidisation machine; determine the power and energy characteristics of this semi-fluidisation process; substantiation of rational speed modes of raw material movement in the processing zone. The scientific novelty of this investigation consists in the development of a vibromechanical source for creating a travelling and standing wave of a flexible load-carrying body. To achieve this goal, the following main tasks were set:

- based on the analysis of structural links of conveyor, wave and vibration machines, to substantiate their functional features and main trends in the development

of vibration-wave transport and technological technical systems;

- determine the main power and energy parameters of the developed oscillatory system and a typical scheme of transport and technological movement of the mass of bulk or small-lump loading;

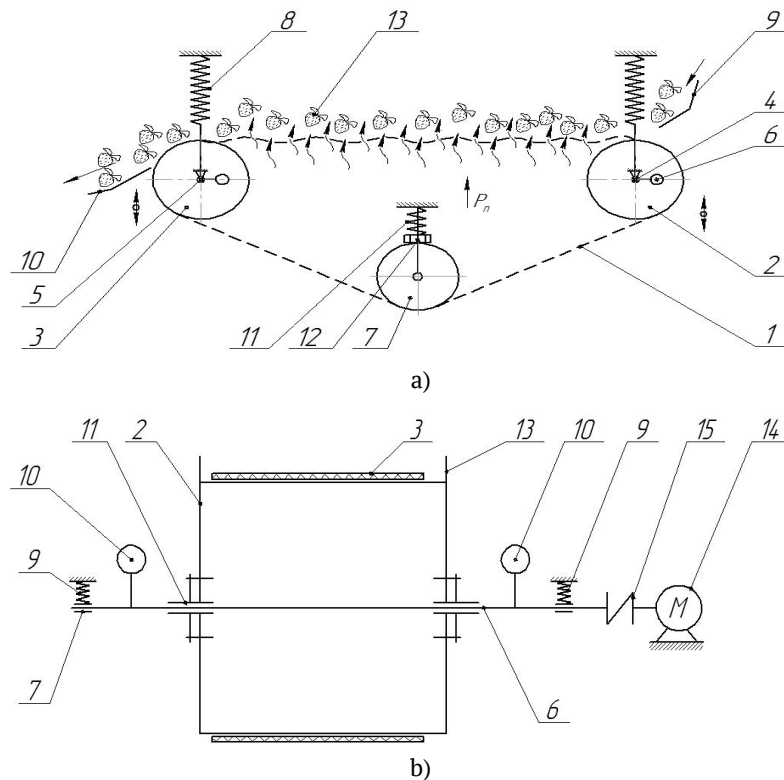
- substantiation of rational speed modes of raw material movement in the processing zone under the condition of minimising energy consumption for the process and ensuring high intensity of processing.

## Materials and Methods

Among the main stages of the research conducted during 2018-2022 are the development and manufacture of a pilot plant for the implementation of the semi-fluidisation process; compilation of the necessary measuring base for estimating the electromechanical and heat exchange parameters of the process; analytical determination of the main kinematic, power and energy parameters using the characteristics of the experimental model; determination of the power and energy parameters of this process for 2 options: with the vibration-wave movement of products and during its transportation by a conventional belt conveyor; processing and graphical interpretation of the comparative analysis of the two presented semi-fluidisation schemes; verifying the validity of the developed mathematical model.

This study shows that the use of a wave conveyor provides both the formation of a fluidised layer and the transfer of products in the production area at a controlled speed [20]. In this case, the transport wave is created due to the vibration of the belt support roller. In such vibration transport and technological infrared machine, the vibration exposure provides a reduction in technological resistance in the mass of products, significantly reducing the force effect on it, as a result of the generated travelling wave on the surface of the load-carrying body, the movement of the processed material along the belt and continuous mixing or renewal of product layers are provided.

For experimental assessment of the transport parameters of fruit and vegetable products during their low-temperature processing, the developed experimental model of a vibration-wave semi-fluidisation machine was used. In this installation (Fig. 1), vibration has a complex effect on the technological parameters of heat and mass transfer treatment: loosens the mass of raw materials, increasing the area of heat exchange with the coolant; constantly mixes and renews the surface layers of the product; creates a standing or travelling wave on the supporting transporting surface to move the product in the production area along a controlled trajectory.



**Figure 1.** Vibrating semi-fluidisation machine (a) with spatial vibration drive in support rollers (b):  
 1 – driving roller; 2 – supporting roller; 3 – conveyor belt; 4 – processed products; 5 – infrared emitters;  
 6 – eccentric shaft of the vibrating exciter; 7 – supporting unit of the vibration exciter;  
 8 – a platform of the vibration exciter; 9 – elastic elements of the supporting unit of the vibration exciter;  
 10 – counterweight; 11 – supporting unit of the roller; 12 – vibration supports; 13 – roller flange;  
 14 – motor of the drive of the vibration exciter; 15 – an elastic clutch of the vibration exciter;  
 16 – drive motor of the drive roller; 17 – drive pinion of the drive roller; 18 – driven gear of the drive roller;  
 19 – supporting units; 20 – elastic coupling of the drive roller; 21 – drive axis of the drive roller;  
 22, 23 – supporting units of the axis of the drive roller; 24 – debalance

To obtain the necessary base of experimental data, a set of devices of the microcontroller system was developed and used, which is presented in more detail in [19]. Such a system contains electrical devices; sensors for evaluating heat exchange parameters; vibrometers for determining the amplitude-frequency and force characteristics; aerometers and accelerometers for measuring and regulating the amplitude-frequency and force parameters, kinematic characteristics of the coolant flow of the semi-fluidisation process under study.

In the developed fluidisation apparatus, a fluidised layer is created using a kinematic eccentric vibration drive (Fig. 1) contains a working surface 1, a support roller 2, a conveyor belt 3, tension rollers 4,5, a drive eccentric shaft 6, a support unit 7 of the device, a support for an elastic suspension 8, an elastic suspension 9, a counterweight 10, bearings 11, a support unit 12 of the roller, a flange 13, a drive motor 14, a spring clutch 15. A conveyor belt 3 with tension rollers 4,5 is installed on the working surface 1 of the support roller 2, a kinematic eccentric vibration drive, the drive eccentric shaft 6 is fixed in the support unit 7, the elastic suspension 9 is fixed on the support of the elastic suspension 8, to level the parasitic inertial loads, a counterweight 10 is installed, bearings 11 in the supporting unit 12 of the roller, place the flange 13 above the conveyor belt 3, the shaft 6 is connected to the drive motor 14 by means of

a spring clutch 15 to prevent the transmission of vibrations to the motor 14. During the operation of the device, the bulk material is delivered to the conveyor belt 3. The drive motor 14 through a flexible coupling 15 provides torque to the eccentric shaft 6, the rotation of which ensures the passage of a dynamic travelling wave on the surface of the belt 3, creating a fluidised state of the processing material and its translational movement along the surface of the load-carrying body. Such a vibration drive is characterised by a decrease in oscillating masses, which reduces energy consumption by 1.5-2 times for the implementation of the oscillatory process compared to the unbalanced one [21]. The oscillating movement of the rollers is transmitted to the flexible conveyor belt 3, forming a travelling or standing dynamic wave on its surface. The kinematic characteristics of this wave, namely the phase frequency and amplitude of oscillations determine, respectively, the speed of product advancement and the thickness of the formed fluidised layer. These characteristics can be changed by adjusting the ratios of amplitudes and frequencies of oscillations for the drive eccentric shaft 6. Thus, the bulk mass of products receives a transport movement due to changes in the parameters of the generated wave, and not due to the longitudinal movement of the conveyor belt.

The use of an accelerometer in the mode of an autonomous probe allows evaluation the effect of vibrations

on the formation of wave motion of the product mass through the response of kinematic parameters and processing time.

The developed microcontroller system is used to determine the main heat and mass exchange parameters of the semi-fluidisation process under study. Besides measuring temperature and humidity values, the system measures the speed of the refrigerating medium, which determines its flow rate and the necessary data for the current calculation of the humidity of the products in the production area. The system has a timer feature. The current temperature and humidity data is automatically stored, and it is possible to pre-set timestamps with an accuracy of up to a minute. The values measured at these points will also be recorded. Data and checkpoint memory are energy-dependent. The accumulated and current information about the parameters of the dewatering process can be transmitted to a computer for further analysis, processing and calculation using the Mathcad programme.

When connected, the microcontroller and computer clock are automatically synchronised. The calculation of the current moisture content of the product is performed by a computer using the obtained values of the coolant moisture content and the entered constants that characterise this process. The application of the developed system provides normalised values of the cooling temperature and allows monitoring of the heat and mass transfer process to determine the rational parameters of the process.

Modern concepts of the theory and basic provisions of the mechanics of deformable solid bodies, solid and bulk media, elasticity theory, vibration processing and transport theory are used for theoretical research [22]. When performing experimental studies, German Robotron equipment was used to assess the kinematic parameters of vibration, and electromechanical equipment to ensure a slow change in the speed of rotation of the drive shaft of the vibration exciter.

## Results and Discussion

The technological effect of vibration can be branched into three main components: targeted effect on the mass of processed products, on the working container and on the working bodies of the machine; targeted change in the technological resistance of the system; functional universalisation when using vibromechanical elements, which are presented in detail in Figure 1. The vibration effect is especially effective for the intensification of heat and mass transfer processes due to a significant increase in the contact area in the conditions of a vibration-weighted layer; improvement of the uniformity of layer-by-layer processing and smoothing of thermal stresses in the material, which is quite important for thermolabile systems; simplicity of implementation and ease of coordination of transport and technological movements in the working area of the devices.

Well-known scientists have proved that the processing of bulk or small lumps of products is characterised by the high dynamic action of the working bodies; the acoustic effect of shock waves can be traced in complex with it [23; 24]. Vibratory movement of technological masses is carried out, as a rule, with a constant or slowly variable speed; which is explained by the phenomena of alternate change of withdrawal movements – displacement of equilibrium positions, the appearance of one or more discrete

positions of quasi-equilibrium; imaginary transformation of dry friction into viscous friction. As a result of reducing the effective coefficient of friction and internal viscosity under conditions of low-frequency oscillations, which leads to an increase in the uniformity of processing up to 100% of the active contact surface in a fluidized layer with a 2-3 times reduction in the processing time and a corresponding decrease in energy consumption [25; 26]. Thus, vibromechanical processing in combination with pneumatic and hydrodynamic actions gives a high potential for effective changes in the physical and chemical processes of product processing, which substantiates vibration processing as one of the most effective types of technological action, becoming increasingly common in food production [27].

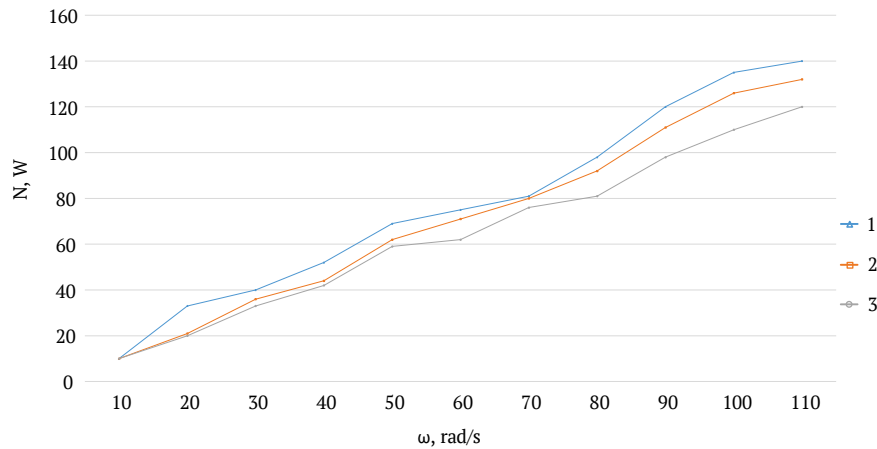
Application of the kinematic forced vibration drive of the proposed design, by installing the drive eccentric shaft, support roll, counterweight, bearings of the support roll, support roll assembly, flange, tension rolls, spring clutch; the presence of elastic suspension of volumetric action, the working rolls carry out forced reciprocating and oscillatory motion, which forms a pseudo-rarefied layer, which allows to simplify the design, improve the vertical movement of the product, increase the intensity of heat and mass transfer due to bringing to 100% the contact surface with the coolant.

Using devices for monitoring vibration parameters, the developed microcontroller system analysed the main technical and economic parameters through the speed and energy characteristics of the technical system under study. The study was conducted at different angles of the imbalances relative to each other to estimate the force action from mechanical vibration exciters. The latter are double gallet elements, the mass of which is not symmetrical with respect to the axis of the drive shaft. Therefore, when changing the angle between these fillings from 0 to  $\pi$  (0, 60°, 90°, 120°, 180°) the inertia force of unbalanced masses decreased inversely from the maximum value to zero. Changing the relative location of the imbalances allowed to trace their influence on the above parameters of low-frequency oscillations. Changes in the positions of unbalanced elements relative to the vertical axis of the machine create an effect on the drive body by force, moment or their combinations, which causes states or modes of force, moment and combined unbalance in the oscillating system and allows determining the corresponding characteristics of the vibration-wave transportation of technological masses. The levelling of parasitic oscillations is realized in the presence of a spring-loaded suspension of the guide belt of the developed semifluidization machine, which can be traced by the changes in the amplitude of oscillations of the supporting unit of the vibration exciter by almost an order of magnitude [28; 29].

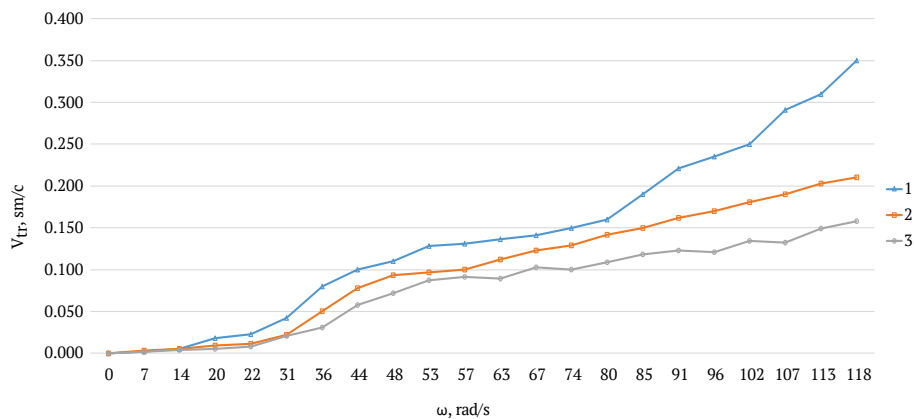
To generate low-frequency vibrations and convert them into wave motion of the belt during interoperative transportation of fruit and berry products in the studied machine, the use of two mechanical inertial or power vibration exciters mounted in the support rollers of the belt mechanism was provided. The machine uses vibration drives with inertial elements – debalances 10 (Fig.1). Changing the angle between these elements and the relative position to the roller 2 allows implementing alternative schemes of mechanical vibration excitation: eccentric or forced kinematic and unbalanced inertial vibration drives.

Accordingly, at the force unbalance of the oscillating system, that is, under the action of only inertial loads, only unbalanced forces act on the drive shaft, at the momentary

unbalance – the result of the action of only moments and at the combined unbalance – when both forces and moments affect the actuator (Figs. 2, 3).



**Figure 2.** Power consumption of the drive body of the machine from the frequency characteristics for such modes of power technological action: 1 – for combined unbalance; 2 – for momentary unbalance; 3 – for power unbalance



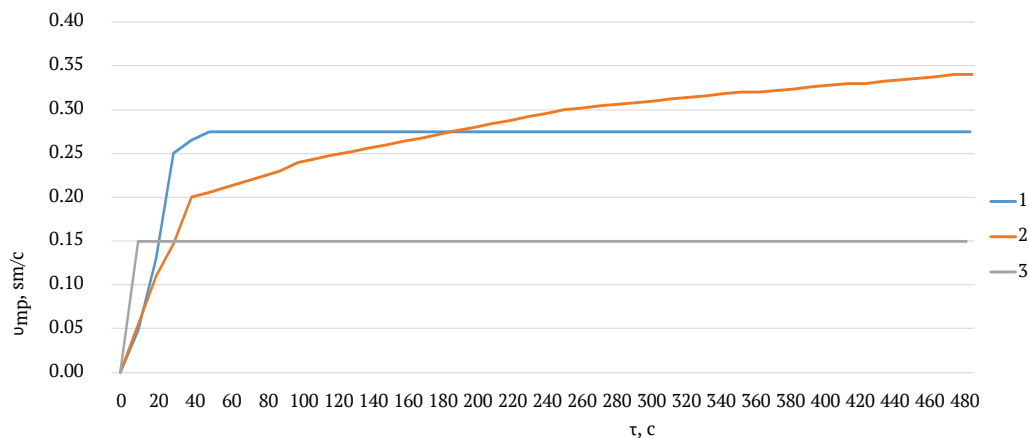
**Figure 3.** The speed of transportation of processed products depending on the angular speed of rotation of the drive shaft  $\omega$  for such modes of power technological action: 1 – for combined unbalance; 2 – for momentary unbalance; 3 – for power unbalance

As a result of reducing the oscillating masses of the eccentric vibrating exciter by 1.5-2 times, the dynamic loads from the specified forces and moments are reduced, which makes it possible to reduce energy consumption accordingly, while maintaining high performance of the supercooling or freezing process, which for the investigated oscillating technological system is determined by the possibility of one passage of the product mass along the processing zone to acquire the required operating temperature, in particular – 10 °C on the product surface.

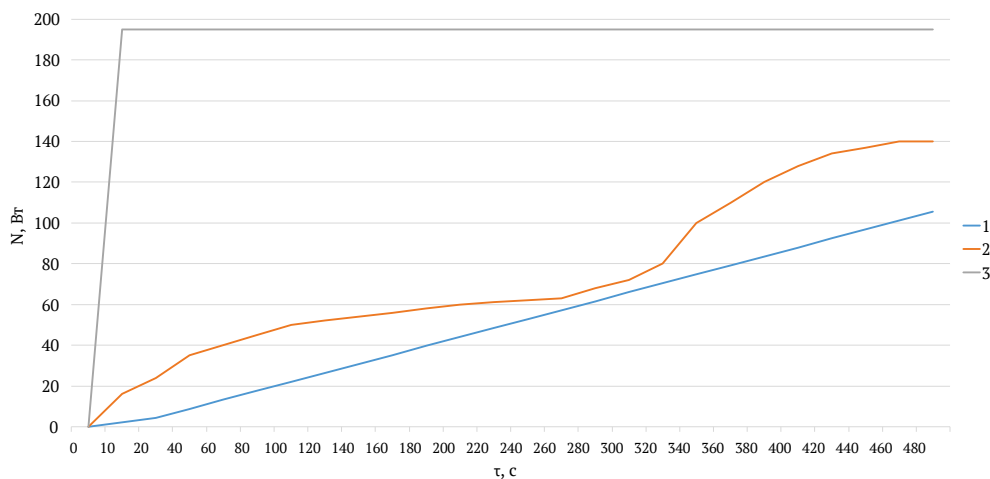
According to the results of experimental studies, for the frequency operating mode range of 80...100 rad/s, energy consumption varies within 17.3...19.1% (Fig. 2), and the change in the transport speed of the processed products is 31...50% (Fig. 3). Evidently, the implementation of the combined unbalance of the oscillating system makes it possible to minimise energy consumption and increase the speed of movement of the technological mass by 27-33% in the production area (Fig. 2) from the wave motion of the belt while maintaining an intensive vibropulse processing mode.

Kinematic and energy parameters were used as criteria for evaluating the conducted studies. As kinematic parameters, the speed of movement of the product flow was determined, which characterises the mass productivity of the vibrating conveyor installation. The power consumption to drive the machine actuators for low-temperature processing in the fluidised layer of the product was used as an energy parameter for evaluation. The given kinematic and energy parameters obviously determine the technical and economic efficiency of the developed refrigeration process. The presented characteristics were determined for two methods of implementing the semi-fluidisation process in the moving product layer (Figs. 4, 5):

- in case of transportation of the mass of products by the movement of the conveyor belt;
- in the case of moving products by the motion of the belt, which is the working body of the wave conveyor, receiving alternating circular motion from the oscillations of the support rollers.



**Figure 4.** Speed characteristics of the load-bearing body of the machine: 1 – the results of analytical calculations and 2 – the results of experimental analysis for the vibro-wave conveying scheme; 3 – the speed of transportation of products using a typical belt conveyor



**Figure 5.** Energy characteristics of the process: 1 – results of analytical calculations; 2 – results of experimental analysis; 3 – power consumption of the belt conveyor drive

When transporting the mass of products by the movement of the travelling wave formed on the surface of the belt, the speed  $v_{tr}$  of the latter is higher by 44-52% according to the results of analytical calculations and experimental analysis (Fig. 4) compared to the traditional belt conveyor when moving technological masses, that is, when transporting the mass of products by the movement of the conveyor belt. To ensure the specified mass productivity of the machine and bring supercooling to the operating temperature in one pass of the production area, we assume that the corresponding speed parameters are:  $v_{pr} = v_{tr} = v_c$ .

When processing products under the conditions of a vibration wave conveyor, the speed of transportation of products on the belt can be assumed to be equal to the vibration velocity  $v_x$ :

$$v_{pr} = v_x = A_x \omega_k, \tag{1}$$

$$A_x = A_{x1} + A_{x2}, \tag{2}$$

$$\omega_k = \frac{2\pi}{T_k}, \tag{3}$$

$A_{x1}, A_{x2}$  – components of the oscillation amplitudes from the drive vibration excitors;  $\omega_k$  – frequency of vibrations of the wave conveyor.

The results of experimental and theoretical studies in determining the speed of product transportation in the processing zone and energy consumption for the process were within the permissible values for almost all frequency modes (curves 1 and 2 in Figs. 4, 5). At the same time, the speed of transportation of products by the movement of the belt conveyor was 44% lower than when using a vibration wave propulsion system, which indicates the high kinematic qualities of the latter and the reserves for increasing the productivity of the process under study (Fig. 4). Power consumption in the studied process for the 1<sup>st</sup> mode was higher by 28...39% for the range of operating frequencies than when using the developed vibration-wave drive of oscillatory movement of the load-carrying belt (Fig. 5).

### Conclusions

1. Based on the analysis of the characteristics of vibrating and wave transporting machines, their classification was developed, the main qualities for effective use in the food and processing industries were substantiated and the following structural and technological advantages over other types of equipment were identified:

- simplicity of design for the implementation of complex transport and technological traffic;
- high level of structural restoration, in particular, ease of technical and technological operation, ease of changing and adjusting the trajectory of product flow;
- high reliability parameters, in particular, durability characteristics under severe operating conditions due to the presence of elastic suspension of the supporting rollers of the conveyor belt and elastic elements of the supporting units of the exciter;
- maintainability and interchangeability of components;
- the possibility of combining transport operations with the simultaneous implementation of certain technological processes, in particular heat and mass exchange.

2. Comparative analysis of the kinematic and energy parameters of the processes of transportation of bulk products in the production area using the developed vibratory wave conveyor machine and the classical belt conveyor revealed an increase in almost twice the speed of transport movement and a reduction in 1.4 times the energy consumption for the process for the designed scheme.

3. The developed drive mechanism of the semi-fluidisation machine intensifies the process of heat exchange in the production area, realising the following processing parameters: product conveying speeds within the value of product conveying speed in the range from 0.125 to 0.25 cm/s with energy consumption for the process in the range of 120-140 W for the frequency range of 80...100 rad/s.

## References

- [1] Ashtiani, S.H., Salarikia, A., & Golzarian, M.R. (2017). Analyzing drying characteristics and modeling of thin layers of peppermint leaves under hot-air and infrared treatments. *Information Processing in Agriculture*, 4(2), 128-139. doi: 10.1016/j.inpa.2017.03.001.
- [2] Li, D., Zhu, Z., & Sun, D.-W. (2018). Effects of freezing on the cell structure of fresh cellular food materials: A review. *Trends in Food Science & Technology*, 75, 46-55. doi: 10.1016/j.tifs.2018.02.019.
- [3] Deng, F., Sun, D., Sun, J., Wen, M., Hu, H., Xu, Y., Xu, S., & Wei, Y. (2019). Experimental simulation of erosion behavior of monolayer metal screen in a sandstone reservoir. *Engineering Failure Analysis*, 105, 255-265. doi: 10.1016/j.engfailanal.2019.06.098.
- [4] Zhu, Z., Li, Y., Sun, D.W., & Wang, H.W. (2019). Developments of mathematical models for simulating vacuum cooling processes for food products – A review. *Critical Reviews in Food Science and Nutrition*, 59(5), 715-727. doi: 10.1080/10408398.2018.1490696.
- [5] Poturaev, V.N., Bulat, A.F., Voloshyn, A.I., Ponomarenko, S.N., & Voloshyn, A.A. (2001). *Mechanics of vibration-pneumatic ejector-type machines*. Kyiv: Naukova dumka.
- [6] Hunko, I., Tsurkan, O., Shargorodskiy, S., Shchur, T., Beloev, H., Kovalyshyn, O., & Domin, M. (2022). The influence of wave processes of hydraulic oils on the operation of a hydraulic drive. *Agricultural Engineering*, 26(1), 91-104. doi: 10.2478/agriceng-2022-0008.
- [7] Palamarchuk, I., Mushtruk, M., Vasylyv, V., & Zheplinska, M. (2019). Substantiation of regime parameters of vibrating conveyor infrared dryers. *Potravinarstvo Slovak Journal of Food Sciences*, 13(1), 751-758. doi: 10.5219/1184.
- [8] Cherntongchai, P., Chaiwattana, S., Leruk, R., Panyaruean, J., & Sriboonnak, S. (2019). Influence of standing wave characteristics on hydrodynamic behaviours in sound-assisted fluidization of Geldart group A powder. *Powder Technology*, 350, 123-133.
- [9] Semenov, G.V., Krasnova, I.S., Khvyliya, S.I., & Balabolin, D.N. (2021). Freezing and freeze-drying of strawberries with an additional effect of micro-vibrations. *Journal of Food Science and Technology*, 58(8), 3192-3198.
- [10] Zhang, Y., Zhao, Y., Dong, L., Duan, C., Zhou, E., Lu, J., Zhang B., & Yang, X. (2018). Flow pattern transition characteristics in vibrated gas-solid fluidized Geldart B magnetite powder bed using pressure drop signals analysis. *Powder Technology*, 327, 358-367. doi: 10.1016/j.powtec.2017.12.089.
- [11] Zhang, Y., Yang, X., Zhu, F., Li, Y., Duan, C., Yang, J., Dong, L., & Zhao, Y. (2019). Using Hilbert-Huang transform, the characteristics of non-linear dynamics and energy transfer in a vibration gas-solid fluidized bed. *Powder Technology*, 344, 970-980. doi: 10.1016/j.powtec.2018.12.087.
- [12] Wei, L., Zhang, B., Lu, C., Lu, Y., & Wang, C.H. (2020). Experimental investigation of pressure fluctuation propagation in two orthogonal directions using a clapboard-type internally circulating fluidized bed. *Advanced Powder Technology*, 31(8), 3395-3407. doi: 10.1016/j.apt.2020.06.026.
- [13] Avci, O., Abdeljaber, O., Kiranyaz, S., Hussein, M., Gabbouj, M., & Inman, D.J. (2021). A review of vibration-based damage detection in civil structures: From traditional methods to machine learning and deep learning applications. *Mechanical Systems and Signal Processing*, 147, article number 107077.
- [14] Bandura, V., Mazur, V., Yaroshenko, L., & Rubanenko, O. (2019). Research on sunflower seeds drying process in a monolayer tray vibration dryer based on infrared radiation. *INMATEH Agricultural Engineering*, 57(1), 233-242.
- [15] Rapur, J.S., & Tiwari, R. (2018). Automation of multi-fault diagnosing of centrifugal pumps using multi-class support vector machine with vibration and motor current signals in frequency domain. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 40(6), 1-21.
- [16] Koptev, V., Kopteva, A., & Ivanova, T. (2021). Directions for the development of transport machines for open-pit mining. *Journal of Applied Engineering Science*, 19(1), 137-141.
- [17] Sukhenko, Y., Sukhenko, V., Mushtruk, M., & Litvinenko, A. (2018). Mathematical model of corrosive-mechanic wear materials in technological medium of food industry. *Lecture Notes in Mechanical Engineering*, 507-514. doi: 10.1007/978-3-319-93587-4\_53.
- [18] Chernenkova, A., Leonova, S., Chernykh, V., & Chernenkov, E. (2019). Influence of biologically active raw materials on rheological properties of flour confectionery products. *Acta Biologica Szegediensis*, 63(2), 195-205. doi: 10.14232/abs.2019.2.195-205.
- [19] Danyliuk, O., Atamanyuk, V., Gumnytsky, Y., & Bachyk, M. (2017). Investigation of the regularities of the process of periodic dissolution of polydisperse benzoic acid particles during pneumatic mixing. *Integrated Technologies and Energy Saving*, 4, 36-40.

- [20] Palamarchuk, I., Zozulyak, O., Mushtruk, M., Petrychenko, I., Slobodyanyuk, N., Domin, O., Udodov, S., Semenova, O., Karpovych, I., & Blishch, R. (2022). The intensification of dehydration process of pectin-containing raw materials. *Potravinarstvo Slovak Journal of Food Sciences*, 16, 15-26. doi: 10.5219/1711.
- [21] Zhou, E., Zhang, Y., Zhao, Y., Luo, Z., Duan, C., Yang, X., & Zhang, B. (2017). Collaborative optimization of vibration and gas flow on fluidization quality and fine coal segregation in a vibrated dense medium fluidized bed. *Powder Technology*, 322, 497-509.
- [22] Zheplinska, M., Mushtruk, M., & Salavor, O. (2021). Cavitation impact on electrical conductivity in the beet processing industry. *Lecture Notes in Mechanical Engineering*, 755-762. doi: 10.1007/978-3-030-68014-5\_73.
- [23] Nakov, G., & Ivanova, N. (2020). The effect of different methods for the production of crackers on their physical and sensory characteristics. *Technological Acta*, 13(1), 41-45. doi: 10.5281/zenodo.4059983.
- [24] Osipenko, V., Denisovich, Y., Gavrilova, G., & Vodolagina, E. (2019). The use of components of plant raw materials from the far eastern region for flour confectionery production. *AIMS Agriculture and Food*, 4(1), 73-87. doi: 10.3934/agrfood.2019.1.73.
- [25] Pyvovarov, P., Cheremskaya, T., Kolesnikova, M., Iurchenko, S., & Andrieieva, S. (2021). Study of properties of wheat germins and meals and their use in the production of dietary hardtacks. *Science Rise*, 4, 39-47. doi: 10.21303/2313-8416.2021.002039.
- [26] Cherntongchai, P., Chaiwattana, S., Leruk, R., Panyaruean, J., & Sriboonnak, S. (2019). Influence of standing wave characteristics on hydrodynamic behaviors in sound-assisted fluidization of Geldart group A powder. *Powder Technology*, 350, 123-133. doi: 10.1016/j.powtec.2019.01.031.
- [27] Bazaluk, O., Struchaiev, N., Halko, S., Miroshnyk, O., Bondarenko, L., Karaiev, O., & Nitsenko, V. (2022). Ways to improve the efficiency of devices for freezing of small products. *Materials*, 15(7), article number 2412. doi: 10.3390/ma15072412.
- [28] Jha, P.K., Xanthakis, E., Jury, V., Havet, M., & Le-Bail, A. (2018). Advances of electro-freezing in food processing. *Current Opinion in Food Science*, 23, 85-89. doi: 10.3136/fstr.24.1.
- [29] Alade, A.O., Jameel, A.T., Muyibi, S.A., Karim, M.I.A., & Alam, Z. (2011). Application of semifluidized bed bioreactor as novel bioreactor system for the treatment of palm oil mill effluent (POME). *African Journal of Biotechnology*, 10(81), 18642-18648.

## Техніко-економічне обґрунтування процесу семіфлюїдаційної обробки плодоягідної продукції

Ігор Павлович Паламарчук<sup>1</sup>, Владислав Ігорович Паламарчук<sup>2</sup>, Віктор Володимирович Сарана<sup>1</sup>, Ярослава Валеріївна Гейпель<sup>1</sup>, Богдан Юрійович Бородич<sup>1</sup>

<sup>1</sup>Національний університет біоресурсів та природокористування України  
03041, вул. Героїв Оборони, 15, м. Київ, Україна

<sup>2</sup>Вінницький торговельно-економічний інститут  
Київського національного торговельно-економічного університету  
21050, вул. Соборна, 87, м. Вінниця, Україна

**Анотація.** Пошук ефективних схем реалізації процесу семіфлюїдації для підморожування та заморожування плодоягідної продукції за умови мінімізації енерговитрат та високої продуктивності на процес становить актуальність проведених досліджень. Метою дослідження є розробка енергоефективних та надійних технологічних схем реалізації віброхвильової холодної обробки плодоягідної продукції на основі розробки вібраційної транспортно-технологічної флюїдаційної машини; визначення силових та енергетичних характеристик процесу семіфлюїдації; обґрунтування раціональних швидкісних режимів просування сировини у зоні обробки. На основі порівняльного аналізу конструктивно-технологічних характеристик хвильових, конвеєрних та вібраційних машин було обґрунтовано основні тенденції їх розвитку; визначені основні силові та енергетичні параметри розробленої коливальної системи. Проведено порівняльний аналіз технологічних схем семіфлюїдації при використанні транспортного руху продукції стрічковим та віброхвильовим конвеєром, що дозволило обґрунтувати ефективність застосування відповідних приводних механізмів досліджуваної машини. Графоаналітичний аналіз швидкісних та енергетичних параметрів досліджуваного семіфлюїдаційного процесу на основі отриманих теоретичних та експериментальних даних дозволив перевірити адекватність розробленої математичної моделі та обґрунтувати основні параметри робочого режиму просування технологічного завантаження вздовж зони обробки. Проведені дослідження при використанні розробленої дослідної моделі та класичного стрічкового конвеєру довели підвищення швидкості транспортування сировини майже у 2 рази при зменшенні енерговитрат на процес у 1,4 раза за віброхвильової схеми. У розробленій вібраційній транспортно-технологічній семіфлюїдаційній машині вібраційний вплив забезпечує зменшення технологічного опору у масі продукції, істотно знижуючи силову дію на неї, внаслідок утвореної біжучої хвилі на поверхні вантажонесучого органу забезпечується переміщення оброблюваного матеріалу по стрічці та неперервне перемішування або оновлення шарів продукції. До практичної цінності проведеної роботи належить застосування комбінованої схеми створення псевдорозрідженого шару продукції за рахунок колювання стрічки та барботування потоком холодоносія; використання хвилі стрічки для створення переміщення продукції у робочій зоні

**Ключові слова:** вібрація, хвильовий конвеєр, дрібнокускова сировина, незрівноваженість коливальної системи, низькотемпературна обробка, дебалансний вібробудувач



UDC 637.528:638.16

DOI: 10.31548/animal.13(2).2022.44-52

## Influence of Parameters of Marinating Meat Semi-Finished Products on the Quality of the Finished Product

Oksana Pylypchuk, Liudmyla Tyshchenko\*, Valentyna Israelian, Nataliia Mushtruk

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

**Abstract.** Improvement and introduction of modern technologies in the creation of new types of meat semi-finished products, the study of promising components and the development of new recipes for marinades, improving the organoleptic and taste properties of the final product is a relevant and promising area of research. Therefore, this study is focused on the influence of marinating parameters in the technology of meat semi-finished products, namely on the organoleptic, physicochemical, and functional-technological properties of the finished product. To solve the tasks, generalisation, comparison and the following research methods were used: organoleptic evaluation of appearance, cut section, taste, smell, colour, consistency, and juiciness; moisture content – by drying samples in a drying oven at a temperature of  $103 \pm 2$  °C to a constant mass; fat content – by the Soxhlet method; ash content – by the conventional weighing method; determination of protein content – by the Kjeldahl method; the yield of the finished product was determined by weighing before and after heat treatment; moisture binding and moisture retention capacity was determined by pressing. The studies found that the effect of the duration of marinating significantly affects the organoleptic characteristics. Thus, the organoleptic characteristics and taste and aroma properties of the finished product when using honey in marinades improve, and the appearance becomes more attractive. According to the results of the organoleptic evaluation, the finished product, after 24 hours of marinating, received a score of 4.9 points. Also, in these samples were observed greater water retention and water binding capacity, which contributes to increased hydration and solubility of muscle tissue proteins. The influence of marinating parameters on the consumptive properties of the product has been established. Thus, the yield of finished baked beef after 24 hours of ageing in the marinade was the highest in sample No. 1 (marinade based on citrus honey – 10 g) and amounted to 84.96%, while the average weight yield of other samples was in the range of 73.18-77.5%. The obtained research results make it possible to expand the range of semi-finished products, correct organoleptic properties and enrich the finished product with biologically active substances

**Keywords:** baking process, organoleptic assessment, physicochemical indicators, functional and technological indicators, sensory analysis, muscle tissue

### Introduction

The combination of meat raw materials and the characteristic components of the marinade makes it possible to create new products with high consumer properties. The functional and technological properties of honey and spices allow for diversifying products and increasing their biological value.

Honey possesses many useful properties due to the fact that it contains such microelements as zinc, iron in

large quantities, B vitamins and vitamin C, antioxidants and other trace elements. Therefore, the expediency of its use as one of the ingredients for marinating meat products before the heat treatment process is quite promising [1; 2].

The introduction and improvement of the latest technological techniques for food production provide an opportunity to produce new meat products that will positively

### Suggested Citation:

Pylypchuk, O., Tyshchenko, L., Israelian, V., & Mushtruk, N. (2022). Influence of parameters of marinating meat semi-finished products on the quality of the finished product. *Animal Science and Food Technology*, 13(2), 44-52.

\*Corresponding author

affect the accumulation of biologically active components to ensure a high level of quality of the finished product. All the above-mentioned techniques with partial improvement of the technological processes of the full cycle of processing meat raw materials, starting with the development of new recipes or their improvement and obtaining innovative products at the output.

One of the main factors that should be considered is the speed of the cooking process, which will contribute to

the creation of new organoleptic properties of the finished product and ensure microbiological safety [3; 4].

During 2017-2021, the structure of meat production underwent drastic changes, the share of poultry meat reached 53.3%, pork – 29.7% and beef – 15.2% [5].

According to the data given in the study [6], poultry meat (chicken) makes up 50% of the diet of each resident of Ukraine, and its share has been increasing over the past few years (Table 1).

**Table 1.** Structure of annual poultry meat consumption

| No. | Year | Per person, (kg)     | Total consumption for the year, (%) |
|-----|------|----------------------|-------------------------------------|
| 1   | 2019 | 24.34                | 49.7                                |
| 2   | 2020 | 25.15                | 51.9                                |
| 3   | 2021 | 8.24 (January-April) | 54.3                                |

Therefore, the provision of the population with meat and meat products, especially high quality with good presentation, taste, culinary and technological properties, and significant nutritional value requires in-depth studies of the properties of raw materials and culinary products by modern chemical and physicochemical methods [7].

In the range of meat products, semi-finished products play a significant role – products that are maximally prepared for culinary processing. The desire of the population to reduce the time for cooking and at the same time eat high-quality and diverse products has led to a significant increase in demand for natural semi-finished meat products, quick-frozen and chilled, and ready-made fried products that have high nutritional value and are affordable [8]. Today, the development of innovative technologies for the preparation of semi-finished products for baking, and optimisation of the ingredient components of the marinade, to increase the nutritional value of the finished product, remains quite relevant.

The quality of finished products processed in ovens largely depends on the technological process, which in turn is determined by the dynamics of adjusting the set parameters, the uniformity of temperature heating and the speed of the coolant in the working chamber. Raw meat depends on the amount of connective, adipose and muscle tissue, thermal state, storage duration, and other factors. In muscle fibres, fibrils are connected by an interfibrillar basic substance; under the action of alkali, this substance liquefies, and the fibre breaks up into separate fibrils. Therefore, in the process of production of semi-finished products, it is advisable to subject the products to marinating, which allows you to get juicy products [9].

The duration of heat treatment of meat and its tenderness largely depends on the ratio of collagen fibres in muscle tissue. Muscle tissue, freed from adipose tissue and largely from connective tissue, contains approximately 70-75% moisture. Moisture is retained in the tissues due to osmotic pressure and the adsorption capacity of proteins and fills the macro- and micro-capillaries. Most of it (50-70%) is in a weakly bound state and is a solution of organic and inorganic substances. Some of the water (0.6 g per 1 g of protein) is firmly held by protein substances [10].

*The purpose of the study* is a development and substantiate the parameters of marinating meat semi-finished products with their subsequent heat treatment. Following the objective, the next tasks were solved: substantiation of the choice of components of the marinade recipe to give the desired structure of the finished product; study of the influence of technological parameters of marinating and culinary processing on the quality indicators of the finished meat product.

### Literature Review

For frying in natural form, semi-finished products are made from tender and soft parts of the carcass (tenderloin, loin, ham). To soften the meat, enzyme preparations of plant, animal and microbiological origin are used. They allow for more or less proteolytic cleavage of connective tissue proteins and muscle fibre proteins [11].

In the process of maturation, which occurs during exposure after the slaughter at a temperature of 1-4 °C, the meat acquires a delicate texture, pleasant smell, and taste. This is due to various biochemical processes caused by the present enzymes. Proteolytic enzymes such as papain, ficin, bromelain, etc., are widely used to improve the consistency of meat [12].

Bacterial and fungal proteolytic enzymes are known to affect only muscle fibre proteins. In this case, there is a softening of the sarcolemma; destruction of the muscle fibre led to the loss of muscle tissue of transverse striation. Proteolytic enzymes of plant origin mainly affect connective tissue fibres [13].

In culinary practice, various marinades are used to soften meat. In addition to softening, marinade imparts flavour to meat and can eliminate or reduce unwanted odour, which is achieved by adding various spices and seasonings. Marination is also widely used as a method of preserving meat products, as it allows to prolong the shelf life and storage of chilled meats.

The authors of scientific papers [14; 15], conducted a number of studies in which the formulations of marinades with the addition of honey of different varieties were used, and the results showed that such mixtures were quite effective and reduced the formation of heterocyclic amines (HCA) in the finished products during the cooking process.

Traditional marinades contain rapeseed oil and plant extracts of paprika or garlic. Emulsion-based marinades contain vegetable oils, water, spices, spice extracts, and salt [15]. The authors of the study [16] found that changing the colour of semi-finished products marinated in various marinades without adding honey reduces the attractiveness of the product, but when it is used, finished products have a more natural colour. The aforementioned changes in colouration may be associated with an enhanced binding reaction of myoglobin and myofibrillar protein [17].

Over the past 10 years, there has been an active development in the use of chilled semi-finished instant meat products, despite the fact that sometimes their price can be higher by 25-30% compared to frozen ones. This trend is observed all over the world [18]. The production of chilled meat products is carried out both by food enterprises and chain stores that have their own shops for the production of semi-finished products.

The main priorities of modern food are fullness, variety, and speed in preparation. Very often each family member has different preferences in food, and rather than cook multiple dishes every day, modern people prefer to buy ready-made meat products and instant meals [19].

## Materials and Methods

The research was conducted in 2019-2020 in the laboratory of the Department of Meat, Fish and Seafood Technology, the Department of Anatomy, Histology and Pathomorphology of Animals named after Academician V.G. Kasyanenko and the Department of Ecobiotechnology and Biodiversity of the National University of Life and Environmental Sciences of Ukraine; at the Institute of Food Resources of the National Academy of Agrarian Sciences of Ukraine, the Palladin Institute of Biochemistry of the National Academy of Sciences of Ukraine, the Ukrainian Laboratory of Quality and Safety of Agricultural Products (Chabany).

For research, a hip part of beef weighing 1.5-2 kg was selected, which was cooled and stored for three days at a temperature of 2-4 °C.

According to the scheme of the experiment, the following technology was performed: preparation of marinade – a mixture of herbs (chopped onions, garlic, basil, coriander, ground paprika, ground tomatoes, ground black pepper, ground ginger, ground red pepper, ground paprika, rosemary, parsley, marjoram, nutmeg, ground allspice, salt); refined oil; honey of two varieties – golden and citrus. Salt was included in the marinade recipe at the rate of 2% by weight of raw materials. 5 marinades for beef were proposed, which are shown in Table 2.

**Table 2.** Methods of marinating beef meat

| Marinade | Components            |        |                    |              |
|----------|-----------------------|--------|--------------------|--------------|
|          | A mixture of herbs, g | Oil, g | Honey variety      | Honey, g     |
| 1        | 6                     | 16     | –                  | –            |
| 2        | 6                     | 16     | Citrus             | 10           |
| 3        | 6                     | 16     | Citrus             | 20           |
| 4        | 6                     | 16     | Goldenrod          | 10           |
| 5        | 6                     | 16     | Goldenrod          | 20           |
| 6        | 6                     | 16     | Citrus + goldenrod | 20 (10 each) |

At the same time, the following basic technological operations were included in the methods of marinating: cutting beef meat, and preparation of marinade, namely mixing oil, spices, and honey in the prescribed amount. The marinade was poured into the raw materials and mixed thoroughly.

Then the product was kept at a temperature of 2-4 °C in the refrigerator for 2 hours and throughout the day. Also, a control sample of beef was marinated without adding honey (No. 1). The next step was baking the semi-finished product in an electric oven with hot air convection at a temperature of 180 °C for 2 hours. 1 control and 5 experimental samples were examined according to the formulation given in Table 1 [20]. To obtain reliable experimental data, all studies were conducted at least five times, with two repetitions for each experiment.

Sampling for organoleptic and physicochemical studies and their preparation for analysis was carried out in accordance with DSTU 4437:2005 Semi-finished meat and meat-vegetable cut. Technical specifications [21].

The organoleptic assessment was performed using a five-point system. Five points were given to a sample that fully complied with the recipe and production technology and in terms of organoleptic characteristics corresponded to a high-quality product. Minor deviations from the established requirements are allowed for a product rating of 4 points. A score of 3 points indicates a violation of the cooking technology. If during the evaluation at least one of the indicators receives 2 points, the product is not subject to further evaluation (Table 3).

**Table 3.** The scale of organoleptic evaluation of semi-finished meat products

| Indicator  | Characteristics  | Points |
|------------|--|--------|
| Appearance | The semi-finished product has a regular oval shape. After baking, the surface of the product has a uniform ruddy crust. The colour in the section is dark grey, there may be particles of marinade components, which does not reduce the positive impression | 5      |

Table 3, Continued

| Indicator   | Characteristics   | Points |
|-------------|---|--------|
| Appearance  | The semi-finished product has a regular oval shape. The surface is crack-free. After roasting, a ruddy crust appears on the surface of the product. The presence of heterogeneous marinade components reduces the positive impression | 4      |
|             | The semi-finished product has an irregular shape. Damaged surface. After baking, the surface is unevenly crusted  | 3      |
|             | The semi-finished product has an irregular shape and is deformed. Damaged surface. After baking, there is no crust on the surface, or there are areas with burns  | 2      |
|             | The semi-finished product has an irregular shape and is deformed. The surface is covered with significant burns. After baking, the product has an unrepresentable appearance  | 1      |
| Smell       | Pleasant, appetizing, harmonious, inherent in this type of food, no extraneous odor   | 5      |
|             | Pleasant, appetizing, dominated by one of the components of the product (spices, honey), too intense or neutral   | 4      |
|             | Pleasant, but specific, honey-like  | 3      |
|             | Unpleasant, unappetizing, smell of oxidized fat   | 2      |
|             | Very unpleasant, sharp, oxidized fat, putrid  | 1      |
| Consistency | Dense, juicy, the product retains its shape well after baking   | 5      |
|             | Slightly dense, juicy, tender, the product retains its shape after baking   | 4      |
|             | Very dense, or loose, crumbly, dryish or soft   | 3      |
|             | Crumbly, brittle, too soft or rubbery   | 2      |
|             | The product does not retain its shape, dry  | 1      |
| Taste       | Pleasant, fresh, appetizing, sweetish, unobtrusive, light, bouquet-like, harmoniously combining the taste of the components of this product (beef, honey, spices), moderately salty   | 5      |
|             | Pleasant, appetizing, but dominated by one component of the product, very intense or neutral, light meat, moderately salty  | 4      |
|             | Pleasant, but specific, honey taste, salty or slightly salty  | 3      |
|             | Unpleasant, sweet, pronounced taste of spices   | 2      |
|             | Very unpleasant, spoiled meat raw materials, oxidized fat   | 1      |

To obtain objective results of the organoleptic assessment of the quality of the finished product, each of the indicators – appearance, colour, smell, taste, consistency, juiciness, and sectional appearance – is given appropriate ratings. Based on the scores for each indicator, the product score is determined in points (as arithmetic mean, the result is calculated to one decimal place).

Physicochemical and functional-technological studies were carried out according to generally accepted methods: moisture content was determined by the arbitration method, which is based on drying samples in a drying oven at a temperature of  $103 \pm 2$  °C to a constant mass according to DSTU ISO1442:2005 [22]; fat content was determined by extraction of a pre-dried sample in a Soxhlet extractor according to DSTU ISO1443: 2005 [23]; ash content was determined by burning the sample in a muffle furnace at a temperature of 400 °C in accordance with DSTU ISO 936:2008 [24]; moisture binding and moisture retention capacity were determined by pressing the samples and separating free moisture, subsequently calculated using the appropriate formulas.

$$MBC = \frac{(A-B \times 8.4)}{A} \times 100 \quad (1)$$

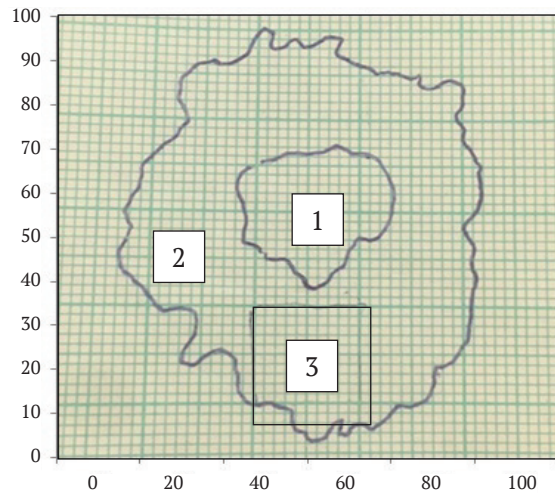
where, *MBC* – moisture binding capacity, %; *A* – total moisture content in suspension, %; 8.4 is a constant indicating the amount of moisture retained by the filter paper 1 cm<sup>2</sup>; *B* – wet spot area, cm<sup>2</sup>.

Moisture retention capacity (%):

$$MRC = \frac{(A-B \times 8.4)}{m} \times 100 \quad (2)$$

where, *MRC* – moisture retention capacity of meat, % *A* – the total amount of moisture in the meat sample, mg; 8.4 is a constant indicating the amount of moisture retained by the filter paper 1 cm<sup>2</sup>; *B* – wet spot area, cm<sup>2</sup>; *m* – the mass of the sample, g.

After pressing, a pencil contour was drawn around the pressed meat (meat spot – MS) and the total spot (TS) along the boundary of moisture spread (Fig. 1). The area of a wet spot (WS) is the difference between the areas of a total spot and a meat spot.



**Figure 1.** Control sample: 1 – meat spot (MS); 2 – total spot (TS); 3 – standard image with an area of 1 cm<sup>2</sup>

According to organoleptic indicators, the varieties of honey met the requirements of DSTU 4497:2005 “Natural honey. Technical specifications”, according to the type of plants from which they were collected, had the aroma, and taste inherent in this variety, and did not contain mechanical impurities and signs of fermentation [20].

### Results and Discussion

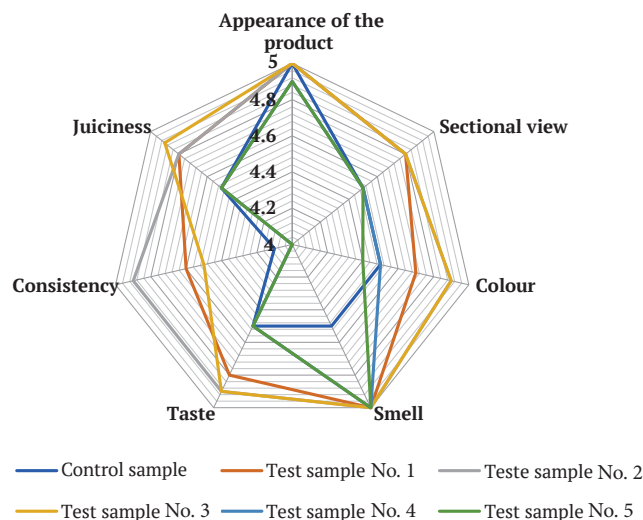
According to the previous author’s research, all the quality indicators of the marinade and marinated portioned semi-finished products were determined [20].

During heat treatment, physicochemical (moisture content, fat, ash) and functional technological (moisture binding, moisture retention capacity and plasticity) changes in the product occur, as well as certain organoleptic properties (appearance, taste, smell, colour, consistency) characterising the finished product are formed [20].

As a result of baking portioned semi-finished products, with ageing in the marinade for 2 hours, the organoleptic score was somewhat lower compared to the 24-hour marinade, especially samples No. 4 and No. 5 (Goldenrod honey – 20 g and citrus + goldenrod – 10 g each, respectively) and amounted to 4.27 points. Sample number 1 (control without adding honey) scored only 4.23 points at 2 hours and 4.51 points at 24 hours of marinating.

Also, for a visual representation of the organoleptic evaluation of baked samples of marinated beef for 24 hours, a profilogram of quality assessment of finished meat products was formed [20].

As can be seen from Figure 2, the taste of the semi-finished products after 24 hours of marinating had the highest number of points, namely the sample No. 2 marinated with citrus honey (20 g), and sample No. 3 with goldenrod honey (10 g).



**Figure 2.** Profilogram of organoleptic quality assessment of portioned semi-finished products

Functional and technological indicators of finished products, namely the moisture content (%), total and meat spots (TS and MS), the area of the wet spot, moisture-retaining

and moisture-binding abilities, the mass of samples after baking, and the determination of meat plasticity are given in Table 3.

**Table 3.** Functional and technological indicators of the finished product

| sample number          | TS, cm <sup>2</sup> | MS, cm <sup>2</sup> | WS, cm <sup>2</sup> | MRC, % | MBC, % | Plasticity of meat, cm <sup>2</sup> /g |
|------------------------|---------------------|---------------------|---------------------|--------|--------|--|
| 2 hours of marinating  |                     |                     |                     |        |        |  |
| 1                      | 6.45                | 1.08                | 5.37                | 43.44  | 22.86  | 17.9                                   |
| 2                      | 6.44                | 1.28                | 5.16                | 46.39  | 28.76  | 17.2                                   |
| 3                      | 5.23                | 1.09                | 4.14                | 43.14  | 36.46  | 13.8                                   |
| 4                      | 5.44                | 1.45                | 3.99                | 40.25  | 34.83  | 13.3                                   |
| 5                      | 5.2                 | 1.08                | 4.12                | 48.30  | 42.16  | 13.73                                  |
| 6                      | 5.04                | 1.76                | 3.28                | 41.11  | 45.22  | 10.93                                  |
| 24 hours of marinating |                     |                     |                     |        |        |  |
| 1                      | 4.76                | 1.13                | 3.63                | 50.65  | 49.86  | 12.1                                   |
| 2                      | 4.15                | 1.63                | 2.52                | 49.43  | 62.52  | 8.4                                    |
| 3                      | 4.01                | 1.11                | 2.9                 | 44.84  | 54.00  | 9.66                                   |
| 4                      | 4.23                | 1.02                | 3.21                | 48.38  | 53.00  | 10.7                                   |
| 5                      | 4.03                | 1.79                | 2.24                | 46.82  | 64.56  | 7.46                                   |
| 6                      | 4.25                | 1.10                | 3.15                | 46.82  | 52.44  | 10.5                                   |

Thus, the process of marinating increases the hydration and solubility of muscle tissue proteins, due to the accumulation of free myosin (the most moisture-binding protein of meat) [20].

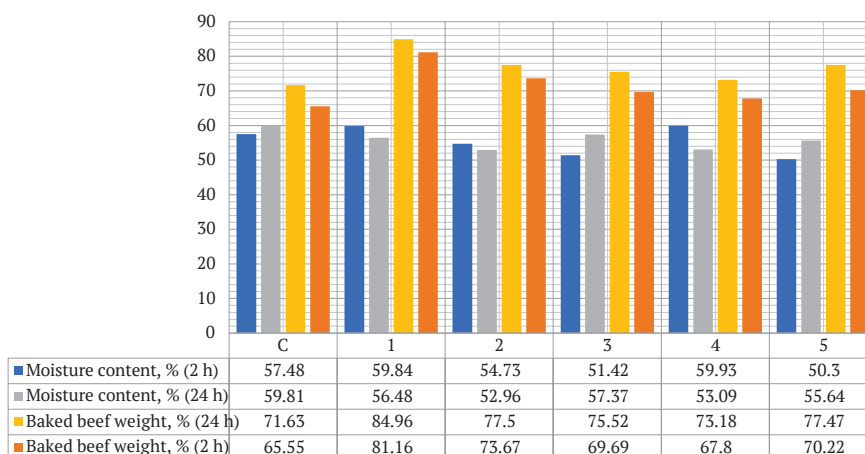
During 24 hours of marinating, the MRC was 1.09 times higher compared to the samples marinated for 2 hours on average, while the MBC was 1.6 times higher. Consequently, meat with increased moisture binding and moisture retention capacity acquired improved consistency and juiciness. Also, as a result of the research, it was found that the moisture-binding capacity at 24 hours of exposure in the marinade of beef meat without the addition of honey (control sample No. 1) was 49.86%, which is 1.15 times less than the average value of other samples. When marinated for 2 hours, the control sample (without adding honey) was 1.64 times lower in terms of WBC values compared to samples marinated with honey added. Consequently, with the addition of honey, the moisture-binding and moisture-retaining ability increase in comparison with the control, which gives the finished product taste, smell, and colour.

The plasticity of the meat of the experimental samples marinated with the addition of honey for 2 hours

averaged 13.79 cm<sup>2</sup>/g, while after 24 hours of exposure – 9.35 cm<sup>2</sup>/g, which characterises the ability of the finished product to irreversible deformation and indicates its quality.

A similar result is described in [17], where the influence of mustard-honey marinade, apple cider vinegar, white wine vinegar and kefir-sour marinades on the properties of pork was studied. Accordingly, it was established that the pH of pork changes when aged in white wine vinegar (pH 3.0), apple cider vinegar (pH 3.1), mustard honey (pH 3.9) and kefir marinade (pH 4.5) with a marinating duration of one, three and seven days. It was found that heat treatment had a lesser effect on the weight loss of samples marinated in a mustard-honey marinade (25.43-27.41%), while samples marinated in kefir lost weight almost as much as the samples of the other two groups. The prepared samples marinated with white wine and apple cider vinegar were tougher than the other two marinades. The data obtained showed that marinating in kefir and mustard honey marinade makes the samples softer after baking.

The dynamics of moisture content of ready-made portioned semi-finished products and mass yield (average weight of raw materials and marinated product) after baking are shown in Figure 3.

**Figure 3.** Dynamics of moisture content and mass yield of finished products

Thus, as can be seen in Figure 3, the moisture content in the experimental samples marinated for 2 hours, namely in No. 1 and No. 4, was higher compared to the 24-hour exposure, while No. 3 and 5 samples were higher compared to the 2-hour marinating.

Also, the output of finished baked beef after 24 hours of ageing in the marinade was the highest in sample number 1 (marinade based on citrus honey – 10 g) and amounted to 84.96%, which is 10.7% more than the average yield after baking of other samples – 75.9%. At the same time, the mass yield of baked beef after 2-hour exposure was also the highest in sample number 1 and amounted to 81.16%, which characterises this marinade as effective to be applied. Unmarinated samples showed significantly higher losses compared to other samples, which is explained by the direct contact of meat raw materials with heat and caused by the loss of moisture from the meat [25; 26]. Similar findings were obtained by the authors of scientific work [14], who argue that the addition of honey to the marinade mixture is effective, which leads to a reduction in weight loss of the finished product as a result of baking. The percentage of losses of grilled beef samples ranged from 28.10% to 35.38%.

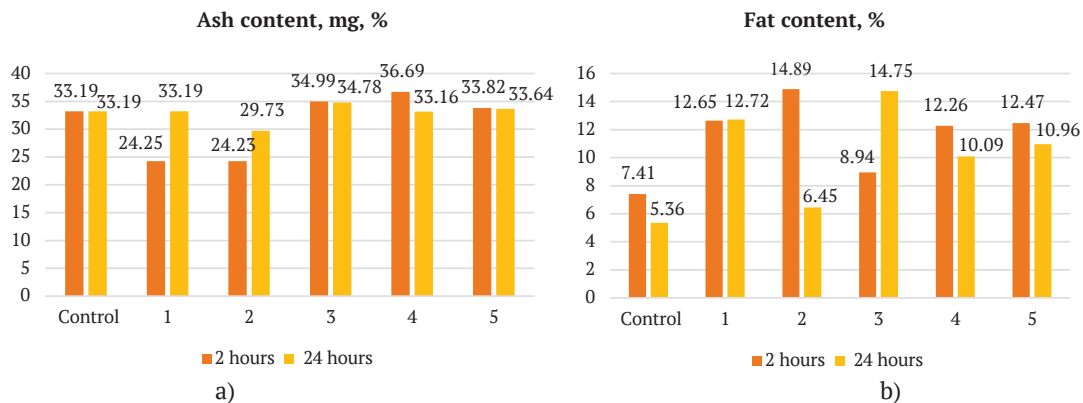


Figure 4. Ash (a) and fat (b) content in the test samples

Thus, in the control sample (without adding honey), both after 2 and 24 hours of marinating, the fat content was 7.41% and 5.36%, respectively. At the same time, sample No. 4 (2 hours of marinating – goldenrod marinade 10 g) and No. 3 (24 hours of marinating – citrus 20 g) had a lower fat content by 1.4 and 1.7 times, according to the marinating time. Regarding the ash content, the average value of the indicators, with the addition of honey to the marinade, at 2 and 24 hours of marinating was 30.79% and 32.83%, respectively, excluding the control sample, which was 33.19% for 2 periods of marinating.

In studies of the effect of various marinades made on the basis of bee honey, pineapple and their combination on the physicochemical and sensory properties of smoked chicken meat, Edema, W.N. *et al.* [29] found that bee honey increased the physicochemical and sensory properties. Thus, based on sensory estimation, smoked chicken jerky with 5% and 15% bee honey were chosen as the best marinating methods ( $p < 0.05$ ). The results also showed that 15% of bee honey had the highest amount of protein and lower ash content. The highest moisture content (66.87%) and losses during baking (54.55%) were obtained in smoked chicken jerky with 5% bee honey.

Losses observed during the roasting of marinated beef meat may be the result of different pH values of the marinades used. In the studies presented in [27], it was found that reducing the weight loss of pork cutlets during cooking can be achieved by adding antioxidants to the ingredient composition.

Additionally, it was found that antioxidants play a protective role against protein denaturation and thus their addition can avoid weight loss during cooking [28]. Due to the introduction of honey into the marinade recipe, which is enriched with antioxidant compounds, it was found that such a technological solution will minimise the loss of the finished product by weight during baking in the range of 5-15%.

Since the taste qualities and technological properties of marinated beef largely depend on the physicochemical properties of raw materials, which are influenced by such factors as breed, age, feeding conditions and others, the content of ash, fat and protein of baked meat marinated in a honey marinade (of own preparation) was investigated. The ash and fat content of the experimental samples of marinated meat for 2 and 24 hours is shown in Figure 4.

## Conclusions

The expediency of using honey in combination with the main ingredients of the marinade to provide the structure of the finished product has been substantiated and experimentally confirmed. It is established that the type and percentage of honey added to the marinade significantly affects the main physical, chemical, structural and mechanical parameters of the finished product.

The sensory analysis found that under different modes of marinating the finished product after 24 hours of ageing was characterised by better organoleptic characteristics compared to 2-hour ageing, namely sample No. 2 (marinade with citrus honey in the amount of 20 g) and sample No. 3 (with goldenrod – 10 g). It has been practically proven that the process of marination increases the hydration and solubility of muscle tissue proteins due to the accumulation of free myosin. The studies have shown that the samples at 24-hour marinating moisture retention and moisture binding capacity of the finished products were 1.1 and 1.6 times higher, respectively, compared to other samples.

It was found that by caramelising the top layer of the semi-finished product during baking, the finished baked beef output after 24 hours of ageing in the marinade

was 84.96%, while the average weight of other samples was in the range of 73.18-77.5%. The results obtained confirm the expediency of using honey as a marinade for semi-finished

products. Further research is aimed at studying the shelf life of beef semi-finished products subjected to marinating which contains honey.

## References

- [1] Ahmed, S., Sulaiman, A.S., Baig, A.A., Ibrahim, M., Liaqat, S., Fatima, S., Jabeen, S., Shamim, N., & Othman, H.N. (2018). Honey as a potential natural antioxidant medicine: An insight into its molecular mechanisms of action. *Oxidative Medicine and Cellular Longevity*, 2018, article number 8367846. doi: 10.1155/2018/8367846.
- [2] Pavlova, T., Dimov, I., & Nakov, G. (2018). Quality characteristics of honey: A review *Proceedings of the University of Ruse*, 57, 31-37.
- [3] Petracci, M., Laghi, L., Rimini, S., Rocculi, P., Capozzi, F., & Cavani, C. (2014). Chicken breast meat marinated with increasing levels of sodium bicarbonate. *The Journal of Poultry Science*, 51(2), 206-212. doi: 10.2141/jpsa.0130079.
- [4] Aroeira, C.N., de Almeida Torres Filho, R., Fontes, P.R., de Lemos Souza Ramos, A., de Miranda Gomide, L.A., Ladeira, M.M., & Ramos, E.M. (2017). Effect of freezing prior to aging on myoglobin redox forms and CIE color of beef from Nelore and Aberdeen Angus cattle. *Meat Science*, 125, 16-21. doi: 10.1016/j.meatsci.2016.11.010.
- [5] Nikolaienko, M., & Bal-Prylypko, L. (2020). Development of an integrated food quality management system. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 862-873. doi: 10.5219/1434.
- [6] Bal-Prylypko, L., Yancheva, M., Paska, M., Ryabovol, M., Nikolaenko, M., Israelian, V., Pylypchuk, O., Tverezovska, N., Kushnir, Y., & Nazarenko, M. (2022). The study of the intensification of technological parameters of the sausage production process. *Potravinarstvo Slovak Journal of Food Sciences*, 16, 27-41. doi: 10.5219/1712.
- [7] Barekat, S., & Soltanizadeh, N. (2017). Improvement of meat tenderness by simultaneous application of high-intensity ultrasonic radiation and papain treatment. *Innovative Food Science and Emerging Technologies*, 39, 223-229. doi: 10.1016/j.ifset.2016.12.009.
- [8] Lukin, A., Khamraeva, G., & Zhuravleva, N. (2021). Research and development of technology for production of canned food using enzyme preparation of animal origin. *Journal of Microbiology, Biotechnology and Food Sciences*, 10(4), 577-580. doi: 10.15414/jmbfs.2021.10.4.577-580.
- [9] Bal-Prylypko, L.V., Derevyanko, L.P., Slobodyanyuk, N.M., Starkova, E.R., & Androschiuk, O.S. (2018). Using of the *Ampullaria glauca* snails' caviar for correction of the effects of the ionizing radiation exposure in small dose. *Nuclear Physics and Atomic Energy*, 19(2), 159-165. doi: 10.15407/jnpae2018.02.159.
- [10] Onopiuk, A., Szpicer, A., Pogorzelski, G., Wierzbicka, A., & Poltorak, A. (2022). Analysis of the impact of exogenous preparations of cysteine proteases on tenderness of beef muscles *Semimembranosus* and *Longissimus thoracis et lumborum*. *Livestock Science*, 258, article number 104866. doi: 10.1016/j.livsci.2022.104866.
- [11] Collados, A., Conversa, V., Fombellida, M., Rozas, S., Hun Kim, J., Arbolea, J.-C., Román, M., & Perezabad, L. (2020). Applying food enzymes in the kitchen. *International Journal of Gastronomy and Food Science*, 21, article number 100212. doi: 10.1016/j.ijgfs.2020.100212.
- [12] Alirezalu, K., Hesari, J., Nemati, Z., Munekata, P.E.S., Barba, F.J., & Lorenzo, J.M. (2019). The combined effect of natural antioxidants and antimicrobial compounds during refrigerated storage of nitrite-free frankfurter-type sausage. *Food Research International*, 120, 839-850. doi: 10.1016/j.foodres.2018.11.048.
- [13] Shamsudin, S., Selamat, J., Sanny, M., Jambari, N.N., Sukor, R., Praveena, S.M., & Khatib, A. (2020). The inhibitory effects of *Heterotrigna itama* honey marinades on the formation of carcinogenic heterocyclic amines in grilled beef satay. *Molecules*, 25(17), article number 3874. doi: 10.3390/molecules25173874.
- [14] Bal-Prylypko L.V., Dubina M.I., & Baranivskyi, V.F. (2012). *Humanitarian and resource problems of the national security of Ukraine*. Kyiv: VPC Express-Polygraph.
- [15] Cherednichenko, O., Bal-Prylypko, L., Paska, M., & Nikolaenko, M. (2021). Expediency of creation of technology of production of meat products of long term of storage of the combined structure. *IOP Conference Series: Earth and Environmental Science*, 723(3), article number 032086. doi: 10.1088/1755-1315/723/3/032086.
- [16] Kim, Y.J., Jin, S.K., Park, W.Y., Kim, B.W., Joo, S.T., & Yang, H.S. (2010). The effect of garlic or onion marinade on the lipid oxidation and meat quality of pork during cold storage. *Journal of Food Quality*, 33, 171-185. doi: 10.1111/j.1745-4557.2010.00333.x.
- [17] Tänavots, A., Pöldvere, A., Kerner, K., Veri, K., Kaart, T., & Torp, J. (2018). Effects of mustard-honey, apple vinegar, white wine vinegar and kefir acidic marinades on the properties of pork. *Veterinarija ir Zootechnika*, 76(98), 76-84.
- [18] Nikolaienko, M., & Bal-Prylypko, L. (2020). Development of an integrated food quality management system. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 862-87.
- [19] Prianishnikov, V. (2017). Technologies for the production of semi-finished products of a high degree of readiness and ready meals. *Food Industry*, 4, 29-31.
- [20] Tyshchenko, L., Pylypchuk, O., Israelyan, V., Adamchuk, L., & Akulyonok, O. (2021). Honey as a marinade component for meat semi-finished products. *Animal Science and Food Technology*, 12(2), 73-81. doi: 10.31548/animal2021.02.008.
- [21] DSTU 4437:2005 "Semi-Finished Meat and Meat-Vegetable Chopped Products. Specifications". (2007). Kyiv: State Standard of Ukraine.
- [22] DSTU ISO1442:2005 "Meat and Meat Products. Methods for Determining Moisture Content (Control Method) (ISO1442:1997, IDT)". (2008). Kyiv: State Standard of Ukraine.

- [23] DSTU ISO1443:2005 "Meat and Meat Products. Method for Determining Total fat Content (ISO 1443: 1973, IDT)". (2008). Kyiv: State Standard of Ukraine.
- [24] DSTU ISO 936:2008 "Meat and Meat Products. Method for Determining the Mass Fraction of Total Ash (ISO 936:1998, IDT)". (2008). Kyiv: State Standard of Ukraine.
- [25] Hasnol, N.D.S., Jinap, S., & Sanny, M. (2014). Effect of different types of sugars in a marinating formulation on the formation of heterocyclic amines in grilled chicken. *Food Chemistry*, 145, 514-521.
- [26] Jinap, S., Iqbal, S.Z., & Selvam, R.M. (2015). Effect of selected local spices marinades on the reduction of heterocyclic amines in grilled beef (satay). *LWT – Food Science and Technology*, 63(2), 919-926.
- [27] Lara, M.S., Gutierrez, J.I., Timon, M., & Andrés, A.I. (2011). Evaluation of two natural extracts (*Rosmarinus officinalis* L. and *Melissa officinalis* L.) as antioxidants in cooked pork patties packed in MAP. *Meat Science*, 88(3), 481-488.
- [28] Bal-Prylypko, L.V., & Nikolayenko, M.S. (2018). Integrated system of management of quality and safety of food products. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine*, 10, 5-6.
- [29] Edema, W.N., Jayarathne, G.G.N., Udayanga, D., Senevirathne, T.A.S.M., & Jayasena, D.D. (2020). Effect of different marinades with bee honey and pineapple on quality attributes of smoked chicken jerky. *Proceedings of the International Research Conference of Uva Wellassa University, July 29-30*. Badulla: Uva Wellassa University.

## Вплив параметрів маринування м'ясних напівфабрикатів на якість готового продукту

Оксана Станіславівна Пилипчук, Людмила Миколаївна Тищенко, Валентина Миколаївна Ізраелян, Наталія Михайлівна Муштрук

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

**Анотація.** Удосконалення та впровадження сучасних технологічних прийомів при створенні нових видів м'ясних напівфабрикатів, дослідження перспективних складових та розробка нових рецептур маринадів, покращення органолептичних та смакових властивостей кінцевого продукту є актуальним та перспективним напрямом досліджень. У зв'язку з цим дана робота спрямована на дослідження впливу параметрів маринування в технології м'ясних напівфабрикатів, а саме на органолептичні, фізико-хімічні та функціонально-технологічні властивості готового продукту. Для вирішення поставлених завдань використовували узагальнення, порівняння та такі методи досліджень: органолептичну оцінку проводили за зовнішнім виглядом, видом на розрізі, смаком, запахом, кольором, консистенцією, та соковитістю; вміст вологи – методом висушування зразків в сушильній шафі при температурі  $103 \pm 2$  °C до постійної маси; вміст жиру – методом Сокслета; зольність – загальноприйнятим ваговим методом; визначення вмісту білка – методом К'ельдаля; вихід готового продукту визначали методом зважування до та після термічної обробки; вологозв'язуючу та вологоутримуючу здатність встановлювали методом пресування. В результаті досліджень встановлено, що вплив тривалості маринування суттєво впливає на органолептичні показники. Так, органолептичні показники та смако-ароматичні властивості готового продукту при застосуванні меду в маринадах покращуються, зовнішній вигляд стає привабливішим. За результатами органолептичної оцінки готовий продукт, після 24-годинного маринування отримав 4,9 бала. Також у цих зразках спостерігалися більша вологоутримуюча та вологозв'язуюча здатності, що сприяє збільшенню гідратації та розчинності білків м'язової тканини. Встановлено вплив параметрів маринування на споживчі властивості продукту. Так, вихід готової запеченої яловичини після 24-годинної витримки в маринаді був найбільшим у зразку №1 (маринад на основі цитрусового меду – 10 г) та становив 84,96 %, тоді як середній показник виходу маси інших зразків знаходився в межах 73,18–77,5 %. Отримані результати досліджень дають змогу розширити асортимент напівфабрикатів, відкоригувати органолептичні властивості та збагатити біологічно-активними речовинами готовий продукт

**Ключові слова:** процес запікання, органолептична оцінка, фізико-хімічні показники, функціонально-технологічні показники, сенсорного аналіз, м'язова тканина



UDC 637.524:510.589

DOI: 10.31548/animal.13(2).2022.53-62

## Mathematical Modelling of the Process of Vibration Mixing of Minced Sausage

Maksym Riabovol\*

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

**Abstract.** The relevance of the study is determined by the need to optimise the process of mixing minced meat in the production of sausages “Ozdorovchi” to reduce the duration of the technological operation, energy and raw material costs. Therefore, the article is concerned with the substantiation and determination of the amplitude-force parameters of a vibro-mechanical machine for mixing sausage mince ingredients. The leading method for studying this issue is mathematical modelling, which allows for comprehensive consideration of the patterns of changes in the main parameters of the oscillatory process. The article theoretically substantiates the expediency of using vibration impact to provide a rapid and uniform distribution of components in the minced mass. An experimental model of a vibrating machine for mixing minced sausage ingredients has been developed. The calculation scheme of the investigated technical system of the process of vibration mixing of minced sausages “Ozdorovchi” is compiled. The equation of motion of the executive bodies of the system is compiled. The dependences for the equations of motion of the actuators of the vibration mixer are determined. Dependences for the main characteristics of the oscillatory system under study are calculated. Based on the analysis of the graphical representation of the amplitude-force dependences, the working amplitude of oscillations of the mixing tank is substantiated in the range of 2-2.5 mm. It is established that the implementation of the required operating oscillatory mode requires for a given capacity relatively small power consumption in the range of 500-600 W. Optimal parameters for mixing minced meat with vibration intensification of the process, as well as the use of appropriate ingredients, allow for achieving a comprehensive technological effect while minimising energy consumption. Therefore, the materials of the article are of practical value for the meat processing industry in the technology of boiled sausage products with health-improving properties

**Keywords:** low-frequency oscillations, Lagrange method, oscillatory system, amplitude-frequency characteristics, power characteristics

### Introduction

One of the largest components of the diet of a modern person is meat products. According to the World Health Organisation, their share in the total volume of consumption is about a quarter and among those, the largest part is accounted for by sausage products, ranging around 60% [1]. However, their consumption can lead to negative health consequences since minced sausage contains from 2 to 6% table salt. Excessive salt intake leads to deterioration of health, which is manifested in the accumulation of water in the body, stretching of muscle ligaments and deterioration

of muscle contractility, inflammation of the kidneys, kidney failure, impaired impulse transmission in the brain, haemorrhage and increased risk of stroke, hyperactivity, and excessive excitability [2]. Sausage products also contain potentially dangerous sodium nitrite for the health of consumers, the ingestion of which can cause the formation of undesirable nitroamines, which are carcinogenic compounds [3; 4] therefore, important issues in the development of sausage products with health-improving properties are reducing the level of intake of sodium cation and

### Suggested Citation:

Riabovol, M. (2022). Mathematical modelling of the process of vibration mixing of minced sausage. *Animal Science and Food Technology*, 13(2), 53-62.

\*Corresponding author

reducing the dosage size in the nitrite ion formulation. Given this, the recipe of sausages "Ozdorovchi" has been improved by reducing the dosage of sodium cation in the minced meat by replacing the usual table salt with sea salt and reducing the dosage of toxic additive nitrite ion in the minced meat by introducing a mixture of antioxidants of natural origin [2; 5]. Changes in the recipe of sausages lead to the improvement of traditional technology and optimisation of the main technological processes due to the introduction of functional additives into their composition; improvement of contact interaction conditions in the loading mass when providing low-frequency vibrations to the executive bodies of the mixer.

One of the most complex and technologically significant processes in sausage production technology is the process of mixing the ingredients of minced sausage. When mixing the components of the minced meat mixture, complex colloidal, physicochemical and biochemical transformations occur under the influence of water and enzyme systems [6]. The course of these processes depends both on the characteristics of the chemical composition and physical and mechanical structure of raw materials, and on the laws of vibro-mechanical mixing. Therefore, to solve pressing issues of the technology of cooked sausage products and impart them with health properties, it is important to study the feasibility of using vibro-mechanical exposure in the mixing process. In the technology of sausages "Ozdorovchi" vibromechanical mixing of ingredients is provided after the initial grinding of meat.

Among the mechanical methods of contact interaction, the use of vibration or low-frequency oscillations makes it possible to transfer the largest energy flux to the system with a small amplitude of displacement of its working bodies during the oscillation period; the ability to influence both significant volumes of products and very limited areas of it; a significant increase in the surfaces of the interaction of technological media up to 100% of the free surface, an increase in the diffusion rate up to 3-3.5 times compared to convection, a decrease in the effective density of the material and a change in other rheological or structural and mechanical properties of the material.

Vibration can be considered a universal form of mechanical effects on processed materials and is widely used during the mixing of technological masses, such as grain, cereals, and meat raw materials, which is one of the most common processes of food production, in particular, primary processing of agricultural raw materials and products [7]. In the "vibration field", the adhesion between the particles of the technological mass can be reduced for bulk masses almost up to 10 times, which leads to the states of pseudo-liquefaction and pseudo-fluidity in the system. In the conditions of elastic and visco-plastic masses, similarly, favourable conditions are created for effective mixing of the mass due to an increase in the area of contact interaction, which reduces the cost of moving the material inside the working 1.5-2 times; due to the reduction of internal friction and mobility of instantaneous equilibrium centres of the particles of the technological load, acceleration of diffusion processes, in particular, salting of meat products, can potentially save energy costs for the operations by 2.5-3 times [9; 10].

Finding the effective regime settings of the investigated process according to the amplitude-power characteristics allows considering both the improvement of contact interaction conditions in the minced meat mass and the reduction of processing time and the corresponding reduction of energy consumption for the process.

In scientific studies, considerable attention is given to the application of vibration in the processes of mixing and the separation of solid bulk heterogeneous systems [11; 12]. According to the results of studies of vibration movement of fine bulk raw materials, the movement of bulk solids in a vessel that performs circular and translational oscillations is examined, the theoretical foundations of layer-by-layer movement of masses on a vibrating surface are developed, recommendations for the process of vibration separation of bulk mixtures are substantiated. In particular, to intensify the process of vibratory sieving of grain, crushed grain feed, the amplitude-frequency characteristics and design parameters of the vibration exciter of the separator of volumetric vibrations are substantiated [9; 10]. The design parameters of the vibratory aspiration separator were developed to improve the quality of separation and clear separation of sunflower seed fractions [13].

Vibration exposure is widely used for the transportation of raw materials and supplies. Thus, the use of vibration conveyors makes it possible to combine the process of material transportation with its technological processing [14].

It is known that due to vibro-mechanical activation of the medium, technological processes are intensified and their productivity increases [15]. The effectiveness of the use of vibration in the drying process has been proved and the operating parameters of vibratory conveyor infrared dryers have been substantiated [16; 17]. It has been established that the vibrating wave conveyor infrared dryer is competitive and superior to existing dryers by generalising indicators of two types due to a significant effect on energy consumption and metal consumption [17; 18]. The positive effect of the process of vibro-mechanical activation of hydrolysis of plant material for pectin extraction was investigated [19].

The use of vibration in the meat processing industry can significantly improve traditional and develop new technological processes based on the acceleration of heat and mass transfer processes. The effectiveness of using wave effects on the intensification of the salting process and meat maturation was confirmed [20]. The use of vibration impact improves the conditions of contact interaction and heat and mass transfer, which allows for reducing the processing time by 2-3 times, as well as the conditions of maturation of meat raw materials, and even distribution of the components in the volume and improve the quality of saturation of raw materials with functional ingredients. Optimisation of the technological process of mixing is necessary to ensure such basic technological requirements for the functional properties of minced cooked sausages, as a bound state of moisture and fat during technological processing and in the finished product, the maintenance of a monolithic structure, juiciness and appropriate organoleptic characteristics [5].

According to the results of the analysis, it is possible to draw conclusions about the expediency of vibro-mechanical influence on the process of mixing minced meat

ingredients and the optimisation of this technological process using mathematical modelling methods.

*Purpose of the study* is to substantiate the operating parameters of the process of vibro-mechanical mixing of minced meat ingredients in the technology of “Ozdorovchi” sausages by determining the amplitude and power parameters of the investigated oscillatory system.

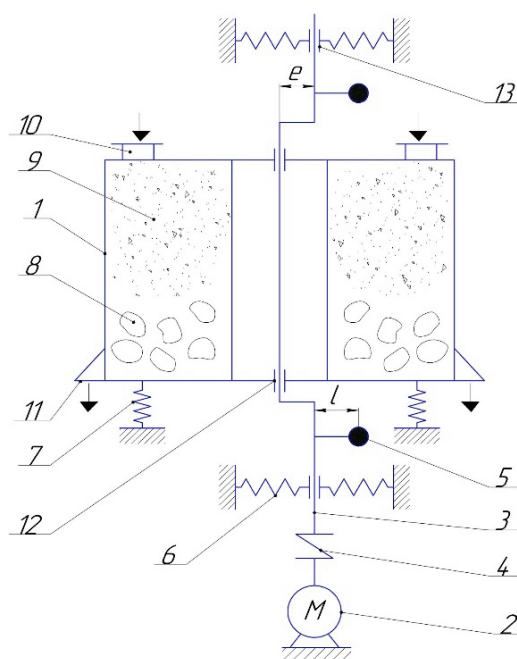
The main objectives of the investigation were: to analyse the application of vibro-mechanical exposure in the technology of food production, to develop a system of vibrating machine for mixing the ingredients of minced sausages “Ozdorovchi” and the design scheme of the studied technical system; to draw up the equations of motion of the executive bodies of the system and determine their

dependencies; to determine the patterns of change in the main parameters of the oscillatory process and to substantiate the amplitude and power parameters of the mixing tank.

## Materials and Methods

Experimental and analytical studies were conducted on the basis of the National University of Life and Environmental Sciences of Ukraine in the laboratory of the Department of Processes and Equipment for Processing of Agricultural Products (agro-industrial complex) during 2020-2021.

To perform the tasks set at the first stage of the experiment, an experimental model of a vibrating machine for mixing minced meat ingredients was developed (Fig.1) [21].



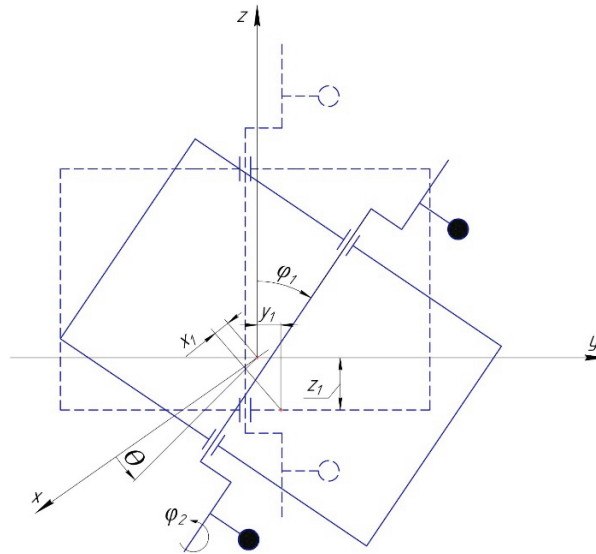
**Figure 1.** Scheme of a vibrating machine for mixing minced meat ingredients in the production of “Ozdorovchi” sausages:

- 1 – container, 2 – electric motor, 3 – drive shaft, 4 – flexible coupling;  
 5 – counterweight, 6 – elastic element of the drive shaft, 7 – elastic element of the container,  
 8, 9 – minced ingredients, 10 – product supply pipe, 11 – discharge pipe;  
 12, 13 – support units of the drive shaft;  $e$  – eccentricity of the drive shaft,  
 $l$  – distance from the centre of mass of the counterweight to the axis of the drive shaft

The investigated oscillating system contains a working container 1 (Fig. 1), which rests on vibration supports 7 and bearing assemblies 12 of the drive shaft 3, which is displaced by the value of eccentricity  $e$  relative to the support elements 13. The latter are equipped with elastic elements 6 to level out parasitic vibrations that can be transmitted from the vibration of container 1. The eccentric shaft receives torque from motor 2 through an elastic coupling 4, which prevents the transmission of vibrations to the driving body. Installation of counterweights 5 on

the drive shaft compensates the inertial forces from the moving masses of the technical system under study. Meat products 8 and necessary ingredients 9 enter the working container through the necks 10, and the processed products are removed from the processing area by means of pipes 11.

At the next stage of the experiment, a calculation scheme was developed to determine the amplitude-frequency and power parameters of the studied technical system of the minced meat vibration mixing process (Fig. 2).



**Figure 2.** Calculation scheme of the studied technical system of the process of vibration mixing of minced sausages “Ozdorovchi”:  $z_1, in_1, X_1, \varphi_1, \varphi_2$  – degrees of freedom of working bodies,  $\theta$  – the angle of rotation of the container relative to the axis  $X$ .

The developed oscillatory system is characterised by six degrees of freedom, namely: displacement of the centre of mass relative to the  $Z$  coordinate axes,  $in_1, X_1$ ; by rotating the drive shaft at an angle  $\varphi_2$ ; angular displacement of the centre of mass  $m_1$  relative to the  $OZ$  axis –  $\varphi_1$ ; angular displacement of the centre of mass relative to the  $Ox - \theta$  axis<sub>1</sub> (Fig. 2).

Among the moving masses of the system (Fig. 2) the following (1), (2) can be distinguished:

$$m_1 = m_K + \xi_m m_3 \quad (1)$$

$$m_2 = m_B + m_{\Pi}, \quad (2)$$

where  $m_K$  – container weight;  $m_3$  – mass of technological loading;  $\xi_m$  – coefficient of attached mass of technological loading;  $m_{\Pi}$  – mass of the drive shaft;  $m_B$  – mass of counterweights.

Further steps in the implementation of the experiment were drawing up equations of motion of the executive bodies of the system and determining their dependence. This result was achieved using the LaGrange method, for which the equations of motion of the executive bodies of the system were compiled and their mathematical analysis was carried out.

In the mathematical modelling of the developed technical system, the Lagrange method was used, which made it possible to estimate the influence of the kinematic and power parameters of the investigated oscillating system separately for each of the degrees of freedom of the executive bodies of the vibration drive of the machine [23; 24]. The obtained dependencies were processed in the MathCAD mathematical environment.

To complete the tasks set, at the second stage of the experiment, studies were conducted on two samples, the composition of which is shown in Table. 1. The composition of the main ingredients of the control mixture is analogous to the sausages “Lubytelski”, LLC “Globino” made according to the standard DSTU 4436:2005 [28], which contains additives recommended for use to give the mixture medicinal properties. The composition of the experimental meat mixture was amended by replacing table salt with sea salt in the traditional sausage recipe and enriching the basic recipe with the *Staphylococcus* bacterial culture, and rosemary and kelp extracts.

**Table 1.** The main ingredients of minced meat

| Ingredient                          | Control mixture | Experimental mixture |
|-------------------------------------|-----------------|----------------------|
| Main raw materials                  |                 |                      |
| Beef                                | 33              | 30                   |
| Semi-fat pork                       | 33              | 26                   |
| Fat pork                            | 34              | 34                   |
| Blood protein                       | –               | 1.0                  |
| Water to moisturise blood albumin   | –               | 2.0                  |
| Cellular tissue (SITRI-Fi 100)      | –               | 0.5                  |
| Water for hydration of cell tissues | –               | 6.5                  |
| Total                               | 100             | 100                  |
| Spices and materials                |                 |                      |
| Table salt sugar                    | 2.2             | –                    |
| Sea salt with kelp                  | –               | 2.1                  |

Table 1, Continued

| Ingredient                          | Control mixture      | Experimental mixture |
|-------------------------------------|----------------------|----------------------|
|                                     | Spices and materials |                      |
| Sugar                               | 0.16                 | 0.16                 |
| Sodium nitrite                      | 0.0075               | 0.005                |
| Bacterial preparation (Iprovit LRR) | –                    | 0.05                 |
| Rosemary extract                    | –                    | 0.015                |
| Water                               | 35.0                 | 30.0                 |

The study of the chemical composition was carried out by the following methods: the mass fraction of moisture was determined by drying the product sample to a fixed mass at a temperature of 100-105 °C according to DSTU 8029:2015 [29]; mass fraction of ash by the weight method after mineralisation of the product weight in a muffle furnace at a temperature of 500-600 °C according to DSTU 8718:2017 [30]; mass fraction of lipids by the Soxhlet method, which consists in weighing the fat after extraction with a solvent from the mass of the dry sample in the Soxhlet apparatus, based on determining the change in the sample mass after extraction of fat with a solvent according to DSTU 8718:2017 [30]; mass fraction of protein by determining total nitrogen by the Kjeldahl method. Distillation was carried out on a Velp Scientifica UDK 129 steam distiller (Italy), DSTU 8030:2015 [31].

Determination of the mass fraction of fibre was carried out by removing acid-base-soluble substances from the product according to DSTU 8844:2019 [32]. Determination of the fatty acid content was performed by chromatographic method on the Kupol 55 chromatograph DSTU 7693:2015 [33].

The mineral composition (the content of potassium, calcium, magnesium, phosphorus, manganese, etc.) was determined by atomic emission spectrometry with induction plasma, and the content of heavy metals (lead, cadmium, arsenic, mercury, copper, zinc) was determined by atomic absorption spectrometry in accordance with DSTU EN ISO 11885:2019 [34].

### Results and Discussion

According to the LaGrange method, the main equations of motion of its executive bodies were obtained for each of the degrees of freedom of the oscillatory system under study. Previously, the kinetic energy of moving masses and

dependences for generalised forces for each of the independent coordinates of the system were determined [23; 24].

To solve these dependences, the kinetic energy of the system is decomposed into two components (3):

$$T = T_1 + T_2; \tag{3}$$

where  $T_1$  – kinetic energy of the container or load, which is defined as (4):

$$T_1 = \frac{1}{2}m_1\dot{x}_1^2 + \frac{1}{2}m_1\dot{y}_1^2 + \frac{1}{2}m_1\dot{z}_1^2 + \frac{1}{2}I_1\dot{\phi}_1^2 + \frac{1}{2}I_1^1\dot{\theta}_1^2; \tag{4}$$

$T_2$  – kinetic energy of mass  $m_2$ , which is determined from dependency (5):

$$T_2 = \frac{1}{2}m_2\dot{x}_1^2 + \frac{1}{2}m_2\dot{y}_1^2 + \frac{1}{2}I_2\dot{\phi}_2^2 \tag{5}$$

Then the total kinetic energy of the system is (6):

$$T = \frac{1}{2}m_0(\dot{x}_1^2 + \dot{y}_1^2) + \frac{1}{2}m_1\dot{z}_1^2 + \frac{1}{2}I_1\dot{\phi}_1^2 + \frac{1}{2}I_1^1\dot{\theta}_1^2; + \frac{1}{2}I_2\dot{\phi}_2^2 \tag{6}$$

where  $m_0 = m_1 + m_2$ ;  $I_1, I_1^1$  – moment of inertia of the container mass relative to the vertical and horizontal axes.

Using the obtained dependences and in accordance with the method of composing the Lagrange equations of the second kind, the partial differentials of the investigated oscillatory system by degrees of freedom (7) are found:

$$\begin{aligned} \frac{\partial T}{\partial \dot{x}_1} &= m\dot{x}_1; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{x}_1} \right) = m\ddot{x}_1; \frac{\partial T}{\partial \dot{y}_1} = m\dot{y}_1; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{y}_1} \right) = m\ddot{y}_1; \\ \frac{\partial T}{\partial \dot{z}_1} &= m\dot{z}_1; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{z}_1} \right) = m\ddot{z}_1; \frac{\partial T}{\partial \dot{\phi}_1} = m\dot{\phi}_1; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{\phi}_1} \right) = m\ddot{\phi}_1; \\ \frac{\partial T}{\partial \dot{\theta}_1} &= I_1^1\dot{\theta}_1; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{\theta}_1} \right) = I_1^1\ddot{\theta}_1; \frac{\partial T}{\partial \dot{\phi}_2} = I_2\dot{\phi}_2; \frac{d}{dt} \left( \frac{\partial T}{\partial \dot{\phi}_2} \right) = I_2\ddot{\phi}_2 \\ \frac{\partial T}{\partial x_1} &= \frac{\partial T}{\partial y_1} = \frac{\partial T}{\partial z_1} = \frac{\partial T}{\partial \phi_1} = \frac{\partial T}{\partial \theta_1} = \frac{\partial T}{\partial \phi_2} = 0. \end{aligned} \tag{7}$$

The expression for generalised system forces for all degrees of freedom can be found in the form of the following dependencies (8):

$$\begin{aligned} Q_{x_1} &= F \cos \phi_2 - C_{x_1}x_1; Q_{y_1} = F \sin \phi_2 - C_{y_1}y_1; Q_{z_1} = F \sin \theta - C_{z_1}z_1; \\ Q_{\phi_1} &= M_{KP} - M_{O\Pi 1} - C_{\phi_1}\phi_1; Q_{\theta_1} = F \sin \theta \cdot e - C_{z_1}z_1R; Q_{\phi_2} = M_{KP} - M_{O\Pi 2} \end{aligned} \tag{8}$$

where  $F = m_1e\omega_2^2$  – driving force module;  $M_{KP}$  – motor shaft torque;  $M_{O\Pi}$  – moment of resistance forces to rotation of the container;  $C_{\phi_1}$  – stiffness of elastic elements;  $R$  – radius of the container.

The obtained dependences of partial differentials and generalised forces for each of the independent coordinates were substituted for Lagrange equations of the 2<sup>nd</sup> kind. As a result, a system of differential equations (9) is obtained.

$$\begin{cases} m_0\ddot{x}_1 = m_1e\omega_2^2 \cos \phi_2 - C_{x_1}x_1 \\ m_0\ddot{y}_1 = m_1e\omega_2^2 \sin \phi_2 - C_{y_1}y_1 \\ m_0\ddot{z}_1 = m_1e\omega_2^2 \sin \theta - C_{z_1}z_1 \\ I_1\ddot{\phi}_1 = M_{KP} - M_{O\Pi 1} - C_{\phi_1}\phi_1 \\ I_1^1\ddot{\theta}_1 = m_1e^2\omega_2^2 \sin \theta - C_{z_1}z_1R \\ M_{KP2} = M_{O\Pi 2} \end{cases} \tag{9}$$

At the next stage, the dependences for the equations of motion of the executive bodies of the vibrating mixer are determined. For this purpose, the solution of the equation is found  $\ddot{x} + \alpha_x\dot{x} + k_x^2x = \frac{m_1}{m_0}e\phi_2^2 \cos \omega_2 t$ , as for a second-order linear differential equation with constant coefficients assuming that  $\phi_2 = \omega_2$  – angular velocity of the drive shaft of the vibration exciter;  $k_x^2 = \frac{C_x}{m_0} = 464 \text{ H/M}$  – natural frequency of the system;  $\alpha_x = 2\sqrt{k_x^2 - \phi_2^2} = 2\sqrt{464 - \omega_2^2}$  – system dissipation factor in the axis direction;  $F_m = \frac{m_1}{m_0}e\omega_2^2$  – specific modulus of the driving force.

In this case, the studied equation took the form (10):

$$\ddot{x} + \alpha_x\dot{x} + k_x^2x = F \cos \omega_2 t \tag{10}$$

The solution of equation (10) can be represented

as  $x = \bar{x} + x^*$ ; where  $\bar{x} = e^{-0.5\alpha_x t}(C_1 \cos \rho_x t + C_2 \sin \rho_x t)$  – general solution of the equation under study;  $x^* = B_1 \sin \omega_2 t + B_2 \cos \omega_2 t$  – its partial solution.

$$\begin{aligned} -B_1 \omega_2^2 \sin \omega_2 t - B_2 \omega_2^2 \cos \omega_2 t + \alpha_x B_1 \omega_2 \cos \omega_2 t - \alpha_x B_2 \omega_2 \sin \omega_2 t + k_x^2 B_1 \sin \omega_2 t + k_x^2 B_2 \cos \omega_2 t &= F_m \cos \omega_2 t \\ \begin{cases} -B_2 \omega_2^2 + \alpha_x B_1 \omega_2 + B_2 k_x^2 = F_m \\ -B_1 \omega_2^2 - \alpha_x B_2 \omega_2 + B_1 k_x^2 = 0 \end{cases} \Rightarrow \begin{cases} B_2(k_x^2 - \omega_2^2) + \alpha_x B_1 \omega_2 = F_m \\ B_1(k_x^2 - \omega_2^2) = B_2 \alpha_x \omega_2 \end{cases} \Rightarrow \begin{cases} B_1 = \frac{F_m \alpha_x \omega_2}{(k_x^2 - \omega_2^2) + \alpha_x^2 \omega_2^2} \\ B_2 = \frac{F_m (k_x^2 - \omega_2^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \end{cases} \end{aligned} \quad (11)$$

Then a separate solution of equation (12) is:

$$x^* = \frac{F_m}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} (\alpha_x \omega_2 \sin \omega_2 t + (k_x^2 - \omega_2^2) \cos \omega_2 t) \quad (12)$$

Given the general solution of equation (10), the desired solution is presented as (13):

$$x = e^{-0.5\alpha_x t} (C_1 \cos \rho_x t + C_2 \sin \rho_x t) + \frac{F_m (\alpha_x \omega_2 \sin \omega_2 t + (k_x^2 - \omega_2^2) \cos \omega_2 t)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \quad (13)$$

Considering the initial conditions  $x_0 = 0$ ;  $\dot{x}_0 = \vartheta_{x_0}$  the differentiation constants (14) and (15) are defined.

$$C_1 = \frac{F_m (\omega_2^2 - k_x^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \quad (14)$$

$$C_2 = \frac{\vartheta_{x_0}}{\rho_x} - \frac{0.5 F_m \alpha_x \rho_x^{-1} (k_x^2 + \omega_2^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \quad (15)$$

$\rho_x = \sqrt{k_x^2 - 0.25 \alpha_x^2}$  – frequency of natural vibrations of the system. As a result, the desired solution took the form (16):

$$x = e^{-0.5\alpha_x t} \left[ \frac{F_m (\omega_2^2 - k_x^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \cos \rho_x t + \left( \frac{\vartheta_{x_0}}{\rho_x} - \frac{0.5 F_m \alpha_x \rho_x^{-1} (k_x^2 + \omega_2^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \right) \sin \rho_x t + \frac{F_m (\alpha_x \omega_2 \sin \omega_2 t + (k_x^2 - \omega_2^2) \cos \omega_2 t)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \right] \quad (16)$$

Due to the energy dissipation in the oscillatory system under study, the free oscillations are attenuated, and for the steady-state mode, equation (16) can be represented as follows (17):

$$x = \frac{F_m \alpha_x \omega_2}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \sin \omega_2 t + \frac{F_m (k_x^2 - \omega_2^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \cos \omega_2 t \quad (17)$$

Using the above methodology, the solution of equation  $\ddot{y} + \alpha_y \dot{y} + k_y^2 y = \frac{m_1}{m_2} e \phi_2^2 \sin \omega_2 t$  (18) is found:

$$y = e^{-0.5\alpha_y t} \left( \frac{F_m \alpha_y \omega_2 \cos \rho_y t}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} + \left( \frac{\vartheta_{y_0}}{\rho_y} + \frac{F_m \omega_2 \rho_y^{-1} (0.5 \alpha_y^2 - k_y^2 + \omega_2^2)}{(k_y^2 - \omega_2^2)^2 + \alpha_y \omega_2^2} \right) \sin \rho_y t \right) + \frac{F_m ((k_y^2 - \omega_2^2) \sin \omega_2 t - \alpha_y \omega_2 \cos \omega_2 t)}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} \quad (18)$$

where  $k_y^2 = \frac{C_y}{m_0} = 1485 \text{ H/M}$ ;  $\alpha_y = 2\sqrt{1485 - \omega_2^2}$ ;  $\rho_y = \sqrt{k_y^2 - 0.25 \alpha_y^2}$

The third component of the movement of the executive organs of the studied machine is found from the system of the following equations (19):

$$\begin{cases} \ddot{z} + \alpha_z \dot{z} + \frac{C_z}{m_0} z = \frac{m_1}{m_0} e \phi_2^2 \sin \theta \\ \ddot{\theta}_1 = (I_1^{-1})^{-1} (m_1 e^2 \phi_2^2 \sin \theta - C_z R z) \end{cases} \quad (19)$$

Assuming that the angular deviation of the container is carried out at a constant angular velocity, i.e.  $\omega_1 = \dot{\theta} = \text{const}$ , and the received information  $\sin \theta = \frac{C_z R}{e m_0} z$  equation is transform (19) to the form

$$\ddot{z} + \alpha_z \dot{z} - k_z^2 z = 0 \quad (20)$$

where

$$k_z^2 = \frac{C_z}{m_0} \left( \frac{R}{e} - 1 \right) = 82665 \text{ H/M}; \alpha_z = 2\sqrt{k_z^2 - \phi_2^2} = 2\sqrt{82665 - \omega_2^2}$$

The solution of equation (20) is found in the form (21):

$$z = e^{-0.5\alpha_z t} (C_5 \cos \rho_z t + C_6 \sin \rho_z t), \quad (21)$$

where  $\rho_z = \sqrt{k_z^2 - 0.25 \alpha_z^2}$

Considering the initial conditions  $z_0 = 0$ ;  $\dot{z}_0 = \vartheta_{z_0}$  constant differentiations are defined  $C_5 = 0$ ;  $C_6 = \frac{\vartheta_{z_0}}{\rho_z}$

As a result (22):

$$z = e^{-0.5\alpha_z t} \vartheta_{z_0} \rho_z^{-1} \sin \rho_z t \quad (22)$$

The next step was to calculate the dependences for

the main characteristics of the investigated oscillatory system.

Using replacement (23):

$$\frac{F_m \alpha_x \omega_2}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} = A_x \cos \phi_x \quad (23)$$

$$\frac{F_m (k_x^2 - \omega_2^2)}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} = A_x \sin \phi_x$$

The equation (21) is transformed as (24):

$$x = A_x (\cos \phi_x \sin \omega_2 t + \sin \phi_x \cos \omega_2 t) = A_x \sin(\omega_2 t + \phi_x) \quad (24)$$

where  $\phi_x = \arctg \left( \frac{k_x^2 - \omega_2^2}{\alpha_x \omega_2} \right)$

After certain transformations, equation (24) presents the component of the oscillation amplitude  $A_x$  as (25):

$$y = \frac{F_m (k_y^2 - \omega_2^2) \sin \omega_2 t}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} - \frac{F_m \alpha_y \omega_2 \cos \omega_2 t}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} \quad (25)$$

Using replacement (26):

$$\frac{F_m (k_y^2 - \omega_2^2)}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} = A_y \cos \phi_y \quad (26)$$

$$\frac{F_m \alpha_y \omega_2}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} = A_y \sin \phi_y$$

The equation (25) is presented as (27):

$$y = A_y \cos \phi_y \sin \omega_2 t - A_y \sin \phi_y \cos \omega_2 t = A_y \sin(\omega_2 t - \phi_y) \tag{27}$$

where  $\phi_y = \arctg\left(\frac{\alpha_y \omega_2}{k_y^2 - \omega_2^2}\right)$

Taking into account the expressions (25), the component of the  $A_y$  oscillation amplitude is obtained as (28):

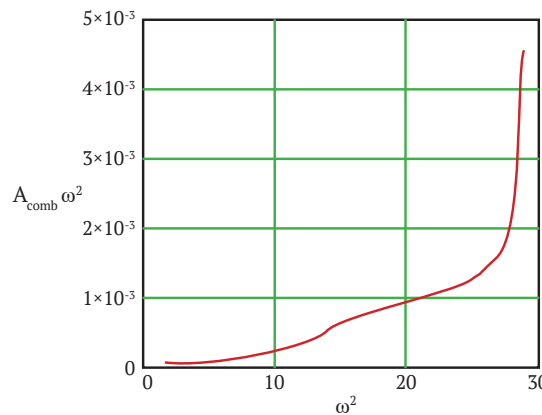
$$A_y = \frac{F_m \sqrt{\alpha_y^2 \omega_2^2 + (k_y^2 - \omega_2^2)^2}}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} = \frac{F_m}{\sqrt{\alpha_y^2 \omega_2^2 + (k_y^2 - \omega_2^2)^2}} \tag{28}$$

The absolute amplitude of vibrations is

$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$ ; for a steady-state mode, vibrations in the vertical direction are attenuated, i.e.,  $A_z = 0$ ; which, given the derived dependencies for its components, is (29):

$$A = \frac{m_1}{m_0} e \omega_2^2 \sqrt{\frac{1}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} + \frac{1}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2}} \tag{29}$$

Using dependence (29), the amplitude-frequency response is constructed (Fig. 3).



**Figure 3.** Dependence of the total amplitude of vibrations  $A_{comb}$  (m) a vibration mixer with mechanical combined vibration excitation of spatial vibrations from the square of the frequency of forced vibrations  $\omega^2$  (rad/s<sup>2</sup>)

Expression for the power of the driving force  $N_F$  is presented it as a product  $N_F = F\vartheta$ , where  $\vartheta = \sqrt{\vartheta_x^2 + \vartheta_y^2 + \vartheta_z^2} = \sqrt{\dot{x}^2 + \dot{y}^2 + \dot{z}^2}$  – expression for the vibration velocity. The modulus of the forcing force is found as  $F = m_1 e \omega_2^2$ .

Considering (30), (31), (32):

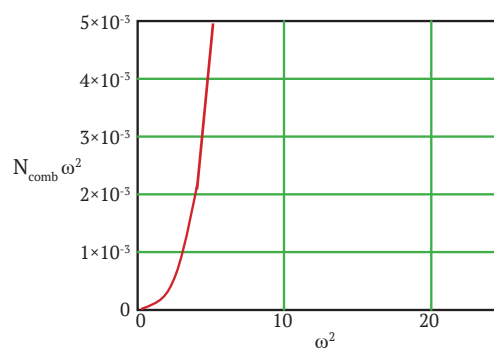
$$\dot{x} = \frac{F_m \omega_2}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} (\omega_2 \alpha_x \cos \omega_2 t - (k_x^2 - \omega_2^2) \sin \omega_2 t) \tag{30}$$

$$\dot{y} = \frac{F_m \omega_2}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} \left( (k_y^2 - \omega_2^2) \cos \omega_2 t + \omega_2 \alpha_y \sin \omega_2 t \right) \tag{31}$$

$$\dot{z} = 0 \tag{32}$$

The desired expression takes the form in Formula (33), which allowed it to be represented in Figure 4.

$$N_F = m_0^{-1} m_1^2 e^2 \omega_2^5 \sqrt{\left[ \frac{\omega_2 \alpha_x \cos \omega_2 t - (k_x^2 - \omega_2^2) \sin \omega_2 t}{(k_x^2 - \omega_2^2)^2 + \alpha_x^2 \omega_2^2} \right]^2 + \left[ \frac{(k_y^2 - \omega_2^2) \cos \omega_2 t + \omega_2 \alpha_y \sin \omega_2 t}{(k_y^2 - \omega_2^2)^2 + \alpha_y^2 \omega_2^2} \right]^2} \tag{33}$$



**Figure 4.** Dependence of the total power consumption  $N_{comb}$  (kW) of a vibration mixer with mechanical combined vibration excitation of spatial oscillations on the square of the frequency of forced oscillations  $\omega^2$  (rad/s<sup>2</sup>)

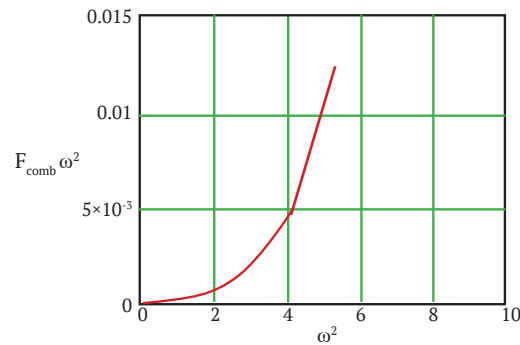
The total inertial forces from unbalanced masses of the oscillatory system, which characterise the reliability of the support units, are found from dependence (34):

$$F_{unb} = F_{com} = m_1 \cdot a_b; a_{in} = A \times \omega^2 \tag{34}$$

Given the features of the elastic system of the drive mechanism of the developed machine, the presented vibration

exciter can be considered as a mechanical combined one, since it combines elements of kinematic forced and unbalanced vibration exciters, respectively, the presence of eccentricity of the drive shaft and an elastic system for levelling parasitic vibrations [9; 23; 24].

Based on the obtained dependence, a graphical representation of this force characteristic is constructed in Figure 5.



**Figure 5.** Dependence of the total inertial forces on unbalanced masses  $F_{\text{comb}}$  (kN) of a vibrating mixer with mechanical combined vibration excitation of spatial oscillations on the square of the frequency of forced oscillations  $\omega^2$  (rad/s<sup>2</sup>)

The analysis of the presented graphical dependences indicates that the frequency  $\omega^2$  exceeds the value of 28 rad/s<sup>2</sup> before the asymptotic increase in the amplitude of oscillations, which can lead to failure of the executive elements of the vibration drive due to the loss of the dynamic equilibrium state by the system, which is observed in systems with power vibration excitation [25]. Therefore, the working amplitude of oscillations of the mixing vessel was chosen in the range of 2-2.5 mm.

The implementation of the above operating oscillatory mode requires for a given container a relatively small power consumption in the range of 500-600 W relative to designs with an unbalanced vibrating exciter, which is satisfactory for the effective processing of minced sausage mass [26; 27].

### Conclusions

Based on the analysis of literature sources, the expediency of application of vibration exposure to the process of mixing minced meat in the technology of sausages “Ozdorovchi” is theoretically substantiated.

To improve the technological process of mixing sausage minced meat, a system of vibrating machine for mixing

ingredients and a design diagram of the investigated technical system of the process of vibration mixing of minced sausages “Ozdorovchi” were developed.

With the help of mathematical modelling, using the Lagrange method, the equations of motion of the executive bodies of the system are compiled and their dependencies are determined.

Graphical representation of the amplitude-force dependences allowed to substantiate the working amplitude of oscillations of the mixing vessel in the range of 2-2.5 mm and to establish the necessary power consumption in the range of 500-600 W.

Experimental initial data and theoretically substantiated operating parameters of mixing sausage minced meat with vibration intensification of the process, and the application of appropriate recipe ingredients provides for the achievement of a comprehensive technological effect, while minimising energy consumption.

Further research will be focused on the development of the hardware and technological scheme for the production of sausages “Ozdorovchi” using improved technology, considering the determined optimal parameters of vibro-mechanical mixing of minced meat.

### References

- [1] Robertson, A., Tirado, C., Lobstein, T., Jermini, M., Knai, C., Jensen, J.H., Ferro-Luzzi, A., & James, W.P. (2004). Food and health in Europe: A new basis for action. *WHO Regional Publications, European Series*, 96. Retrieved from <https://apps.who.int/iris/handle/10665/272255>.
- [2] Riabovol, M., & Bal-Prylypko, L. (2021). Justification and development of sausage technology with health properties. *Animal Science and Food Technology*, 12(1), 39-47. doi: 10.31548/animal2021.01.039.
- [3] Alirezalu, K., Hesari, J., Nemat, Z., Munekata, P.E.S., Barba, F.J., & Lorenzo, J.M. (2019). The combined effect of natural antioxidants and antimicrobial compounds during refrigerated storage of nitrite-free frankfurter-type sausage. *Food Research International*, 120, 839-850. doi: 10.1016/j.foodres.2018.11.048.
- [4] De La Pomélie, D., Santé-Lhoutellier, V., Sayd, T., Théron, L., & Gatellier, P. (2019). Using a dynamic artificial digestive system to investigate heme iron nitrosylation during gastrointestinal transit. *Food Chemistry*, 281, 231-235. doi: 10.1016/j.foodchem.2018.12.094.
- [5] Bal-Prylypko, L., Yancheva, M., Paska, M., Ryabovol, M., Nikolaenko, M., Israelian, V., Pylypchuk, O., Tverezovska, N., Kushnir, Y., & Nazarenko, M. (2022). The study of the intensification of technological parameters of the sausage production process. *Potravinarstvo Slovak Journal of Food Sciences*, 16, 27-41, doi: 10.5219/1712.
- [6] Nikolaienko, M., & Bal-Prylypko, L. (2020). Development of an integrated food quality management system. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 862-873. doi:10.5219/1434.
- [7] Biswas, S., Mohapatra, S.S., Kumari, U., Meikap, B.C., & Sen, T.K. (2020). Batch and continuous closed circuit semi-fluidized bed operation: Removal of MB dye using sugarcane bagasse biochar and alginate composite adsorbents. *Journal of Environmental Chemical Engineering*, 8(1), article number 10363. doi: 10.1016/j.jece.2019.103637.
- [8] Bazaluk, O., Struchaiev, N., Halko, S., Miroshnyk, O., Bondarenko, L., Karaiev, O., & Nitsenko, V. (2022). Ways to improve the efficiency of devices for freezing of small products. *Materials*, 15(7), article number 2412. doi: 10.3390/ma15072412.

- [9] Kovalyshyn, S., & Kovalyshyn, O. (2018). Improvement of the efficiency of perennial seed mixtures separation on a Drum Vibro electric separator. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 66(5), 1157-1164. doi: 10.11118/actaun201866051157.
- [10] Ospanova, S.S., Maximov, V.Y., Bolegenova, S.A., & Beketayeva, M. (2018). The computational study of heat and mass transfer processes at combustion of pulverized Kazakh coal in real conditions of energy objects. *Bulgarian Chemical Communications*, 50, 61-67. doi: 10.32014/2018.2518-1726.11.
- [11] Barrero, A.R., Taiebat, M., & Dafalias, Y.F. (2020). Modeling cyclic shearing of sands in the semifluidized state. *International Journal for Numerical and Analytical Methods in Geomechanics*, 44(3), 371-388. doi: 10.1002/nag.3007.
- [12] Wei, L., Zhang, B., Lu, C., Lu, Y., & Wang, C.H. (2020). Experimental investigation of pressure fluctuation propagation in two orthogonal directions using a clapboard-type internally circulating fluidized bed. *Advanced Powder Technology*, 31(8), 3395-3407. doi: 10.1016/j.appt.2020.06.026.
- [13] Zhang, Y., Yang, X., Zhu, F., Li, Y., Duan, C., Yang, J., Dong, L., & Zhao, Y. (2019). Using Hilbert-Huang transform, the characteristics of non-linear dynamics and energy transfer in a vibration gas-solid fluidized bed. *Powder Technology*, 344, 970-980. doi: 10.1016/j.powtec.2018.12.087.
- [14] Bal-Prylypko, L., Yancheva, M., Paska, M., Ryabovol, M., Nikolaenko, M., Israelian, V., Pylypchuk, O., Tverezovska, N., Kushnir, Y., & Nazarenko, M. (2022). The study of the intensification of technological parameters of the sausage production process. *Potravinarstvo Slovak Journal of Food Sciences*, 16, 27-41. doi: 10.5219/1712.
- [15] Bal-Prylypko, L.V., Derevyanko, L.P., Slobodyanyuk, N.M., Starkova, E.R., & Androshchuk, O.S. (2018). Using of the *Ampullaria glauca* snails' caviar for correction of the effects of the ionizing radiation exposure in small dose. *Nuclear Physics and Atomic Energy*, 19(2), 159-165. doi: 10.15407/jnpae2018.02.159.
- [16] Tavaniello, S., Maiorano, G., Stadnicka, K., Mucci, R., Bogucka, J., & Bednarczyk, M. (2018). Prebiotics offered to broiler chickens exert a positive effect on meat quality traits irrespective of the delivery route. *Poultry Science*, 97(8), 2979-2987. doi: 10.3382/ps/pey149.
- [17] Deng, F., Sun, D., Sun, J., Wen, M., Hu, H., Xu, Y., Xu, S., & Wei, Y. (2019). Experimental simulation of erosion behavior of monolayer metal screen in a sandstone reservoir. *Engineering Failure Analysis*, 105, 255-265. doi: 10.1016/j.engfailanal.2019.06.098.
- [18] Ashtiani, S.H., Salarikia, A., & Golzarian, M.R. (2017). Analyzing drying characteristics and modeling of thin layers of peppermint leaves under hot-air and infrared treatments. *Informaon Processing in Agriculture*, 4(2), 128-139. doi: 10.1016/j.inpa.2017.03.001.
- [19] Cherednichenko, O., Bal-Prylypko, L., Paska, M., & Nikolaenko, M. (2021). Expediency of creation of technology of production of meat products of long term of storage of the combined structure. *IOP Conference Series: Earth and Environmental Science*, 723(3), article number 032086. doi: 10.1088/1755-1315/723/3/032086.
- [20] Ashtiani, S.H.M., Salarikia, A., & Golzarian, M.R. (2017). Analyzing drying characteristics and modeling of thin layers of peppermint leaves under hot-air and infrared treatments. *Informaon Processing in Agriculture*, 4(2), 128-139.
- [21] Bal-Prylypko, L.V., & Nikolayenko, M.S. (2018). Integrated system of management of quality and safety of food products. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine*, 10, 5-6.
- [22] Mushtruk, M., Bal-Prylypko, L., Slobodyanyuk, N., Boyko, Y., & Nikolaienko, M. (2022). Design of reactors with mechanical mixers in biodiesel production. In V. Ivanov, I. Pavlenko, O. Liaposhchenko, J. Machado, & M. Edl (Eds.), *Advances in design, simulation and manufacturing. Lecture notes in mechanical engineering* (pp 197-207). Cham: Springer. doi: 10.1007/978-3-031-06044-1\_19.
- [23] López-Pedrouso, M., Lorenzo, J.M., Gullón, B., Campagnol, P.C.B., & Franco, D. (2021). A novel strategy for developing healthy meat products replacing saturated fat with oleogels. *Current Opinion in Food Science*, 40, 40-45. doi: 10.1016/j.cofs.2020.06.003.
- [24] Stadnyk, I., Bodnarchuk, O., Kopylova, K., Petrov, P., Bal-Prylypko, L., & Narizhnyy, S. (2021). Modification of the properties of milk-fat emulsions with the phase structure of "oil in water" in the dependence on the mass part of the lipid and the stabilizing systems. *Potravinarstvo Slovak Journal of Food Sciences*, 15, 741-748. doi: 10.5219/1389.
- [25] Bal-Prilipko, L.V., Patyka, N.V., Leonova, B.I., Starkova, E.R., & Brona, A.I. (2016). Trends, achievements and prospects of biotechnology in the food industry. *Microbiological Journal*, 78(3), 99-111. doi: 10.15407/microbiolj78.03.099.
- [26] Schivazappa, C., & Virgili, R. (2020). Impact of salt levels on the sensory profile and consumer acceptance of Italian dry-cured ham. *Journal of the Science of Food and Agriculture*, 100(8), 3370-3377. doi: 10.1002/jsfa.10370.
- [27] Zhu, Z., Li, Y., Sun, D.-W., & Wang, H.-W. (2018). Developments of mathematical models for simulating vacuum cooling processes for food products – A review. *Food Science and Nutrition*, 5(5), 715-727. doi: 10.1080/10408398.2018.1490696.
- [28] DSTU 4436:2005 "Boiled Sausages, Sausages, Wieners, Meat Loaf". (2006). Kyiv: State Standard of Ukraine.
- [29] DSTU 8029:2015 "Cooked Sausages and Meat Products. Moisture Determination Methods General Specifications. Quality Management Systems – Requirements". (2016). Kyiv: State Standard of Ukraine.
- [30] DSTU 8718:2017 "Methods for determination of ash and mineral impurities. General specifications. Quality management systems – Requirements". (2019). Kyiv: State Standard of Ukraine.
- [31] DSTU 8030:2015 "Cooked Sausages and Meat Products. Methods for Determining Protein Substances. General Specifications. Quality Management Systems – Requirements". (2017). Kyiv: State Standard of Ukraine.
- [32] DSTU 8844:2019 "Feeds, Compound Feeds, Compound Feed Raw Materials. Methods for Determination of Crude Fiber. Quality Management Systems – Requirements". (2020). Kyiv: State Standard of Ukraine.

- [33] DSTU 7693:2015 “Feeds, Compound Feeds. Determination of the Content of Fatty Acids. Part 1. Preparation of Methyl Esters. Quality Management Systems – Requirements”. (2016). Kyiv: State Standard of Ukraine.
- [34] DSTU EN ISO 11885:2019 “Cooked Sausages and Meat Products. Moisture Determination Methods. General Specifications. Quality Management Systems – Requirements”. (2020). Kyiv: State Standard of Ukraine.

## Математичне моделювання процесу вібраційного перемішування сосисочного фаршу

Максим Віталійович Рябовол

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

**Анотація.** Актуальність дослідження зумовлена необхідністю оптимізації процесу перемішування фаршу в технології сосисок «Оздоровчі» для скорочення тривалості технологічної операції, зменшення енергетичних та сировинних витрат. У зв'язку з цим стаття спрямована на обґрунтування та визначення амплітудно-силових параметрів вібротехнічної машини для перемішування інгредієнтів сосисочного фаршу. Провідним методом до дослідження цієї проблеми є метод математичного моделювання, що дозволяє комплексно розглянути закономірності зміни основних параметрів коливального процесу. В статті теоретично обґрунтовано доцільність використання вібраційного впливу для забезпечення швидкого та рівномірного розподілення компонентів у фаршевій масі. Розроблено дослідну модель вібраційної машини для перемішування інгредієнтів сосисочного фаршу. Складено розрахункову схему досліджуваної технічної системи процесу вібраційного перемішування фаршу сосисок «Оздоровчі». Складено рівняння руху виконавчих органів системи. Визначено залежності для рівнянь руху виконавчих органів віброзмішувача. Розраховано залежності для основних характеристик досліджуваної коливальної системи. На основі аналізу графічного представлення амплітудно-силових залежностей, обґрунтовано робочу амплітуду коливань ємкості для перемішування у межах 2–2,5 мм. Встановлено, що реалізація необхідного робочого коливального режиму вимагає для даної ємкості порівняно невеликих витрат потужності у межах 500–600 Вт. Оптимальні параметри перемішування фаршу з вібраційною інтенсифікацією процесу, а також застосування відповідних інгредієнтів дозволяє досягти комплексний технологічний ефект при мінімізації витрати енергії. Тому, матеріали статті становлять практичну цінність для м'ясопереробної галузі в технології варених ковбасних виробів з оздоровчими властивостями

**Ключові слова:** низькочастотні коливання, метод Лагранжа, коливальна система, амплітудно-частотні характеристики, силові характеристики



UDC 635.21:631.53.01

DOI: 10.31548/animal.13(2).2022.63-70

## Methodological Aspects of Assessing the Competence of Laboratory Personnel Determining the Quality of Seed Potatoes

Olha Samoilenko<sup>1</sup>, Olha Priadko<sup>1\*</sup>, Valentyn Mokiichuk<sup>2</sup>, Yuliia Slyva<sup>1</sup>

<sup>1</sup>National University of Life and Environmental Sciences of Ukraine  
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<sup>2</sup>National Technical University of Ukraine “Ihor Sikorskyi Kyiv Polytechnic Institute”  
03056, 37 Peremohy Ave., Kyiv, Ukraine

**Abstract.** Most of the quality indicators regulated by the standard for seed potato certification are determined by the subjective component, that is, the competence of the personnel. However, the regulatory framework does not establish criteria for assessing competence, which poses uncontrolled risks in the laboratory. The purpose of the study is to develop and investigate the methodology for assessing the competence of laboratory personnel involved in the testing of seed potatoes and determine the extent of application of the methodology. The methods of probability theory and mathematical statistics are used for the tasks of selection and research of statistical criteria that correspond to the law of distribution of the obtained data and provide the necessary reliability for the available sample volumes. The statistics and the method of determining the threshold value, which mathematically describes the decision-making on competence, are provided for the binomial distribution law. The properties of the proposed statistical method for assessing the competence of personnel in terms of finding the maximum differences in the results of the analysis, at which the personnel are recognised as competent, are investigated. The study demonstrates the dependence of the method capacity on the data volume. It is determined that to obtain a confidence probability of 0.95 for quality indicators, the content of which in the average sample according to the technical conditions is minimal, the sample size should be 600-1000 tubers. At the same time, up to 100 tubers are sufficient for indicators whose content is under 5%. The method proposed by the authors showed that the average sample of 250 tubers recommended by the standard is entirely justified in terms of attracting resources during certification but must be adjusted during competence monitoring in a testing laboratory that confirms its competence by the requirements of DSTU ISO IEC 17025:2019. The findings presented can be used by the personnel in the seed testing laboratories as a measure to minimise the risks caused by the impact of personnel incompetence

**Keywords:** seed potato, certification, potato quality indicators, statistical criterion, reliability of decision-making, seed testing laboratory

### Introduction

Industrial potato growing is a separate important branch of agriculture, as Ukraine is one of the four leading countries in the world in terms of gross potato production, in 2021, 20.8 thousand tons of potatoes were produced [1]. In 2020, the Cabinet of Ministers of Ukraine (CMU) adopted an order “On approval of the concept of the State target programme for the development of industrial potato growing for the

period up to 2025” [2]. The programme aims, among other things, to increase the production of high-added-value products and strengthen Ukraine’s presence on the world market of agricultural products and food. The production of seed potatoes belongs to the state-regulated sphere and is regulated by the resolution of the Cabinet of Ministers of Ukraine No. 97 of February 21, 2017 [3]. Each batch of potato

### Suggested Citation:

Samoilenko, O., Priadko, O., Mokiichuk, V., & Slyva, Yu. (2022). Methodological aspects of assessing the competence of laboratory personnel determining the quality of seed potatoes. *Animal Science and Food Technology*, 13(2), 63-70.

\*Corresponding author

seed material or part of it sold must be accompanied by a sowing certificate. The resolution defines the certification, issuance, and cancellation procedure of seed potato sowing certificates and certificate forms. During the certification process, the certification body authorised by the Ministry of Agrarian Policy and Food of Ukraine sends the samples selected by the authorised certification auditors (agronomist-inspector) to the testing laboratory (TL) accredited for compliance with the DSTU ISO IEC 17025:2019 Standard [4]. The certification body decides to certify/not certify the batch based on the results of tests of seed quality indicators. At the same time, the competence of TL personnel is crucial, and any inconsistencies in the work of personnel lead to erroneous decisions on batch certification. Thus, the assessment of the competence of TL personnel by accurate and reliable methods is an urgent task.

The requirements for the competence of TL personnel who evaluate seed potatoes at the request of the certification body are established in the national standard of Ukraine DSTU ISO IEC 17025:2019 [4]. In addition to the general requirements of overhead lines, it is necessary to have a procedure and keep records on the selection, training, supervision, authorization, and monitoring of personnel competence. This article will discuss methods for monitoring personnel competence using statistical criteria. There are no clear instructions on the choice of statistical criteria but the bibliography for the standard [4] contains standards of the DSTU GOST ISO 5725 series, accuracy (correctness and precision) of measurement methods, and results. Part 2. The main method of determining the repeatability and reproducibility of the standard measurement method [5]. Part 3. Intermediate indicators of precision of the standard method of measurement [6]. Part 4. Basic methods for determining the correctness of the standard measurement method [7]. Part 5. Alternative methods for determining the precision of the standard method of measurement [8]. Part 6. Using accuracy values in practice [9]. The standards do not provide methods for assessing and monitoring personnel competence for test results obtained for determining the quality indicators of seed potatoes.

The study [10] analysed the requirements for the competence of laboratory personnel and methods of evaluation, but the proposed methods do not consider the specifics of seed laboratories and do not contain decision-making criteria. The work [11] considers the competence of personnel as a component of service quality when comparing laboratories accredited following ISO/IEC 17025:2017 without providing methodological aspects of competence assessment. Articles [12; 13] compare best practices in accredited laboratories using critical factors, including personnel competence. However, they do not provide methods for assessing competence.

The study [14] identifies the needs and areas of personnel training to meet the requirements of accredited laboratories without practical methods for assessing their competence. In [15] the object of study is the assessment of total uncertainty during calibration in terms of assessing the component due to the competence of the personnel. However, the study does not examine the specifics of evaluating personnel competence for discrete distribution laws depending on the sample size.

The investigation [16] allows for measuring the readiness of the laboratory to meet the requirements of

ISO/IEC 17025: 2017. Descriptive statistics were used to create radar charts and empirical research methods, including personnel competence, but quantitative estimation methods were not considered.

The article reveals [17] the process of determining the compliance of quality characteristics of TL specialists, using the approach “People Development Tools”, which focuses on the human factor in the implementation and maintenance of quality systems [17; 18]. However, given the requirements of the Standard regarding the reliability of the results, the TL should document the data to identify trends and, if possible, apply statistical methods to analyse the findings. Common recommendations on the process of personnel competence management, such as the Eurolab Federation do not contain quantitative criteria for evaluating competence but give generalised recommendations [17; 19].

Thus, the assessment of personnel competence is an integral component in the confirmation of the TL competence. However, the assessment of personnel competence for seed labs was not investigated. The scientific novelty of the study consists in the development of a method for reliable determination of personnel competence based on statistical processing and establishing the limits of its application.

Given that the full description of the competence of overhead line personnel, which declares and confirms its competence, should contain both a qualitative and quantitative component, *the purpose of this study* is to develop and analyse a methodology for assessing the competence of overhead line personnel using statistical criteria and establish the boundaries of the application of the methodology following the tasks faced in practice.

## Materials and Methods

The research was conducted on the basis of an accredited potato seed laboratories LLC AROSERT in 2019-2022. The object of research was samples of original, elite, and reproductive seed material of potato varieties included in the State Register of plant varieties suitable for distribution in Ukraine [20]. Samples were taken from batches of seed potatoes for certification purposes. Testing of samples was carried out by the personnel of overhead lines accredited according to the methods for determining seed qualities set out in DSTU 4014-2001 [21]. Quality indicators certifying the sowing qualities of seed potatoes are selected following the content of the certificate [3, Appendix 2], in which, in addition to the indicators of sowing qualities indicating information about the origin of seeds, the results of evaluation according to the acts of crop assessment, acceptance of basic crops by the commission, analysis of tubers, quarantine inspection, site, and laboratory varietal control.

Requirements for the sowing qualities of potato seed material are taken from DSTU 4013-2001 [22]. The research methods used the mathematical apparatus of probability theory and mathematical statistics about solving problems of assessing the competence of personnel.

As is known from the general theory of measurements, the uncertainty of the measurement result generally contains three components: instrumental, due to the use of measuring equipment (ME), methodological, due to the method, and subjective, due to the competence of personnel. Determination of the sowing qualities of seed potatoes is conducted by methods that can be divided into

two groups depending on their contribution to the total uncertainty of the test result: the first – method using ME, and the second – method based on the competence of personnel. Methods that involve the use of ME provide for the organisation and improvement of metrological support and will not be considered in this paper. Methods of the second group will be subjected to detailed analysis, which determines the following indicators of seed sowing qualities (as a percentage) [2, Appendix 2]: 1) the presence of tubers of other varieties; 2) the presence of tubers affected by diseases: 2.1) wet rot, 2.2) late blight, 2.3) black leg, 2.4) dry rot (fomosis, *Fusarium*), 2.5) rhizoctoniosis, 2.6) common and silver scab, 2.7) powdery scab; 3) the presence of damaged tubers, of which: 3.1) affected stem nematode, 3.2) damaged by wireworm, 3.3) damaged by rodents, may beetle, scoops 3.4) with mechanical damage (more than 10 millimetres deep); 4) the presence of tubers damaged by chemicals, with signs of burns, freezing, deformation, with root nodules, crushed, cut, peeled.

The determination of these indicators depends entirely on the competence of the personnel and can be used as a basis for monitoring competence. In addition, the use of these methods allows us to implement the requirements regarding the monitoring of reliability in terms of duplication of testing using the same methods as testing blind samples [4].

250 potato tubers ( $N=250$ ) selected were analysed. The assessment is conducted in pairs with two specialists [21]. A tuber that belongs to the same sample is examined sequentially and independently of each other by each of the specialists.

Considering the method of representation (the number of detected facts out of the total number), the analysis results are presented in a discrete distribution. From a wide class of discrete distributions (binomial, Poisson, negative binomial, Pascal, geometric, hypergeometric), the binomial distribution law was chosen for the problem of monitoring the competence of seed potato test results.

In the language of mathematical statistics, the task of monitoring competence the following: the first specialist analyses a sample with a volume of  $N1$  tests and identifies  $m1$  defective cases, the second specialist analyses a sample with a volume of  $N2$  tests and identifies  $m2$  defective cases. Under the defective case, we mean a potato tuber in which lesions and inconsistencies are detected according to the selected list of quality indicators [22].

Samples  $N1$  and  $N2$  are distributed according to the binomial distribution law. We set the problem of statistical comparison of two perimeters of binomial distributions. We put forward zero hypothesis  $H0$ : the difference between the fate of defective cases is insignificant (the results of analysing potato tubers do not differ statistically, and the competence of the personnel is confirmed).

Alternative hypothesis  $H1$ : the difference between

the fate of defective cases is significant (the results of analysing potato tubers are statistically different; the competence of personnel is not confirmed).

You can solve the problem set in this way if you apply the appropriate statistics. With a normal approximation of the binomial distribution law the statistics for testing the  $H0$  hypothesis have the form [23]:

$$z = \frac{\frac{m_1}{N_1} + \frac{1}{2N_1} - \frac{m_2}{N_2} - \frac{1}{2N_2}}{\sqrt{\frac{m_1+m_2}{N_1+N_2} \left( \frac{1}{N_1} + \frac{1}{N_2} \right)}} \quad (1)$$

The resulting value of z-statistics is compared with the limit value of U. As the limit value, we choose the quantile of the Gaussian distribution law for the selected confidence probability  $\alpha$ . For laboratory tests  $\alpha = 0.95$ ,  $U = 1.96$ .

If we use the normal approximation using the arcsine transformation, formula (1) for clarification can be replaced with the following:

$$z = \sqrt{\frac{1}{N_1} + \frac{1}{N_2}} \left( 2 \arcsin \frac{m_2}{N_1} - 2 \arcsin \frac{m_2}{N_2} \right) \quad (2)$$

However, in it is shown that the results of determining z according to (1) and (2) give the same result. Based on this, in the practice of TL, the value of z-statistics should be calculated using Formula (1).

For simplicity, given that the same sample is analysed during competence monitoring, we assume  $N1=N2=N$ . Formula (1) will take the form:

$$z = \frac{\frac{m_1-m_2}{N}}{\sqrt{\frac{(m_1+m_2)(2Nm_1-m_2)z}{4N^3}}} \quad (3)$$

The statistical method proposed by the authors for assessing the competence of personnel is tested in the practical activities of accredited overhead lines during the planned monitoring of the competence of personnel authorised to determine the sowing qualities of seed potatoes. According to the weaning method, the average sample for analysis contains 250 tubers ( $N = 250$ ). [21]. To determine the competence of specialists to identify affected and unsuitable tubers, an average sample from a standard batch was selected to check their competence.

## Results and Discussion

The results of the assessment of personnel competence using the selected z-statistics with the proposed simplification (3) are presented in Table 1. The results were obtained experimentally in an accredited TL. It should be noted slight differences between specialists in the number of detected tubers with signs of disease. The calculated values of z-statistics allowed to make a statistically sound conclusion about the sufficient competence of the first and second specialists when comparing their results with each other.

Table 1. Personnel competence analysis

| Indicator of sowing qualities | Specialist 1<br>m1 | Specialist 2<br>m2 | z     | Are specialists competent? |
|-------------------------------|--------------------|--------------------|-------|----------------------------|
| (1)                           | 1                  | 2                  | 0.579 | Yes                        |
| (2)                           | 8                  | 10                 | 1,016 | Yes                        |
| (2.1)                         | 0                  | 0                  | 0     | Yes                        |
| (2.2)                         | 1                  | 0                  | 1,001 | Yes                        |

Table 1, Continued

| Indicator of sowing qualities | Specialist 1 m1 | Specialist 2 m2 | z     | Are specialists competent? |
|-------------------------------|-----------------|-----------------|-------|----------------------------|
| (2.3)                         | 2               | 3               | 0.449 | Yes                        |
| (2.4)                         | 2               | 2               | 0     | Yes                        |
| (2.5)                         | 0               | 0               | 0     | Yes                        |
| (2.6)                         | 0               | 0               | 0     | Yes                        |
| (2.7)                         | 3               | 5               | 0.713 | Yes                        |
| (3)                           | 8               | 7               | 0     | Yes                        |
| (3.1)                         | 1               | 1               | 0     | Yes                        |
| (3.2)                         | 1               | 2               | 0.579 | Yes                        |
| (3.3)                         | 2               | 1               | 0.579 | Yes                        |
| (3.4)                         | 4               | 3               | 0.381 | Yes                        |
| (4)                           | 1               | 1               | 0     | Yes                        |

Based on the results of statistical processing, the specialists were recognised as competent. A special feature of this method is the possibility of mutual verification of only two specialists, which is a limitation when applying the proposed method. One specialist, usually with more experience and without recorded inconsistencies in the results of testing seed potatoes, is accepted as a reference. Its results are compared in pairs with the results of other authorised personnel.

To determine the maximum differences between

the selected quality indicators, which confirm the competence of personnel for sample size  $N = 250$  the authors conducted the following simulation. The difference between the number of detected tubers was calculated using the selection method.

Table 2 shows that a feature of z-statistics is an increase in permissible deviations between the readings of specialists with an increase in the total number of detected discrepancies, which should be considered in the TL when planning competence monitoring.

Table 2. Maximum differences between certain quality indicators

| Detection range | Specialist 1 m1 | Specialist 2 m2 | z     | Are specialists competent? |
|-----------------|-----------------|-----------------|-------|----------------------------|
| Smallest        | 1               | 6               | 1,903 | Yes                        |
|                 | 1               | 7               | 2,139 | no                         |
| Medium          | 10              | 20              | 1,883 | Yes                        |
|                 | 10              | 21              | 2,040 | no                         |
| Largest         | 20              | 33              | 1,889 | Yes                        |
|                 | 20              | 34              | 2,017 | no                         |

That is, a maximum difference of 6 tubers is suitable at in the smallest detection range. In the medium detection range a difference of 9 tubers is permissible. The largest detection range allows a difference of 12 potatoes. These results are explained by the binomial distribution law and can be used by the quality department during competency monitoring. An important issue in assessing competence is the reliability of decisions made. As is known the power of statistical criteria depends on the volume of the studied samples [24].

TL can always use samples that have been submitted for testing to monitor reliability. The average sample for analysis always contains 250 tubers, but for analysis, elite, original, or reproductive seed material is usually passed, which does not contain a large number of disease lesions, and damage and does not contain tubers of other varieties. The use of such material will not test the ability of personnel to detect and correctly identify diseases or injuries.

There is a need to create your tuber sample, in which the person authorised to create samples for intra-laboratory

control introduces sick and damaged tubers found in the batch. To answer the question of what the minimum volume of the average sample (the number of tubers) should be and what is the number of damaged tubers in it, the authors suggest using the expression (4) given in [23]:

$$N_{min} = \frac{\ln(1-\alpha)}{\ln(1-p_0)} \quad (4)$$

where  $p_0$  – a value of the binomial distribution parameter.

The authors carried out simulation modelling using an expression (4). In the Table 3 showed calculated recommended sample sizes  $N_{min}$  so the number of damaged/affected tubers  $m$  (total  $N_{min}$ ) to ensure a confidence level of 0.95 assessment of personnel competence for the original seed and potato elite (4), and norms (in percent) of sowing qualities of seed potatoes, which are given in [22], were used for calculation. Volumes were calculated for the next categories of seed material established by the standard [22].

**Table 3.** Sample sizes of original and elite potato seed material to ensure a confidence level of 0.95

| Indicator of sowing qualities | Polissia and forest-steppe |                 | Steppe          |                 |
|-------------------------------|----------------------------|-----------------|-----------------|-----------------|
|                               | OH, $N_{min}/m$            | EH, $N_{min}/m$ | OH, $N_{min}/m$ | EH, $N_{min}/m$ |
| (1)                           | 300/3                      | 300/3           | 300/3           | 300/3           |
| (2.1)                         | 300/3                      | 300/3           | 300/3           | 300/3           |
| (2.2)                         | 600/3                      | 200/3           | 600/3           | 200/3           |
| (2.3)                         | 300/3                      | 1000/3          | 300/3           | 1000/3          |
| (2.4)                         | 600/3                      | 600/3           | 300/3           | 300/3           |
| (2.5) from 1/8 to 1/4         | 300/3                      | 200/3           | 600/3           | 300/3           |
| (2.5) over 1/4                | 300/3                      | 300/3           | 300/3           | 300/3           |
| (2.6)                         | 100/3                      | 100/3           | 60/3            | 60/3            |
| (2.7)                         | 300/3                      | 300/3           | 300/3           | 300/3           |
| (3.1)                         | 300/3                      | 300/3           | 300/3           | 300/3           |
| (3.2)                         | 300/3                      | 300/3           | 600/3           | 600/3           |
| (3.3)                         | 300/3                      | 300/3           | 300/3           | 300/3           |
| (3.4)                         | 86/3                       | 86/3            | 53/3            | 53/3            |
| (4)                           | 300/3                      | 300/3           | 300/3           | 300/3           |

**Note:** OH – original seed material, EN – the elite seed material for climatic zones of Ukraine “Polissya” and “forest steppe” and “steppe”

Table 4 shows calculated by the simulation modelling recommended sample size  $N_{min}$  and the number of damaged/affected tubers  $m$  (in total  $N_{min}$ ) to ensure a confidence level of 0.95 assessment of personnel competence.

**Table 4.** Recommended sample sizes to ensure the reliability of personnel Competence assessment for potato seed reproduction

| Indicator of sowing qualities | PH-1-2<br>$N_{min}/m$ | PH-3-4<br>$N_{min}/m$ |
|-------------------------------|-----------------------|-----------------------|
| (1)                           | 600/3                 | 300/3                 |
| (2.1)                         | 300/3                 | 300/3                 |
| (2.2)                         | 150/3                 | 75/3                  |
| (2.3)                         | 1000/3                | 600/3                 |
| (2.4)                         | 300/3                 | 200/3                 |
| (2.5) from 1/8 to 1/4         | 200/3                 | 150/3                 |
| (2.5) over 1/4                | 300/3                 | 300/3                 |
| (2.6)                         | 100/3                 | 60/3                  |
| (2.7)                         | 300/3                 | 300/3                 |
| (3.1)                         | 600/3                 | 300/1                 |
| (3.2)                         | 150/3                 | 150/3                 |
| (3.3)                         | 300/1                 | 300/1                 |
| (3.4)                         | 67/3                  | 45/3                  |
| (4)                           | 300/3                 | 300/3                 |

**Note:** RN-1 – reproductive seed (RN) of the first reproduction; RN-2 – the second reproduction; RN-3 – the third reproduction; RN-4 – the fourth reproduction

As can be seen from Tables 3 and 4, a low percentage of crop quality standards and features of the binomial distribution law showed the need to study 10,000 tubers in some cases. For cases where the standard [22] does not allow the presence of any affected/damaged tuber, the authors took 1% availability as an example (demonstrating

that personnel can detect the affected/damaged tuber), such cells are highlighted in grey.

In practice, this means that such results raise questions about the actual reliability of estimates obtained for the volume of an average sample of 250 tubers, as regulated in, if the calculations show a different minimum volume.

On the other hand, selecting and analysing 1,000 tubers will require significant resources, which would be impractical. Therefore, the specialists who developed the standard most likely chose the average volume of the average sample.

Secondly, given that valid for a long period, tested, there is no notification of its cancellation, the question of the reliability of assessing the sowing qualities of potatoes by the seed personnel of the overhead line can be assigned to the management of the TL using Table 3,4, allocating time and human resources in such a way as to minimize the unnecessary burden on personnel, the management of TL plans and ensures the implementation of monitoring of personnel competence in the presence of the required number of tubers and the content of damaged/affected tubers in the average sample.

The results obtained in Table 1 are the results of a unique test of the examined batch of seed potatoes. The results obtained in Tables 2-3 can be reproduced by the method of simulation modelling and do not contain restrictions on reproduction.

Studies similar to the ones cited have not been conducted by Ukrainian or foreign scientists. In works [25; 26] the competence of personnel in agro-industrial laboratories was considered. However, the maximum differences are not determined for which personnel are recognised as competent (similarly to those obtained in Table 1). In works [27; 28], the issue of determining the varietal affiliation of potatoes was considered, however, not defined sample sizes of original and elite potato seed material to ensure a confidence level of 0.95, as done by the authors. In the works of foreign authors [29; 30], issues of quality and reliability of assessments obtained in laboratories

are considered. However, no recommendations have been made for sample sizes as in Table 4. Similar studies performed in accordance with the recommendations [31; 32] can be considered a continuation of this study.

## Conclusions

Determination of the sowing qualities of seed potatoes belongs to the legally regulated sphere and largely depends on the competence of personnel. The organisation of reliable monitoring of personnel competence in testing laboratories allows for avoiding erroneous decisions during the certification of a batch of seed material.

The method proposed by the authors for assessing the competence of personnel using statistical processing makes it possible to avoid subjectivity in decision-making. The research of the method conducted by the authors allows for determining the maximum differences between certain potato quality indicators for different volumes of identified unsuitable tubers, which confirms the competence of the personnel.

Recommended sample sizes to ensure the reliability of personnel competence assessment for potato reproduction seed material allow TL management to plan and organise competence monitoring that considers the required number of tubers studied, and the minimum content of tubers with damage and diseases to obtain monitoring results. The findings obtained can be used in the development of new regulatory documents that contain both guidelines for assessing the competence of personnel, and updated requirements that will minimise the volume of average samples for determining individual quality indicators of potato reproduction seed material.

## References

- [1] Ukraine must become a leader in potato import substitution, – Roman Leshchenko. (2021). Retrieved from <https://minagro.gov.ua/news/ukrayina-maye-stati-liderom-iz-importozamishchennya-kartopli-roman-leshchenko>.
- [2] Order of the Cabinet of Ministers of Ukraine No. 1345-p “On Approval of the Concept of the State Target Program for the Development of Industrial Potatoes for the Period up to 2025”. (2020, October). Retrieved from <https://zakon.rada.gov.ua/laws/show/1345-2020-%D1%80#Text>.
- [3] Resolution of the Cabinet of Ministers of Ukraine No. 97 “On Approval of the Procedure for Certification, Issuance, and Revocation of Certificates for Seeds and/or Planting Material and Forms of Certificates for Seeds and/or Planting Material”. (2017, February). Retrieved from <https://zakon.rada.gov.ua/laws/show/97-2017-%D0%BF#Text>.
- [4] DSTU EN ISO/IEC 17025:2019. General Requirements for the Competence of Testing and Calibration Laboratories (EN ISO/IE 17025:2017, IDT; ISO/IE 17025:2017, IDT). (2021). Retrieved from <http://shop.uas.org.ua/ua/zagal-ni-vimogi-do-kompetentnosti-viprobuval-nih-ta-kalibruval-nih-laboratorij-43535.html>.
- [5] DSTU GOST ISO 5725-2:2005. Accuracy (Correctness and Precision) of Measurement Methods and Results. Part 2. The Main Method of Determining the Repeatability and Reproducibility of the Standard Measurement Method. (GOST ISO 5725-2-2003). (2006). Retrieved from <http://shop.uas.org.ua/ua/tochnist-pravil-nist-i-precizijnist-metodiv-ta-rezul-tativ-vimirjuvannja-chastina-2-osnovnij-metod-viznachennja-povtorjuvanosti-i-vidtvorjuvanosti-standartnogo-metodu-vimirjuvannja.html>.
- [6] DSTU GOST ISO 5725-3:2005. Accuracy (Correctness and Precision) of Measurement Methods and Results. Part 3. Intermediate Indicators of Precision of the Standard Method of Measurement (GOST ISO 5725-3-2003). (2006). Retrieved from <http://shop.uas.org.ua/ua/tochnist-pravil-nist-i-precizijnist-metodiv-ta-rezul-tativ-vimirjuvannja-chastina-3-promizhni-pokazniki-precizijnosti-standartnogo-metodu-vimirjuvannja.html>.
- [7] DSTU GOST ISO 5725-4:2005. Accuracy (Correctness and Precision) of Measurement Methods and Results. Part 4. Basic Methods for Determining the Correctness of the Standard Measurement Method. (GOST ISO 5725-4-2003). (2006). Retrieved from <http://shop.uas.org.ua/ua/tochnist-pravil-nist-i-precizijnist-metodiv-ta-rezul-tativ-vimirjuvannja-chastina-4-osnovni-metodi-viznachennja-pravil-nosti-standartnogo-metodu-vimirjuvannja.html>.
- [8] DSTU GOST ISO 5725-5:2005. Accuracy (Correctness and Precision) of Measurement Methods and Results. Part 5. Alternative Methods for Determining the Precision of the Standard Method of Measurement (GOST ISO 5725-5-2003). (2006). Retrieved from <http://shop.uas.org.ua/ua/tochnist-pravil-nist-i-precizijnist-metodiv-ta-rezul-tativ-vimirjuvannja-chastina-5-al-ternativni-metodi-viznachennja-precizijnosti-standartnogo-metodu-vimirjuvannja.html>.

- [9] DSTU GOST ISO 5725-6:2005. Accuracy (Correctness and Precision) of Measurement Methods and Results. Part 6. Using Accuracy Values in Practice. (GOST ISO 5725-5-2003). (2006). Retrieved from <http://shop.uas.org.ua/ua/tochnist-pravilnist-i-precizijnist-metodiv-ta-rezul-tativ-vimirjuvannja-chastina-6-vikoristannja-znachen-tochnosti-na-praktici.html>.
- [10] LaDuke, S.D. (2001). The role of staff development in assuring competence. *Journal for Nurses in Staff Development*, 17(5), 221-225. doi: 10.1097/00124645-200109000-00001.
- [11] Karthiyayini, N., & Rajendran, C. (2021). An approach for benchmarking service excellence in accredited services of Indian calibration and testing laboratories. *Materials Today: Proceedings*, 46(17), 8218-8225. doi: 10.1016/j.matpr.2021.03.216.
- [12] Karthiyayini, N., & Rajendran, C. (2017). Critical factors and performance indicators: Accreditation of testing- and calibration laboratories. *Benchmarking*, 24(7), 1814-1833. doi: 10.1108/BIJ-04-2016-0058.
- [13] Karthiyayini, N., Rajendran, C., & Kumaravel, M. (2018). Importance-performance analysis (IPA) for testing – and calibration – laboratories in India. *Benchmarking: An International Journal*, 25(4), 1232-1244. doi: 10.1108/BIJ-12-2016-0190.
- [14] Mossalaeie, M.M. (2009). Laboratory quality regulations and accreditation standards in Iran. *Clinical Biochemistry*, 42(4-5), article number 316. doi: 10.1016/j.clinbiochem.2008.09.030.
- [15] Eremenko, V., Mokiichuk, V., Pashchenko, N., Samoilichenko, O., & Priadko, O. (2022). Analysis of the impact of personnel competency on uncertainty during calibration. *Eastern-European Journal of Enterprise Technologies*, 3(3(117)), 35-42. doi: 10.15587/1729-4061.2022.259779.
- [16] Belezia, L.C., & de Almeida, M.F.L. (2021). Self-assessment model for testing and calibration laboratories based on ISO/IEC 17025:2017 requirements. *Journal of Physics: Conference Series*, 1826(1), article number 012026. doi: 10.1088/1742-6596/1826/1/012026.
- [17] Sereda, D.V., Klimas, R.V., & Maladika, L.V. (2020). Methodological aspects of assessing the professional competence of specialists in research and testing laboratories of territorial bodies of the SES of Ukraine. *Scientific Bulletin: Public Administration*, 1(3), 176-184.
- [18] Skolozdra, M.M., & Baitsar, R.I. (2011). The mechanism of personnel evaluation in the implementation and maintenance of quality systems of testing laboratories. *Bulletin of Vinnytsia Polytechnic Institute*, 6, 24-28.
- [19] “Cook Book”. (2018). How to assess the competence of staff. *EUROLAB*, 6. Retrieved from <https://www.africanfoodsafetynetwork.org/wp-content/uploads/2021/09/EUROLAB-Cook-Book-%E2%80%93-Assessing-staff-6.pdf>.
- [20] Ministry of Agrarian Policy and Food of Ukraine. (2022). *State register of plant varieties suitable for distribution in Ukraine*. Retrieved from <https://minagro.gov.ua/file-storage/rejestr-sortiv-roslin>.
- [21] DSTU 4014-2001. Seed Potatoes. Sampling and Methods of Determining Sowing Qualities. (2002). Retrieved from <http://shop.uas.org.ua/ua/kartoplja-nasinneva-vidbir-prob-i-metodiki-viznachennja-posivnih-jakostej.html>
- [22] DSTU 4013-2001. Varietal and Sowing Qualities of Seed Potatoes. Specifications. (2002). Retrieved from <http://shop.uas.org.ua/ua/sortovi-ta-posivni-jakosti-kartopli-nasinnevoi-tehnichni-umovi.html>.
- [23] Gupta, S.C., & Kapoor, V.K. (2020). *Fundamentals of mathematical statistics*. New Delhi: Sultan Chand & Sons.
- [24] Samoilichenko, O.V., Mokiychuk, V.M., & Yeremenko, V.S. (2008). Determination of statistical estimates of the power of homogeneity criteria in small samples. *Information Processing Systems*, 4(71), 30-33.
- [25] Gardas, B.B., Raut, R.D., Cheikhrouhou, N., & Narkhede, B.E. (2019). A hybrid decision support system for analyzing challenges of the agricultural supply chain. *Sustainable Production and Consumption*, 18, 19-32. doi: 10.1016/j.spc.2018.11.007.
- [26] Raut, R.D., Luthra, S., Narkhede, B.E., Mangla, S.K., Gardas, B.B., & Priyadarshinee, P. (2019). Examining the performance oriented indicators for implementing green management practices in the Indian agro sector. *Journal of Cleaner Production*, 215, 926-943. doi: 10.1016/j.jclepro.2019.01.139.
- [27] Polishchuk, M. (2021). The effect of fertilization system on the productivity of Serpanok-early mature variety of potatoes under the conditions of Right-Bank Forest-Steppe of Ukraine. *The Scientific Heritage*, 68(3), 18-28.
- [28] Yeremenko, O., Fedorchuk, M., Drobitko, A., Sharata, N., & Fedorchuk V. (2020). Adaptability of different sunflower hybrids to the conditions of insufficient moisturing. *WSEAS Transactions on Environment and Development*, 16, 330-340. doi: 10.37394/232015.2020.16.35.
- [29] Stollenwerk, M.M., Gustafsson, A., Edgren, G., Gudmundsson, P., Lindqvist, M., & Eriksson, T. (2022). Core competencies for a biomedical laboratory scientist – a Delphi study. *BMC Medical Education*, 22(1), article number 476. doi: 10.1186/s12909-022-03509-1.
- [30] Tripković, K., Šantrić Miličević, M., Mandić Miladinović, M., Kovačević, L., Bjegović Mikanović, V., & Vuković, D. (2022). Implementation of the workload indicators of staffing need (WISN) method in determining staff requirements in public health laboratories in Serbia. *Disaster Medicine and Public Health Preparedness*, 16(1), 71-79. doi: 10.1017/dmp.2020.133.
- [31] Order of the Ministry of Economic Development, Trade and Agriculture of Ukraine No. 91 “On the Approval of the Methodology for Determining the Varietal and Sowing Qualities of Seed Potatoes”. (2021, January). Retrieved from <https://zakon.rada.gov.ua/laws/show/z0300-21#Text>.
- [32] Order of the Ministry of Agrarian Policy and Food of Ukraine No. 384 “On the Approval of Methodological Requirements in the Field of Seed Production Regarding the Preservation of Varietal and Sowing Qualities of Seed Potatoes”. (2019, July). Retrieved from <https://zakon.rada.gov.ua/laws/show/z0829-19#n109>.

## Методологічні аспекти оцінювання компетентності персоналу лабораторій визначення якості картоплі насінневої

Ольга Вікторівна Самойліченко<sup>1</sup>, Ольга Анатоліївна Прядко<sup>1</sup>,  
Валентин Михайлович Мокійчук<sup>2</sup>, Юлія Володимирівна Слива<sup>1</sup>

<sup>1</sup>Національний університет біоресурсів та природокористування України  
03041, вул. Героїв Оборони, 15, м. Київ, Україна

<sup>2</sup>Національний технічний університет України  
«Київський політехнічний інститут імені Ігоря Сікорського»  
03056, просп. Перемоги, 37, м. Київ, Україна

**Анотація.** Більшість регламентованих стандартом показників якості для сертифікації насінневої картоплі визначаються суб'єктивною складовою – компетентністю персоналу, однак нормативними документами не встановлено критеріїв оцінювання компетентності, що спричиняє неконтрольовані ризики в лабораторії. Метою роботи є розроблення та дослідження методики оцінювання компетентності персоналу лабораторії, яка здійснює випробування насінневої картоплі та встановлення меж застосування методики. Використано методи теорії ймовірності та математичної статистики для задач вибору та дослідження статистичних критеріїв, які відповідають закону розподілу отримуваних даних та забезпечують необхідну достовірність за наявних обсягів вибірки. Для біноміального закону розподілу наведено статистику та спосіб визначення граничного значення, який математично описує прийняття рішення про компетентність. Досліджено властивості запропонованого статистичного методу оцінювання компетентності персоналу в частині знаходження максимальних різниць в результатах аналізування, за яких персонал визнають компетентним. Показана залежність потужності методу від обсягів даних. Визначено, що для отримання довірчої ймовірності 0,95 для показників якості, вміст яких у середній вибірці згідно з технічних умов мінімальний, обсяг вибірки повинен бути 600-1000 шт. Водночас для показників, вміст яких допускається до 5 % достатньо до 100 шт. Запропонований авторами метод показав, що рекомендована стандартом середня проба об'ємом 250 шт цілком виправдана з точки зору залучення ресурсів під час сертифікації, однак повинна бути скоригована під час моніторингу компетентності у випробувальній лабораторії, яка підтверджує свою компетентність відповідно до вимог ДСТУ ISO IEC 17025:2019. Отримані результати можна використовувати персоналом з якості у насінневих випробувальних лабораторіях як захід для мінімізації ризиків, спричинених впливом некомпетентності персоналу

**Ключові слова:** сертифікація насінневої картоплі, показники якості картоплі, статистичний критерій, достовірність прийняття рішень, насіннева випробувальна лабораторія



UDC 664.994: 547

DOI: 10.31548/animal.13(2).2022.71-80

## The Use of Inulin-Containing Raw Materials in the Technology of Sausage Production

Olha Snizhko\*, Iryna Momot

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

**Abstract.** Since the second half of the twentieth century, the popularity and accumulation of research on various methods of improving sausage products has been growing, which necessitates the systematisation of available information, especially regarding the use of non-traditional functional components such as inulin-containing raw materials. The purpose of the study was to analyse the scope of the research and systematise the available information on methods of improving the quality and nutritional value of sausage products, and to determine the prospects and feasibility of using inulin-containing raw materials in the formulation of sausage products to increase their consumer benefits and improve nutritional characteristics. The method of meta-analysis of evidence was applied, based on the search of literature data for the period 2001-2022 using the international scientific platform Research4Life, which includes publications indexed in Scopus, Web of Science, etc. The study used statistical data from the Organisation for Economic Cooperation and Development, the State Statistics Service of Ukraine, etc. A total of 64 articles related to the use of inulin in the composition of inulin-containing raw materials in sausage products were found, four of them about sausage with chicory, six – about sausage with Jerusalem artichoke. The article also presents statistical data on meat consumption in Ukraine and in the world, the distribution of consumer purchasing and taste preferences, and systematises the ways to improve the quality of sausages. As a result of the research, a low tendency towards an increase in demand for meat products was noted, it was found that the most promising, in terms of improving health qualities, meat products are boiled sausages, as they are in great demand among Ukrainian consumers. The most common methods of improving the quality of sausage products are fat correction and calorie reduction. research of technology of sausage products with inulin-containing raw materials. Systematization and structuring of the available array of information on the use of inulin-containing raw materials in the technology of sausage products will facilitate the establishment of the feasibility and necessity of practical application of this method of improving the quality of this segment of food products

**Keywords:** fat substitutes, meat products, inulin, chicory, Jerusalem artichoke, organoleptic, health-improving properties

### Introduction

Analysis of the preferences of Ukrainians when choosing meat products shows that more than two-thirds of national consumption is accounted for by sausage products, which belong to instant meat products [1]. It is worth noting that the sausage market products belong to the traditional dishes of Ukrainian cuisine. Sausages are included in the list of products of the consumer basket, which is approved by the

Resolution of the Government of Ukraine of October 11, 2016, No. 780 [2].

At the same time, there is evidence [3] that sausage can be harmful to health (nutritional diseases, in particular obesity, and cardiovascular disorders), mainly due to its composition, which includes natural fat as a thickener, and in cheap products, hydrogenated vegetable fats are added

### Suggested Citation:

Snizhko, O., & Momot, I. (2022). The use of inulin-containing raw materials in the technology of sausage production. *Animal Science and Food Technology*, 13(2), 71-80.

\*Corresponding author

to stabilise the structure [3]. Excess lipids in the human diet combined with low physical activity lead to undesirable consequences, most often obesity [4].

Today, many scientific studies are devoted to the impact of nutrition on human health. In the last year alone, the international scientific platform Research4Life has collected more than 32 thousand sources of evidence of the direct impact of food components on the consumer [5].

According to experts, healthy sausage in the modern world simply does not exist, but the safest is boiled sausage, mainly due to the manufacturing technology [6]. It is possible to reduce the caloric content of cooked sausages by reducing the relative amount of fat in the recipe, however, without introducing any substitutes, this will lead to a deterioration in the organoleptic parameters and structure of the finished product [7]. The relevance of the research topic is determined by the necessity to analyse the existing practice of improving the quality of sausage products by full or partial replacement of fat, including at the expense of inulin-containing raw materials.

Adding dietary fibres such as inulin to meat products has become a new trend due to their potential health benefits for the consumer. Inulin is used in the food industry either alone or in combination with other related ingredients. At the same time, it is defined as a prebiotic, dietfibereary modifying, low-calorie sweetener, fat substitute, gelling agent, viscosity modifier and texture- ingredient in various food products [8].

It is worth noting that in general, the global inulin market is characterised by high competition. Most major producers are geographically located in North America and Europe. The largest players in the market are Beneo GmbH, Cosucra Group Warcoing SA, Tierra Group, Cargill, Inc. and Sensus BV [9]. The average annual growth rate for inulin is estimated to be 6.5% on the world market [10].

*The purpose of the study* was to analyse the statistical data on the dynamics of meat consumption in Ukraine and in the world, to examine the distribution of consumer purchasing and taste preferences; to systematise the available information on methods of reducing calories and increasing the nutritional value of sausage products, and to determine the scope of study and practical application of inulin-containing raw materials in the formulation of sausage products to improve their quality and nutritional value.

To achieve this goal, it is necessary to conduct a meta-analysis of the international and Ukrainian publications by keywords; to research and process statistical data on the level of meat consumption; to establish the feasibility of improving sausages by determining the features of consumer priorities in relation to meat and sausage products; to find and structure the available information on improving the health properties of sausages.

## Materials and Methods

During the research, the methods of formal logic, analysis, synthesis, generalisation, comparative method, etc. were used, a meta-analysis of studies based on the search of literature data for the period 2001-2022 (descriptors: inulin, inulin-containing raw materials, sausages) using the international scientific platform Research4Life [5], which contains publications of such bibliographic and abstract databases of peer-reviewed literature as Scopus, Web of

Science, Google Scholar and others. The paper contains statistical data from the Organisation for Economic Cooperation and Development [11], the state statistics service of Ukraine [12] and others [13].

Articles must meet the following criteria: published in English; prospective, retrospective nature of research; open free access to the text; articles were peer-reviewed; publication date ranged from 2001 to 2022.

Mathematical processing of digital material and various table formats, and visualisation of the processed data was carried out using Microsoft Office Excel with a standard set of options.

## Results and Discussion

### *Analysis of recent studies*

Meat is a concentrated source of nutrients that have traditionally been considered essential for optimal growth and development. This animal product is vital for a healthy and balanced diet. Meat products play a unique role throughout the history of human development [14]. They have always been and are an important component of the human diet, and their consumption has acquired a tendency to gradually increase both in Ukraine and around the world [11].

Meat and meat products are an important source of energy, essential nutrients such as amino acids, proteins with high biological value, b vitamins, especially vitamin B<sub>12</sub> and minerals such as iron, zinc, selenium, and manganese. A large number of studies indicate that, in addition to macronutrients (proteins and lipids), meat and meat products are also rich in some biologically active components (L-carnitine, taurine) with antioxidant properties that play an important biotransformation role for consumer health [15]. There are studies confirming the antioxidant properties of L-carnitine, taurine, and L-carnosine, which are based on the ability of these substances to remove radicals and chelate (bind) metal ions with a ligand (a molecule connected to a protein) [16]. Other animal studies reported that the consumption of L-carnitine, L-carnosine, taurine significantly reduced serum triglyceride and total cholesterol levels and could prevent liver obesity [17].

L-carnitine performs several important functions in living organisms, in particular, energy production, participating in the reactions of fatty acid oxidation in the mitochondrial matrix, in the transport of activated fatty acids (acyl-CoA) from the cytoplasm through the mitochondrial membrane, thereby stimulating the processes of  $\beta$ -oxidation, while enhancing thermogenesis (heat production in the body) [15].

Taurine is a sulphur-containing amino acid found in nature mainly in excitable tissues such as the heart, brain, retina, and skeletal muscles. In 1985, taurine was first approved for the treatment of patients with heart failure in Japan [18]. In particular, it was claimed that taurine protects against pathologies associated with mitochondrial defects, such as ageing, metabolic syndrome, cancer, cardiovascular diseases and neurological disorders. A number of studies have confirmed the antioxidant properties of taurine and its ability to protect mitochondria from oxidative stress. In addition to antioxidant properties, the data also show the hypotensive and immunomodulatory effects of some components of meat products, the protective effect of taurine on the retina and the ability to reduce the level of free and

esterified cholesterol [19]. Peptides extracted from meat showed antithrombotic properties and cytotoxic effects against various cancer cells [15].

Despite all the advantages of food products from raw meat, nutritionists report that an excess of meat in the diet can provoke a number of diseases [20-22], including cancer [23], and, most likely, a violation of normal metabolism [4]. Sausage products are especially criticised [24]. Therefore, scientists and producers of the meat processing industry are looking for methods to improve the quality of meat products, including sausages, that would meet modern requirements for these food products.

Among the current solutions are the elimination of nutrient deficiencies and the potentially toxic compounds without reducing the organoleptic quality and safety of finished products, enrichment with natural bioactive plant compounds (antioxidants, dietary fibre) or probiotics, reduction of harmful components (salts, nitrates/nitrites, N-nitrosamines), use of alternative technologies (high-pressure processing, cold plasma [25], ultrasound) [15; 25], the introduction of monounsaturated and polyunsaturated fats [26-28] and reduction of fat content [29].

Scientists have proposed various means of reducing the fat content of sausage products, in particular through the use of lean meat and the addition of more water than in products made according to the classical recipe, they also propose the use of ingredients with low-calorie content or even those that do not contain calories at all [30]. Some studies have shown that cereal and legume fibres,  $\beta$ -glucans, starches, gums, and pectin can be used to reduce calories and fat content in sausage products [31; 32].

Previous investigations related to changes in sausage formulation aimed at reducing fat content and improving fatty acid profile demonstrate and analyse the use of different oils (olive, soybean, flaxseed, grape seed, etc.) in liquid, encapsulated or stabilized with isolated soy protein [33].

More recent publications demonstrate the effects of the use of special gels of complex structure, which provided a combination of oils with carrageenans, gellan gum and reduced fat content in fermented sausages up to 80% [34; 35].

Most of the technological solutions for processing meat raw materials discussed above have encountered various production obstacles, in particular those related to reducing the content of animal fat since it performs important functions in determining the three main organoleptic characteristics: appearance (colour and surface uniformity), texture (viscosity, elasticity and hardness), and the intensity of taste. Loss of product weight and moisture retention capacity can also become a problem. For example, the replacement of fat in the formulation with rapeseed and olive oils caused a stiffness of meat products in the experiment conducted by R. Afshari *et al.* [8]. At the same time, they found that the samples made from similar raw materials, but with the addition of inulin (3.1%) and  $\beta$ -glucan (2.2%), had better organoleptic quality indicators. The study of organoleptic qualities and subjective assessment of the appetite of meat products when using different doses of rye bran and pea fiber was carried out by a group of scientists led by Ursula Kelet [36]. Pea fibre or rye bran was added to minced meat in doses of 3 to 6 g of dietary fibre per 100 g of minced meat. The sensory profile rated the meatballs in terms of smell, appearance, texture and taste and found

that the addition of rye bran enhanced the grain smell, texture and taste. Pea fibre led to a more crumbly, firm, and grainy texture, especially with increasing fibre doses, while the addition of fibre did not affect subjective appetite.

According to F. Balestra [37], dietary fibre can be effectively incorporated into processed meat products as a functional ingredient with a “clean label” with a corresponding effect on the technological, nutritional and organoleptic characteristics of meat. Dietary fibres are mainly used in meat products to improve moisture retention capacity and retain additional added water, thus acting as a kind of filler. They improve the uniformity and shape of crushed meat products, and have a positive effect on the stability of the emulsion and fat retention of meat (for example, sausages). Dietary fibres are a powerful tool to change the texture and sensory properties of the finished product towards the desired profile (to add spice or increase tenderness and juiciness). Some soluble dietary fibre fractions can be useful for the formulation of low-fat meat products due to their “fat-like” behaviour.

In water systems, when stirred intensively and then cooled, inulin forms a smooth gel-like structure that provides a combination of creamy and juicy sensations in the oral cavity during the tasting of the product. This ability potentially provides it with the role of a fat substitute, without changing the rheological properties, but resembling the feeling of fatty taste in a lean meat product [38].

Thus, inulin is a fat mimetic and can be beneficially used in the technology of meat products with low-fat content and low-calorie content, including in the technology of sausage products.

Inulin in its native form is found in tubers, rhizomes and bulbs of plants of the family *Asteraceae* such as chicory (*Cichorium intybus*), artichoke (*Cynara*), garlic (*Allium sativum*), Jerusalem artichoke (*Helianthus tuberosus*), onion (*Allium porrum*), dahlias (*Dahlia pinnata*), asparagus (*Asparagus falcaus*), Kalgan the great (*Alpinia calcarata*), aloe vera (*Aloe vera*), elephant bread (*Amorphophallus campanulatus*), beetroot (*Beta vulgaris*), yams (*Dioscorea alata*) [39], devyasil (*Inula helenium*) [40] and some others.

Plants with a high content of inulin are usually called inulin-containing raw materials. The number one raw material with an inulin content of 42 to 76 g/100 g of dry weight is chicory roots. Jerusalem artichoke tubers also have high levels of inulin and fructo-oligosaccharides, which are 45-75.0 g/100 g dry weight [41]. Artichoke, which also contains inulin as a reserve carbohydrate, is grown mainly in the Mediterranean basin, where Italy and Spain are its main producers and consumers. The amount of inulin in the artichoke core ranges from 2-10 g/100 g of dry weight [42]. The technology of inulin production from artichoke is special because it results in a large amount of waste and up to 77% of the mass of all raw materials is lost by the food industry [41].

Due to the steady growth trend in demand for inulin, Europe will dominate the market in the near future. The interest of consumers is explained by the awareness of the importance of a healthy diet, which, according to modern beliefs, should contribute to the prevention of alimentary diseases. The consumption of food products with inulin, which is a polymer of fructase – fructan, and all fructans are prebiotics, the benefits of which are confirmed by many studies [39-41].

Among the search results, 73% of publications reported on inulin-containing raw materials as a source of inulin. Data on the use of inulin-containing raw materials in sausage products are quite limited in both international and Ukrainian sources. Among the findings are the results of comparing the quality indicators of two groups of sausages during an 80-day experiment at a storage temperature of 2 °C [43]. Both groups had the same recipe and component composition, with the exception of pork fat. In the experimental group, 5.2% of all animal fat was replaced with chicory root inulin, while the control group of sausages contained 7.8% pork fat. Control sausages were more elastic, cohesive, firm and juicy, while sausages with fat mimetic showed higher gel strength and hardness. Both groups had acceptable quality not only immediately after production but also during storage. However, the sausage with fat mimetic had lower calorie content, which is a positive change towards the health benefits of the sausage. The authors also indicate that inulin did not affect microbial growth, which was within the normal range.

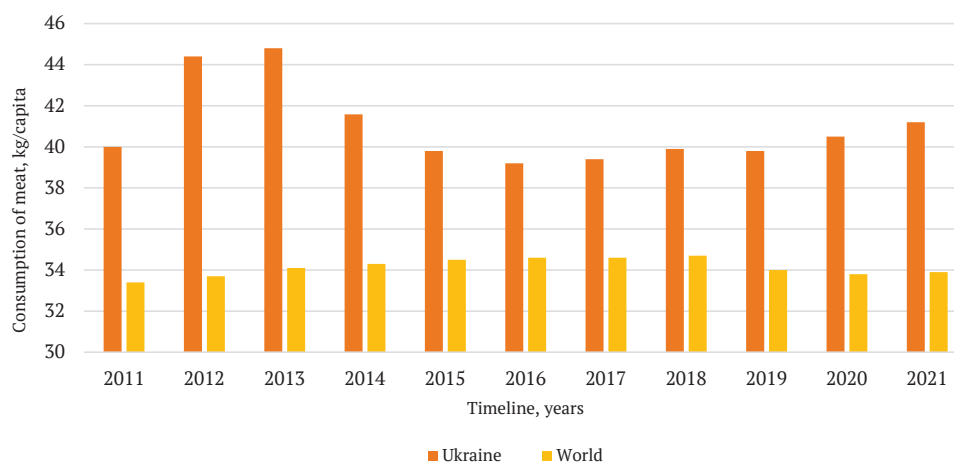
The study, which was conducted to evaluate the organoleptic and physicochemical properties of lean chicken sausages with the addition of garlic inulin, showed that the fat content in sausages can be reduced from 13.67% (control sample) to 4.47-4.85% due to the inclusion of water-based inulin gel at the level of 3%. At the same time, 2% of inulin contributed to an improvement in sensory qualities, such as taste and overall impression (appetite). It is noted that the content of protein, ash and moisture in the sausage samples increased with an increase in the percentage of inulin in the formulation. The authors concluded that garlic inulin can be successfully used to replace fat in sausage production without changing meat quality indicators [10].

The journal "Korean Journal for Food Science of Animal Resources" published a study on the influence of chicory on the quality characteristics of sausages. The bottom line was that chicory in the formulation of restructured sausages in general had a negative impact on the quality characteristics of the sausage, which the researchers successfully levelled by applying smoke. In conclusion, it was recommended to use chicory in restructured sausages with a reduced fat content, subject to quality compensation [44].

It is worth paying attention to several other experiments aimed at reducing calories and increasing the usefulness of sausage products, in which vegetable oil was successfully replaced by inulin in the composition of sausages to improve the physicochemical, microbiological and textural parameters. Léia Zenaide Menegas and co-authors studied the physicochemical, microbiological, and textural characteristics and stability during storage (4 °C for 45 days) of sausages with partially replaced corn oil in the recipe. They found that the addition of inulin did not change the physicochemical and microbiological parameters, but affected the texture and colour, while also softening them. The authors noted that the created product had stable quality in terms of physical, chemical, microbiological and organoleptic properties during 45 days of storage at 4 °C [45]. Also, there are results showing that reducing the fat content in emulsion-type sausages (from 6% to 18%) leads to a decrease in the energy value of the product by 20% and 64%, respectively; that inulin can be used as a fat mimetic without any significant changes in the overall perception and attractiveness of the final product [46]. Other researchers analysed four options for replacing fat with inulin in chicken sausage (25%, 50%, 75%, 100%). After the preparation of the samples, their physicochemical, textural, calorimetric and organoleptic properties were assessed. As the amount of inulin increased, the stiffness, cohesiveness, stickiness, and fibrousness decreased, but the elasticity and rubberiness of the structure increased. Organoleptic evaluation of the samples showed that as the amount of inulin increased, the average scores for colour, appearance, and texture increased, but the average scores for smell and taste decreased. Finally, they concluded that the use of inulin can be recommended as a fat substitute in the formulation of chicken sausages, provided that the dose of the component is adjusted [7].

#### Description of statistical data

Analysis of Ukrainian and international data suggests a minor trend of about 2% (Fig. 1) towards an increase in consumption of meat products in the world. Ukraine would have similar dynamics, but the armed aggression of Russia poses a threat to the food security of Ukraine (Fig. 1).



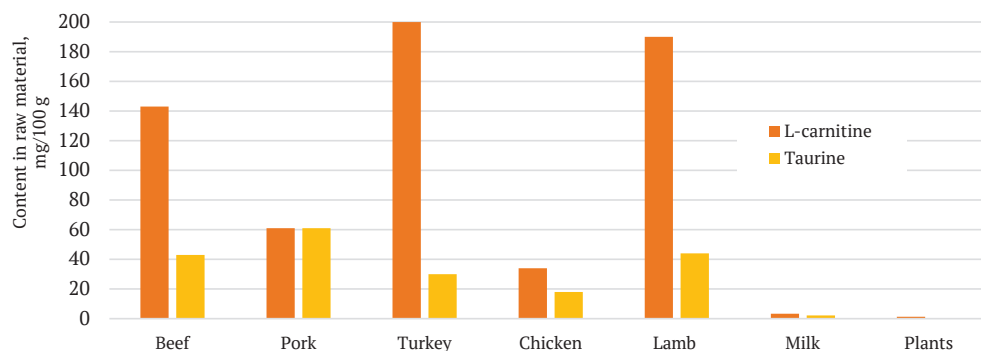
**Figure 1.** Consumption of meat products in Ukraine and in the world 2011-2021

**Source:** compiled by the author based on data from [47]

Over the past 10 years, meat consumption in the world has not been uniform and after rising in 2013 to a value of about 45 kg per capita per year, it fell in 2016 by 11% to 40 kg per capita. However, over the past three years, there has been a steady upward trend in meat consumption in the world and as of 2021, reached the mark of 41.2 kg per capita. In Ukraine in 2018, according to European statistics, meat consumption began to decline over the next two years

and amounted to 33.8 kg per capita in 2020. However, in 2021, there was a barely noticeable increase in this indicator.

According to sources [16; 17] meat products are rich in biologically active substances – L-carnitine, taurine. The data on the content of these components in food raw materials of various origins were analysed (Fig. 2) and it was found that taurine and L-carnitine are found mainly in animal food.



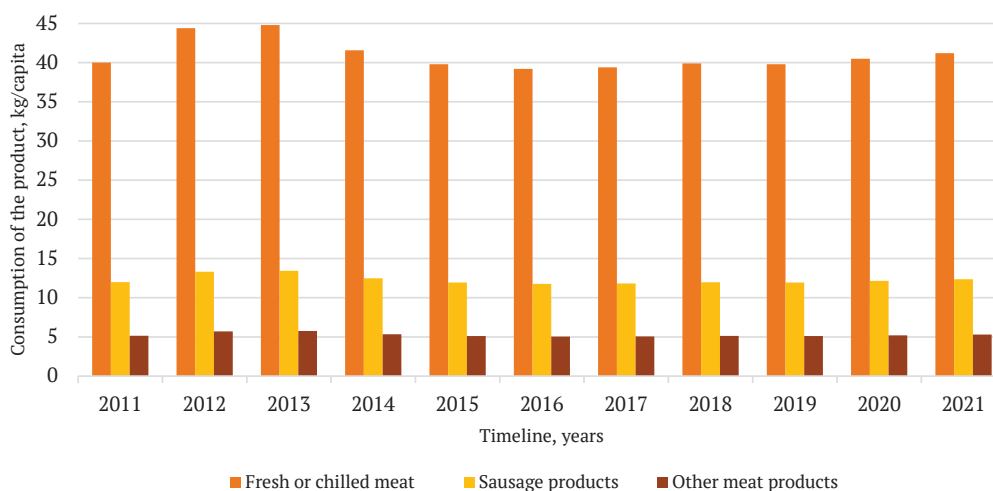
**Figure 2.** L-carnitine and taurine content in raw materials of various origins

**Source:** compiled by the author based on data from [16]

Turkey, lamb, and beef are leaders in the content of L-carnitine, as they have 200 mg/100 g, 190 mg/100 g and 143 mg/100 g, respectively, of this nutrient. Most taurine is found in pork, lamb and beef – 61 mg/100 g, 43 mg/100 g, 44 mg/100 g. Pork contains an equal amount of L-carnitine and taurine, which makes this raw material unique. Chicken is quite poor in carnitine and taurine compared to the previously mentioned raw materials. However, these two substances

are almost absent in plants. Therefore, meat, according to this indicator, has no alternatives and is really a high-value source of necessary nutrients for the body. And, despite the decline in meat consumption, for objective reasons, meat and meat products are the most promising products for a healthy diet.

It is worth noting that among the total number of meat products the most popular in Ukraine are sausages (Fig. 3).

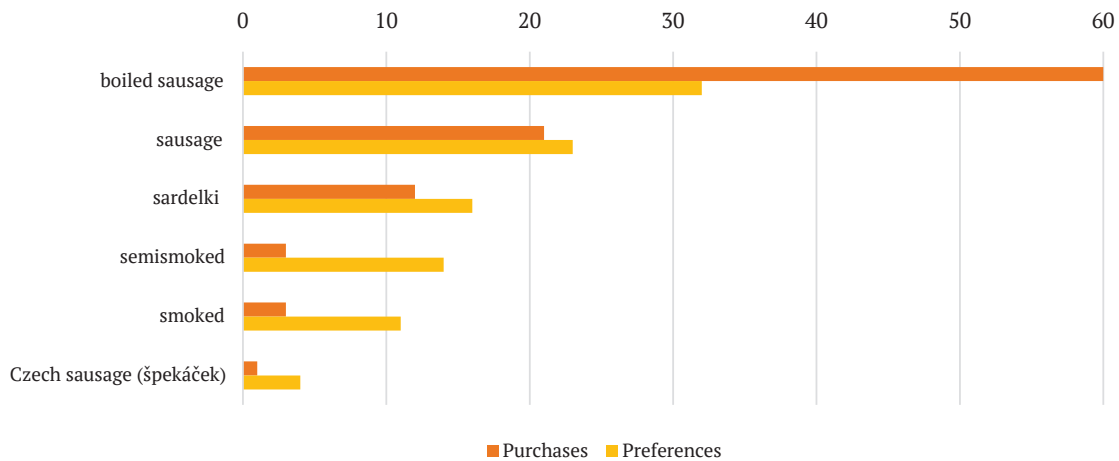


**Figure 3.** Consumption of meat and meat products in Ukraine 2011-2021

**Source:** compiled by the author based on data from [47; 48]

The graph in Fig. 3 shows that during the last decade sausage consumption was almost stable and averaged 12.3 kg per capita. In addition, it should be noted that Ukrainians consume 70% more sausages as compared to other meat products.

Due to the popularity of sausage products, it is advisable to improve their health properties. Comparisons of opinion polls and consumer portraits taken from Ukrainian literature sources, as well as statistical data, are shown in Figure 4.

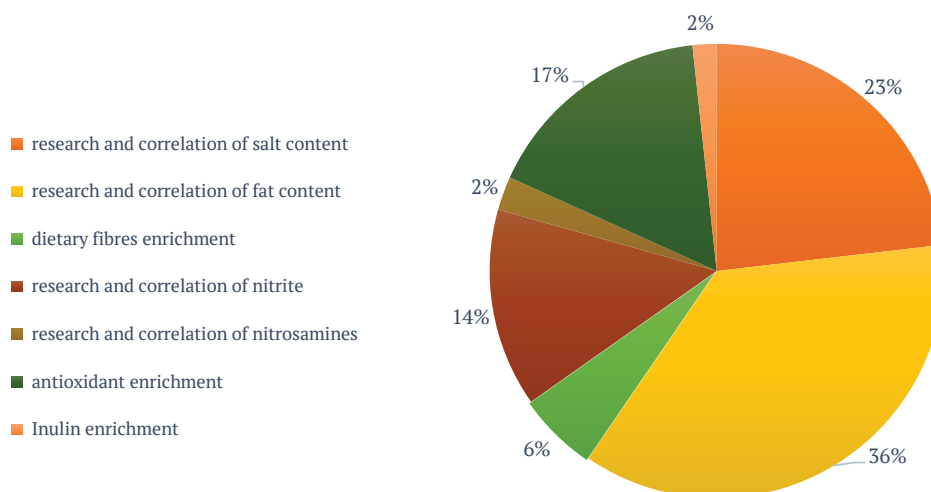


**Figure 4.** Distribution of consumer and taste preferences, % of respondents

**Source:** compiled by the author according to [49-51]

The analysis of consumer preferences shows that among the wide range of sausages on the Ukrainian market, respondents choose boiled sausages due to their versatility, availability and taste. The second and third most popular sausage products are sausages and sardelki, followed by semi-smoked and smoked sausages and the last place is Czech sausage (špekáček). Consumers most often

buy boiled sausage, less often buy sausages and sardelki than smoked and semi-smoked. According to the data obtained through author's literature search, the replacement of fat in sausages is the most relevant area in the field of research on the quality of sausage products. When searching for the keywords "sausage" and "fat", the system offered 3,426 results, among which the predominant majority are journal articles (Fig. 5).



**Figure 5.** Research of directions for improving the quality of sausages

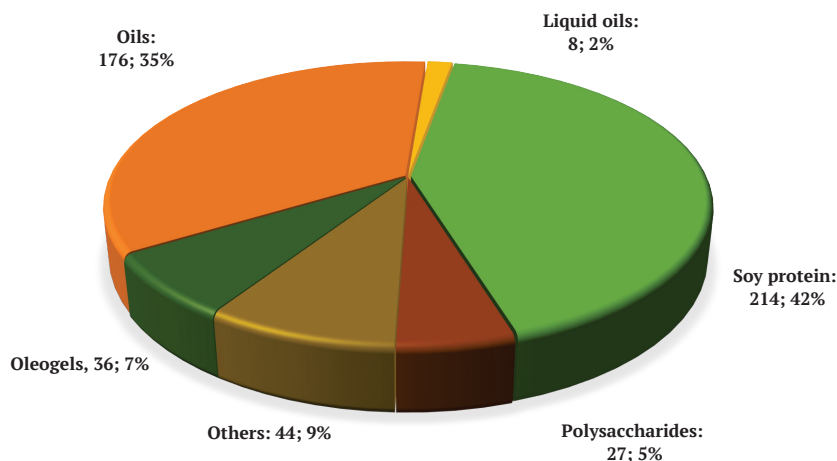
Sausages are popular all over the world due to the combination of several properties. First, they have a high nutritional and caloric value (406.96 kcal (or 1703 kJ) per 100 g, the average value for semi-smoked sausages). This amount is  $\frac{1}{4}$  of the norm of protein and up to  $\frac{1}{2}$  of the norm of fat, based on the daily norm – 2000 kcal per 1 day. Secondly, sausages do not require initial heat treatment. Additional shelf life is another important characteristic of sausage products, which makes it possible to transport them over long distances for a long time without loss [52]. However, as noted earlier, sausage products also have a number of disadvantages, which are based on raw meat and animal fat.

Monitoring of freely available data on the directions of improving the quality of sausages, in accordance with modern world requirements, showed that most articles were devoted to the correction of fat content and calorie reduction – 36% (8,050 publications) (Fig. 5). The topics of research and correction of salt content – 23%, enrichment with antioxidants – 17%, research and correction of nitrites – 14% and 6% of publications concerned the enrichment with dietary fibre in general. Nitrosamines in the composition of sausages, which can be formed in the presence of amines (chemicals derived from ammonia and found in large quantities in protein products) during the technological production, culinary preparation and storage of sausages, were

mentioned in 2% (225) of the sources. Enrichment of sausage products with inulin is also not a sufficiently studied area, as only 161 articles (also about 2%) were found by relevant keywords in international databases of scientific publications.

Improving the quality of sausages is often suggested to be accomplished by introducing vegetable raw

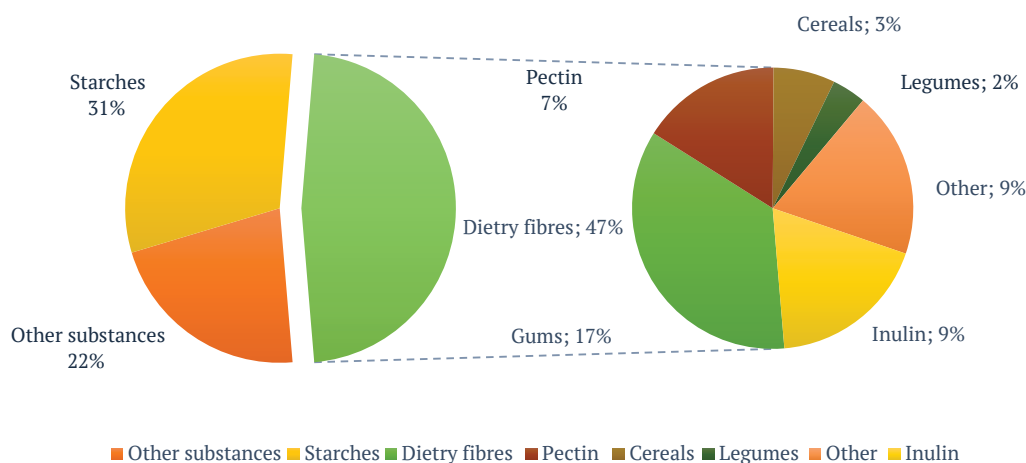
materials – protein, carbohydrate, and fat (Fig. 6). The first place is occupied by soy protein (214 articles – 42%), and the second – by oils (220 articles – 44%), among which there can be both liquid (8 articles – 2%) and oleogels (36 articles – 7%). The use of polysaccharides is proposed in 5% of articles (27 articles), which indicates incomplete development of the direction.



**Figure 6.** The use of plant components to reduce the fat content of sausages according to Research4Life publications

The scientific base of Research4Life includes 1844 articles that report on the experience of using various polysaccharides in the formulation of sausage products, among which the most popular group is “dietary fibre”, which currently has 873 (47%) publications, most of which

are journal articles (Fig. 7). This group accounts for almost half of all sources found by search keywords related to the names of the group of polysaccharides and sausage products. The second half is made up of starches and other substances.



**Figure 7.** The content of polysaccharides in studies on reducing the caloric content of sausages

Among dietary fibre, gum (17%) and inulin (9%) are the most commonly used. The rest were pectin (7%), dietary fibre from cereals (3%), legumes (2%) and other crops that contain dietary fibre in their structure (9%).

The search for information on the use of inulin-containing raw materials such as chicory, Jerusalem artichoke, artichoke, banana, dahlia in the technology of sausage products did not yield fruitful results.

A total of 64 articles related to the use of inulin in the composition of inulin-containing raw materials in

sausage products were found, four of them about sausage with chicory, six – about sausage with Jerusalem artichoke. The article presents statistical data on meat consumption in Ukraine and the world, the distribution of consumer purchasing and taste preferences, and systematises areas for improving the quality of sausages.

### Conclusions

Meat and meat product are promising foods for a healthy diet, as they contain valuable biologically active

components – L-carnitine and taurine, which have important functions (antioxidant, hypotensive and immunomodulatory) and are absent in plant products. Over the past 10 years, meat consumption in the world has not been uniform, however, over the past three years, there has been a steady upward trend in consumption of this product.

An analysis of the consumption of meat and meat products in Ukraine in 2011-2021 revealed that over the past decade, the consumption of sausages has been almost stable. Ukrainians consume 70% more sausages compared to other meat products, therefore, due to their popularity among consumers, it is advisable to increase their health properties.

The analysis of consumer preferences shows that among the wide range of sausages on the Ukrainian market, respondents choose boiled sausages due to their versatility, availability and taste.

Monitoring of open access data on the areas of improving the quality of sausages in accordance with modern world requirements showed that most articles were devoted to the correction of fat content and calorie reduction – 36% (8050 publications). Enrichment of sausage products with inulin is not a sufficiently studied area, as only 2% (161 articles) were found by relevant keywords in international databases of scientific publications.

According to the literature review, of 64 articles found on inulin as a raw material component of sausage products, four were about sausage with chicory and six were about sausage with Jerusalem artichoke.

The use of inulin-containing raw materials in the production of sausage products is a promising, but insufficiently studied direction of improving the health properties of this type of product, so it needs wider coverage and more in-depth study.

## References

- [1] Market analysis of cooked sausage, sausages and anchovies. (2019). *Pro-Consulting*. Retrieved from <https://pro-consulting.ua/ua/issledovanie-rynka/analiz-rynka-varenoj-kolbasy-sosisok-i-sardelek-2019-god>.
- [2] Law of Ukraine No. 780 “On Approving Sets of Food Products, Sets of Non-Food Products and Sets of Services for Major Social and Demographic Groups”. (2016, October). Retrieved from <https://zakon.rada.gov.ua/laws/show/780-2016-#Text>.
- [3] Why eating sausage is almost like smoking and why even sausage with a “good” composition is harmful to health? Bukovyna independent information portal (BukInfo). (2018.) Retrieved from <https://bukinfo.com.ua/>.
- [4] Waldhart, N., Muhire, B., Pospisilik, J.A., Johnson, B., Pettinga, D., Madaj, Z.B., Wolfrum, E., Dykstra, H., Wegert, V., Han, X., & Wu, N. (2021). Excess dietary carbohydrate affects mitochondrial integrity as observed in brown adipose tissue. *Cell Reports*, 36(5), article number 109488. doi: 10.1016/j.celrep.2021.109488.
- [5] Official website of the Research4Life. Academic and professional content for the developing world. (n.d.). Retrieved from <https://www.research4life.org/>.
- [6] Leonova, O. (2021). *Experts named the most harmful type of sausage: What is dangerous*. Retrieved from <https://novyny.live/health/eksperty-nazvali-samyi-vrednykh-vid-kolbasy-chem-opasna-30353.html>.
- [7] Alaei, F., Hojjatoleslami, M., & Hashemi Dehkordi, S.M. (2018). The effect of inulin as a fat substitute on the physicochemical and sensory properties of chicken sausages. *Food Science & Nutrition*, 6(2), 512-519. doi: 10.1002/fsn3.585.
- [8] Afshari, R., Hosseini, H., Mousavi Khaneghah, A., & Khaksar, R. (2017). Physico-chemical properties of functional low-fat beef burgers: Fatty acid profile modification. *LWT*, 78, 325-331. doi: 10.1016/j.lwt.2016.12.054.
- [9] Official website of the iCrowdnewswire German. (n.d.). Retrieved from <https://icrowdnewswire.com/category/language/german/>.
- [10] Jayarathna, G.N., Jayasena, D.D., & Mudannayake, D.C. (2022). Garlic inulin as a fat replacer in vegetable fat incorporated low-fat chicken sausages. *Food Science of Animal Resources*, 42(2), 295-312. doi:10.5851/kosfa.2022.e5.
- [11] Official website of the Organisation for Economic Co-operation and Development. OECD. (n.d.). Retrieved from <https://data.oecd.org/>.
- [12] State Statistics Committee of Ukraine. (2022). Retrieved from <http://ukrstat.gov.ua/>.
- [13] Pro-Consulting. Market analysis (database). (2022). Retrieved from <https://pro-consulting.ua/ua/>.
- [14] Higgs, J.D. (2000). The changing nature of Red Meat: 20 years of improving nutritional quality. *Trends in Food Science & Technology*, 11(3), 85-95. doi: 10.1016/s0924-2244(00)00055-8.
- [15] Ursachi, C.Ş, Perța-Crișan, S., & Munteanu, F. (2020). Strategies to improve meat products' quality. *Foods*, 9(12), article number 1883. doi: 10.3390/foods9121883.
- [16] Kulczyński, B., Sidor, A., & Gramza-Michałowska, A. (2019). Characteristics of selected antioxidative and bioactive compounds in meat and animal origin products. *Antioxidants*, 8(9), article number 335. doi: 10.3390/antiox8090335.
- [17] Rospond, B., & Chłopicka, J. (2013). The biological function of L-carnitine and its content in the particular food examples. *Przegląd Lekarski*, 70(2), 85-91.
- [18] Jong, C.J., Sandal, P., & Schaffer, S.W. (2021). The role of taurine in mitochondria health: More than just an antioxidant. *Molecules*, 26(16), article number 4913. doi: 10.3390/molecules26164913.
- [19] Albenzio, M., Santillo, A., Caroprese, M., Della Malva, A., & Marino, R. (2017). Bioactive peptides in animal food products. *Foods*, 6(5), article number 35.
- [20] Chen, H., Fu, T., Dan, L., Chen, X., Sun, Y., Chen, J., & Hesketh, T. (2021). Meat consumption and all-cause mortality in 5763 inflammatory bowel disease patients: A prospective cohort study. *American Journal of Gastroenterology*, 116(1). doi: 10.14309/01.ajg.0000798612.41695.91.
- [21] Zhang, H., Greenwood, D.C., Risch, H.A., Bunce, D., Hardie, L.J., & Cade, J.E. (2021). Meat consumption and risk of incident dementia: Cohort Study of 493,888 UK Biobank participants. *The American Journal of Clinical Nutrition*, 114(1), 175-184. doi: 10.1093/ajcn/nqab028.

- [22] Wang, M., Ma, H., Song, Q., Zhou, T., Hu, Y., Heianza, Y., Manson, J.E., & Qi, L. (2022). Red meat consumption and all-cause and cardiovascular mortality: Results from the UK biobank study. *European Journal of Nutrition*, 61(5), 2543-2553. doi:10.1007/s00394-022-02807-0.
- [23] Manaker, L. (2022). Will avoiding meat really lower your risk of cancer? Retrieved from <https://www.verywellhealth.com/can-avoiding-meat-can-reduce-cancer-risk-5222005>.
- [24] Li, R., Li, F., Zhe, T., Li, M., Liu, Y., & Wang, L. (2021). Three-dimensional (3D) hierarchical structure engineering of AuNPs/CO(OH)<sub>2</sub> nanocomposite on Carbon Cloth: An advanced and efficient electrode for highly sensitive and specific determination of nitrite. *Sensors and Actuators B: Chemical*, 342, article number 130061. doi: 10.1016/j.snb.2021.130061.
- [25] Rudy, M., Kucharyk, S., Duma-Kocan, P., Stanisławczyk, R., & Gil, M. (2020). Unconventional methods of preserving meat products and their impact on health and the environment. *Sustainability*, 12(15), article number 5948. doi:10.3390/su12155948.
- [26] Delgado-Pando, G., Cofrades, S., Ruiz-Capillas, C., & Jiménez-Colmenero, F. (2010). Healthier lipid combination as functional ingredient influencing sensory and technological properties of low-Fat Frankfurters. *European Journal of Lipid Science and Technology*, 112(8), 859-870. doi:10.1002/ejlt.201000076.
- [27] Pérez-Palacios, T., Ruiz-Carrascal, J., Jiménez-Martín, E., Solomando, J.C., Antequera, T. (2018). Improving the lipid profile of ready-to-cook meat products by addition of omega-3 microcapsules: Effect on oxidation and sensory analysis. *Journal of the Science of Food and Agriculture*, 98(14), 5302-5312. doi:10.1002/jsfa.9069.
- [28] Pérez-Palacios, T., Ruiz-Carrascal, J., Solomando, J.C., Antequera, T. (2019). Strategies for enrichment in  $\omega$ -3 fatty acids aiming for healthier meat products. *Food Reviews International*, 35(5), 485-503. doi: 10.1080/87559129.2019.1584817.
- [29] Wongkaew, M., Sommano, S.R., Tangpao, T., Rachtanapun, P., & Jantanasakulwong, K. (2020). Mango Peel pectin by microwave-assisted extraction and its use as fat replacement in dried Chinese sausage. *Foods*, 9(4), article number 450. doi: 10.3390/foods9040450.
- [30] Balestra, F., Bianchi, M., & Petracci, M. (2019). Applications in meat products. In *Dietary Fiber: Properties, Recovery, and Applications* (pp. 313-344). doi: 10.1016/b978-0-12-816495-2.00010-1.
- [31] Uşan, E., Kılıç, G.B., & Kılıç, B. (2021). Effects of aloe vera utilization on physicochemical and microbiological properties of Turkish dry fermented sausage. *Journal of Food Science and Technology*, 59(5), 1727-1738. doi: 10.1007/s13197-021-05183-5.
- [32] Kim, D.H., Shin, D.M., Seo, H.G., & Han, S.G. (2019). Effects of konjac gel with vegetable powders as fat replacers in Frankfurter-type sausage. *Asian-Australasian Journal of Animal Sciences*, 32(8), 1195-1204. doi:10.5713/ajas.18.0781.
- [33] Glisic, M., Baltic, M., Glisic, M., Trbovic, D., Jokanovic, M., Parunovic, N., Dimitrijevic, M., Suvajdzic, B., Boskovic, M., & Vasilev, D. (2018). Inulin-based emulsion-filled gel as a fat replacer in prebiotic- and pufa -enriched dry fermented sausages. *International Journal of Food Science & Technology*, 54(3), 787-797. doi:10.1111/ijfs.13996.
- [34] Chen, J., Zhao, J., Li, X., Liu, Q., & Kong, B. (2021). Composite gel fabricated with Konjac Glucomannan and carrageenan could be used as a cube fat substitute to partially replace pork fat in Harbin dry sausages. *Foods*, 10(7), article number 1460. doi: 10.3390/foods10071460.
- [35] Jommark, N., Chantarathethimakul, S., & Ratana-arporn, P. (2021). Effect of phosphates substitution with carboxymethyl cellulose and Konjac Glucomannan on quality characteristics of low-fat emulsion sausage. *Journal of Food Processing and Preservation*, 46(2), article number 16256. doi: 10.1111/jfpp.16256.
- [36] Kehlet, U., Pagter, M., Aaslyng, M.D., & Raben, A. (2017). Meatballs with 3% and 6% dietary fibre from Rye Bran or pea fibre - effects on sensory quality and subjective appetite sensations. *Meat Science*, 125, 66-75. doi: 10.1016/j.meatsci.2016.11.007.
- [37] Balestra, F., Bianchi, M., & Petracci, M. (2019). Applications in meat products. In *Dietary Fiber: Properties, Recovery, and Applications* (pp. 313-344). doi: 10.1016/b978-0-12-816495-2.00010-1.
- [38] Illippangama, A.U., Jayasena, D.D., Jo, C., & Mudannayake, D.C. (2022). Inulin as a functional ingredient and their applications in meat products. *Carbohydrate Polymers*, 275, article number 118706. doi: 10.1016/j.carbpol.2021.118706.
- [39] Mudannayake, D., Wimalasiri, K., Silva, K., Ajlouni, S. (2015). Selected Sri Lankan food plants and other herbs as potential sources of inulin-type fructans. *Journal of the National Science Foundation of Sri Lanka*, 43(1), 35. doi:10.4038/jnsfsr.v43i1.7913.
- [40] Petkova, N., Vrancheva, R., Mihaylova, D., Ivanov I., Pavlov, A., & Denev, P. (2015). Antioxidant activity and fructan content in root extracts from elecampane (*Inula helenium* L.). *Journal of BioScience and Biotechnology*, 4(1), 101-107.
- [41] Redondo-Cuenca, A., Herrera-Vázquez, S.E., Condezo-Hoyos, L., Gómez-Ordóñez, E., & Rupérez, P. (2021). Inulin extraction from common inulin-containing plant sources. *Industrial Crops and Products*, 170, article number 113726. doi: 10.1016/j.indcrop.2021.113726.
- [42] Singh, R., Singh, T., & Larroche, C. (2019). Biotechnological applications of inulin-rich feedstocks. *Bioresource Technology*, 273, 641-653. doi: 10.1016/j.biortech.2018.11.031.
- [43] Cardoso, C., Mendes, R., & Nunes, M.L. (2008). Development of a healthy low-fat fish sausage containing dietary fibre. *International Journal of Food Science & Technology*, 43(2), 276-283. doi: 10.1111/j.1365-2621.2006.01430.x.
- [44] Choi, H., Choi, H., Choi, Y., Kim, J., Lee, J., Jung, E., Lee, S-H., Choi, Y- I., & Choi, J. (2016). Effect of chicory fiber and smoking on quality characteristics of restructured sausages. *Korean Journal for Food Science of Animal Resources*, 36(1), 131-136. doi: 10.5851/kosfa.2016.36.1.131.
- [45] Menegas, L.Z., Pimentel, T.C., Garcia, S., & Prudencio, S.H. (2013). Dry-fermented chicken sausage produced with inulin and corn oil: Physicochemical, microbiological, and textural characteristics and acceptability during storage. *Meat Science*, 93(3), 501-506. doi: 10.1016/j.meatsci.2012.11.003.

- [46] Berizi, E., Shekarforoush, S., & Mohammadinezhad, S. (2017). The use of inulin as fat replacer and its effect on texture and sensory properties of emulsion type sausages. *Iranian Journal of Veterinary Research*, 18(4), 253-257.
- [47] OECD-FAO Agricultural Outlook 2021-2030. (2022). Retrieved from [https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2021-2030\\_19428846-en](https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2021-2030_19428846-en).
- [48] Ukrinform. (2013). *Ukrainians began to eat more meat than sausages – experts*. Retrieved from [https://www.ukrinform.ua/rubric-economy/1523111-ukraiintsi\\_stali\\_iisti\\_bilshe\\_myasa\\_nig\\_kovbasi\\_\\_eksperti\\_1847512.html](https://www.ukrinform.ua/rubric-economy/1523111-ukraiintsi_stali_iisti_bilshe_myasa_nig_kovbasi__eksperti_1847512.html).
- [49] Poltoratskaia, A. (2022). *Ukrainian meat and sausage market: Analysis*. Retrieved from <https://koloro.ua/ua/blog/issledovaniya/ukrainskiy-rynok-myasa-i-kolbasy-analiz.html>.
- [50] Serhieieva, U., & Bolila, S. (2022). *Research of consumer preferences in the Kherson meat market*. Retrieved from [http://www.rusnauka.com/5\\_NTSEB\\_2007/Economics/20255.doc.htm](http://www.rusnauka.com/5_NTSEB_2007/Economics/20255.doc.htm).
- [51] Myhal, O. (2010). *Research on the behavior of consumers of meat products in the conditions of the economic crisis*. Retrieved from <http://dspace.wunu.edu.ua/handle/316497/13576>.
- [52] Wang, X., Xie, Y., Li, X., Liu, Y., & Yan, W. (2018). Effects of partial replacement of pork back fat by a camellia oil gel on certain quality characteristics of a cooked style Harbin sausage. *Meat Science*, 146, 154-159. doi: 10.1016/j.meatsci.2018.08.011.

## Використання інулінвмісної сировини у технології ковбасних виробів

Ольга Олегівна Сніжко, Ірина Василівна Момот

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

**Анотація.** Починаючи з другої половини двадцятого століття зростає популярність та накопичення дослідження різнобічних шляхів поліпшення ковбасних виробів, що спричиняє необхідність систематизувати наявну інформацію, особливо стосовно використання нетрадиційних функціональних компонентів таких, як інулінвмісна сировина. Метою дослідження було проаналізувати ступінь вивчення проблеми і систематизувати наявну інформацію стосовно методів удосконалення якості і підвищення харчової цінності ковбасних виробів, а також з'ясувати перспективність і доцільність застосування інулінвмісної сировини у рецептурі ковбасних виробів для підвищення їх споживчих переваг та поліпшення нутриціологічних характеристик. Застосовано метод метааналізу доказових даних, що базувався на пошуку літературних даних за період 2001–2022 роки з використанням міжнародної наукової платформи Research4Life, де представлені публікації індексовані у Scopus, Web of Science тощо. Використані статистичні дані Організації економічного співробітництва та розвитку, Державної служби статистики України тощо. Усього було знайдено 64 статті, які стосувалися використання інуліну у складі інулінвмісної сировини у ковбасних виробках, чотири з них про ковбасу з цикорієм, шість – про ковбасу з топінамбуром. У статті також представлені статистичні дані споживання м'яса в Україні та світі, розподілу купівельних та смакових переваг споживачів, систематизовано напрямки удосконалення якості ковбас. У результаті проведених досліджень була відмічена невисока тенденція до зростання попиту на м'ясні вироби, з'ясовано, що найперспективнішим, з точки зору покращення оздоровчих якостей, м'ясними виробами є варені ковбаси, оскільки вони користуються найбільшим попитом серед українських споживачів. Найпоширеніші методи удосконалення якості ковбасних виробів – корекція жирності і зниження калорійності. досліджень технології ковбасних виробів з інулінвмісною сировиною. Систематизація та структурування наявного масиву інформації щодо використання інулінвмісної сировини у технології ковбасних виробів полегшить встановленню доцільності та необхідності практичного застосування цього методу поліпшення якості зазначеного сегменту харчових продуктів

**Ключові слова:** замітники жиру, м'ясні вироби, інулін, цикорій, топінамбур, артишок, органолептика, оздоровчі властивості

# ТВАРИННИЦТВО ТА ТЕХНОЛОГІЇ ХАРЧОВИХ ПРОДУКТІВ

*Науковий журнал*

**Том 13, № 2. 2022**

Заснований у 2010 р. Виходить чотири рази на рік

Оригінал-макет видання виготовлено у відділі науково-технічної інформації  
Національного університету біоресурсів і природокористування України

**Відповідальний редактор:**

Д. Набок

**Редагування англomовних текстів:**

С. Воровський, К. Касьянов

**Комп'ютерна верстка:**

К. Соседко

Підписано до друку 27 квітня 2022 р. Формат 60\*84/8

Умов. друк. арк. 9,5

Наклад 50 прим.

**Адреса видавництва:**

Національний університет біоресурсів і природокористування України

вул. Героїв Оборони, 15, м. Київ, 03041, Україна

E-mail: [info@animalscience.com.ua](mailto:info@animalscience.com.ua)

www: <https://animalscience.com.ua/uk>

# ANIMAL SCIENCE AND FOOD TECHNOLOGY

*Scientific Journal*

**Volume 13, No. 2. 2022**

Founded in 2010. Published four times per year

The original layout of the publication is made in the Department of Scientific and Technical Information of National University of Life and Environmental Sciences of Ukraine

**Managing Editor:**

D. Nabok

**Editing English-Language Texts:**

S. Vorovsky, K. Kasianov

**Desktop Publishing:**

K. Sosiedko

Signed for print of April 27, 2022. Format 60\*84/8

Conventional printed pages 9.5

Circulation 50 copies

**Editors Office Address:**

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony, Kyiv, Ukraine

E-mail: [info@animalscience.com.ua](mailto:info@animalscience.com.ua)

www: <https://animalscience.com.ua/en>