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The journal "Theory and practice of meat processing" is an international peer-reviewed scientific journal covering a wide range of meat science issues.

We publish original results of the fundamental and applied research in the field of:

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- targeted modification (selection, hybridization, operative manipulation);
- processing of meat raw materials;
- improvement of technologies for meat product manufacture;
- study of effects of meat and meat product consumption on human health;
- rational use of secondary resources of the meat industry and the ecological problems of the industry

The journal "Theory and practice of meat processing" publishes scientific and review articles, reports, communications, critical reviews, short research communications (letters to the editorial office), informative publications covering themes from the raw material base of the meat industry to innovative technologies of meat processing and food production, including the use of food biotechnology, from quality and safety management and risk analysis to information technologies, modeling in the meat industry as well as trophological chain management, marketing, economics, consumer demand analysis.

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MANAGEMENT OF FOOD COLD CHAINS TRACEABILITY AMID THE COVID-19 PANDEMIC

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Keywords: *continuous cold chain, COVID-19 pandemic, supply of perishable food, meat and meat food products*

Abstract
The present article considers the functioning of food supply chains and their major component — a continuous cold chain of perishable food products, including meat products, under the conditions of COVID-19 pandemic. The issues of the impact of the pandemic on production, processing and commercial supply of meat and meat products in Russia and worldwide are being considered. The traceability of temperature fluctuations in meat processing plants is relevant; it becomes an increasingly important factor for efficient logistics to provide the best supply and to keep the food safe in the current conditions. Research data is presented here. The results of the research show that frozen foods serve as carriers and distributors of SARS-CoV-2 infection without any contact between people. This conclusion highlights additional challenges in controlling the spread of COVID-19 worldwide, and reveals the mechanism of the disease transmission, taking into account the peculiarities of temperature modes during storage and transportation of perishable meat products. The risks of food cold chains functioning under the conditions of pandemic, the adaptive strategies for their mitigation and logistical systems of tracking are considered, in particular, the application of various data technologies.

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Introduction

Continuous cold chains (CCC) serve to maintain the quality and safety of highly perishable food (HPF) while delivering it from the producer to the consumer while reducing the loss of raw materials of [1,2]. Studies show that the efficiency of CCC is often lower than the perfect one due to violations of the required temperature modes used for storage and transportation of the particular product, which deviation endangers the health of the consumer [3,4].

The concepts of the continuity of the "cold chain" of low temperature storage modes and the traceability of the "temperature history" of the HPF are the main characteristics of CCC for food, and especially for meat products. The lack of control and records of temperature at any of its main or auxiliary stages of delivery or storage can adversely affect the safety of the HPF and thus may prevent the timely withdrawal of poor-quality food products [3,5,6].

The importance of the efficient functioning of CCC for HPF was proven, among other things, by the global COVID-19 pandemic, since the survival of coronavirus 2 of severe acute respiratory syndrome of (SARS-CoV-2) predominantly depends on the ambient temperature [7,8,9].

The COVID-19 pandemic has also put an unprecedented load on the food supply chain (FSC), having revealed the weak points in its major stage, i. e. CCC, that impose challenges for agricultural food producers and suppliers (especially HPF) at the stages of its processing, storage and transportation, as well as significant changes in demand and logistics of HPF distribution.

As a rule, food supply chains, including CCC, are associated with various activities, people, materials, information, financial resources, knowledge and skills, which serve as the building bricks, which need to be managed within the FSC (Figure 1). Three important attributes of FSC, that determine its performance, are: adaptability, consistency and flexibility. The most efficient FSCs make it possible to detect structural shifts and violations, sometimes before they occur, by collecting data in "real time mode", filtering out the external influences and tracking key patterns [7].

In our interconnected and interdependent world, the management and traceability of all stages of FSC, including food refrigeration (CCC), is essential to identify the potential long-term impacts of the pandemic, and ensure food safety and human health.

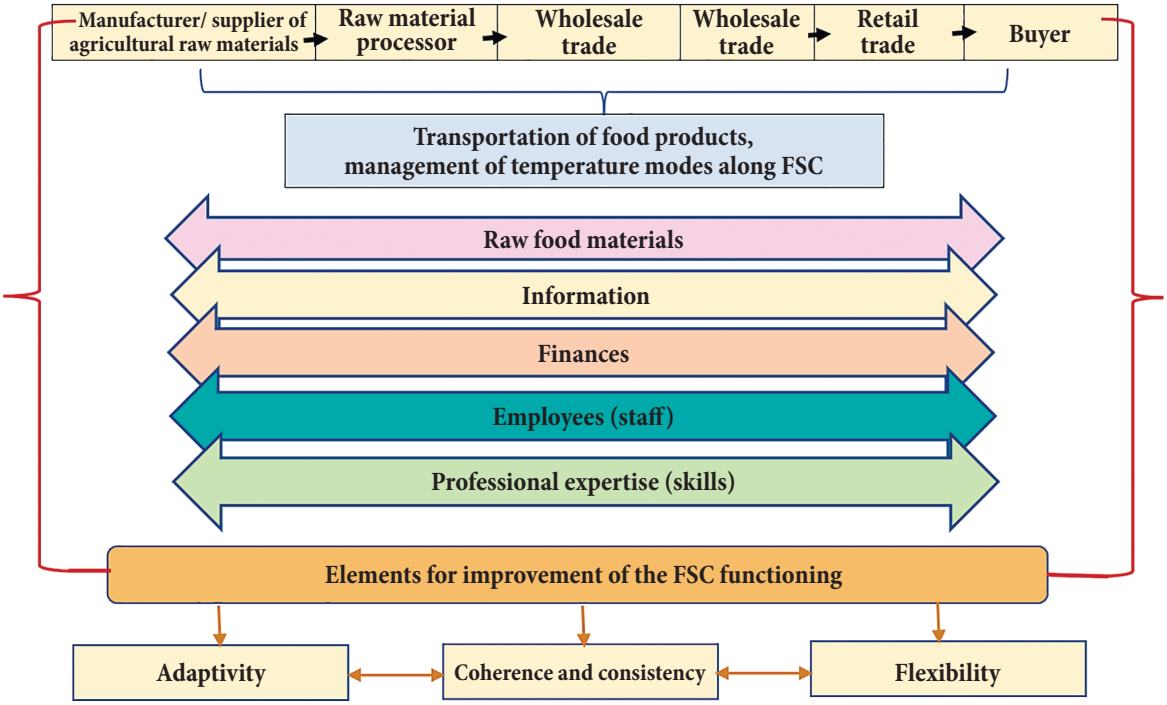

Figure 1. Mutual correlation of FSC elements

Impact of COVID-19 on meat food production and supply chain

The processing chain of agricultural products in a number of countries under the conditions of COVID-19 was disrupted due to the introduction of social distancing rules, labor shortages caused by disease, quarantine measures to restrain the spread of the virus, etc. It should be noted that not all sectors of the agro-industrial complex and types of products were affected by the pandemic in equal degree. Highly perishable food products suffered the greatest failures at various stages of the CCC.

The meat industry in developed countries has been seriously affected — the links between processing of raw material, production and supply of meat products has been disrupted due to restrictions imposed by governments of numerous countries [10,11]. In addition, meat processing appears to be more pandemic-sensitive than other food industries, in particular due to the labor-consuming nature of food processing operations [10,11]. The outbreaks of Covid-19 among production personnel in meat processing plants (MPs) have been reported in a number of countries, including the United States of America, Canada, Brazil and Europe [12,13].

The impact of COVID-19 on meat production and meat products supply chain is shown below in the Figure 2 [14].

Usually, the employees of a meat-processing plant work together, literally "side by side" in a cold and damp environment, which can facilitate the spread of the virus. This way of virus distribution was indirectly confirmed by the temporary closure of meat-processing plants (MPP) due to severe outbreaks of diseases among the employees. These outbreaks seriously disrupted the supply chain of livestock and meat [12].

For example, at french MPPs in some regions of the country, most affected by COVID-19, the number of working employees decreased by 30% [15]. In the United States of America, the slaughter of cattle and pigs in April 2020 decreased by about 40% in comparison with the same period in 2019 due to low demand of MPPs for livestock [16]. The impact of MPPs closure in 2020 was particularly pronounced in North America due to high concentration of this industry, because almost 60% of pork processing capacities in US are covered by 15 MPPs only [17]. The loss of production capacity has reached 25–43% in the USA [18].

Studies of the impact of the COVID-19 pandemic on the meat production sector in America and Brazil have shown its incredibly destructive and devastating effect on meat processing, especially during April and May 2020, caused by the outbreak of the virus in slaughterhouses, which led to extraordinary increase in livestock prices. Beef processors encountered a decline in beef production compared to January-March of 2020, by 21% in April and 19% in May; pork production declined by 18% and 19% in April and May, respectively.

During the last week of April and the first week of May, 2020, U.S. daily beef and pork processing volumes fell down about 40% below the levels of 2019. It is also noted that for the two-month period from early April to early June 2020, federally controlled cattle slaughter volumes were on average 22% lower than in the same period in 2019, while pig slaughter decreased by 13%, compared to the previous year [19]. In Canada 75% of beef processing plants were shut down due to slaughterhouse closures, especially in Alberta province.

The study [20] highlighted the impact of COVID-19 on the price of beef in the USA. The first surge of price increases was mainly caused by the effects of the quarantine,

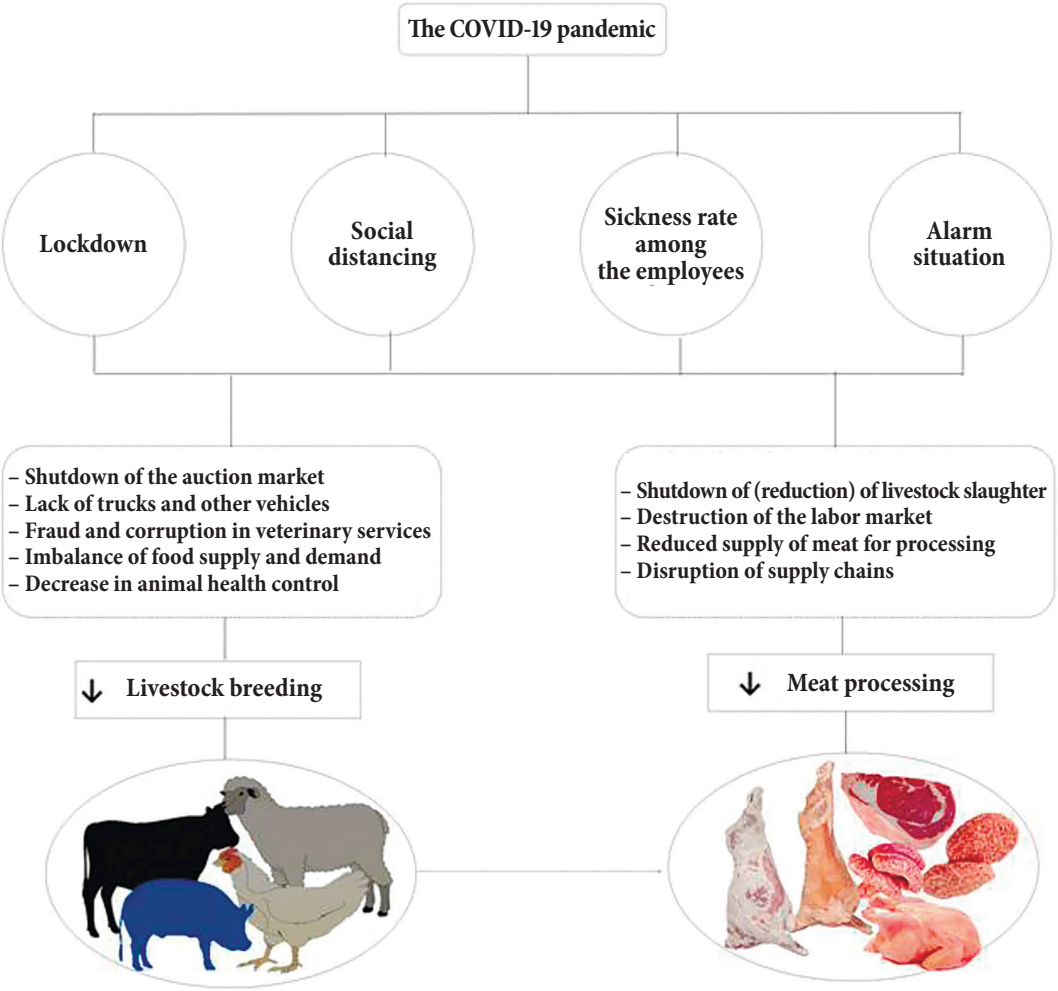

Figure 2. Impact of COVID-19 on meat production and supply chain [14]

held from March 06 to April 10, 2020 (the prices increased up to 39.1%), especially for boneless beef cuts, widely used in the production of ground beef, due to increased demand. On the contrary, the price of, for example, ribs and tenderloin decreased by up to 42% due to the wide closure of diners and eateries. The second surge of prices (April 10 to May 08, 2020) was more pronounced due to a reduction in beef production, which led to a 150% increase in boneless cuts prices. By the end of March 2020 in the United States of America, the wholesale meat prices jumped more than 1.2 times in comparison with March prices. This increase in prices was mainly caused by the widespread concern, which provoked a panic among consumers, which in its turn led to an increase in demand in grocery stores. The wholesale price for beef kept rising, thus reaching the highest recorded price of USD459 per ton of beef on May 15, 2020 due to reduced meat production and the shutdown of MPPs [21].

In the Russian Federation, as of May 2020, more than 50% of manufacturers declared financial losses. Only 47% of surveyed companies in various regions of the country showed no negative financial result for April 2020, while 53% showed a significant loss from 1 to 50 million rubles. The situation of regional meat producers is more complicated than at the federal level. 75% of the surveyed federal players show a positive financial result (25% of them showed slightly negative result), while regional producers feel absolutely opposite — more than 69% of them suffered from negative financial result as of April 2020. Experts recognize HoReCa the most affected sales channel — as it is a wholesale trade sector and specialized meat stores and shops, developed by many local producers [22].

Taking into account the impact of the COVID-19 pandemic, the Ministry of Agriculture of the Russian Federation lowered the forecast for level of agricultural production. According to the Ministry's assessment, presented in the National Report on results of implementation of the state program for agriculture development, the increase in the agro-industrial complex was reduced from 1.8 to 1.0% in 2020 [23].

The initial estimated impact of the pandemic on the meat industry accounts for about 13.6 billion USD, while additional impacts are highly likely to occur in the future [24]. For example, a possible impact of the COVID-19 pandemic on the meat industry is a change in the habitual diet of a part of the population: people may change their diet to consumption of more plant products against the backdrop of a decrease in consumption of animal products due to disruption of the FCS, rush demand and rising prices for meat. [25].

The availability of meat and meat products for consumers is an important and socially significant task, aimed to

reduce the consequences of those devastating pandemic situations. For implementation of this social task, it is necessary to ensure the continuity of meat production and the efficient functioning of CCC as part of FCS, without violating the required temperature modes in order to maintain the quality and safety of the HPF.

Traceability of risks in food CCC during the pandemic and the adaptive strategies to mitigate the risks

The pandemic creates a whole range of uncertainties for the food industry, not only because of its uncertain duration and serious consequences. The economic downturn and unemployment caused by the pandemic significantly decrease the consumers' incomes, which could lead to lower demand and cause substitution among the food categories (i. e. substitute costly food with cheaper substitutes). Therefore, an important condition for the efficient functioning of the FSC in the medium and long term, especially under conditions of social uncertainty, is FSC adaptability.

The other main source of uncertainty for FSC is the possibility of recommencement of quarantines in areas exposed to COVID-19 and other infectious diseases, like monkeypox. Where these quarantines require the closure of food service outlets, their FSC face further failures and disruptions. This script was observed during the second wave of the pandemic since autumn 2020 till 2021, when regional and national lockdowns were reintroduced in an attempt to slow the spread of the virus.

The study of the key strategies for FSC organizing has shown that new methods for ensuring their flexibility and sustainable development can play a dominant role in optimization of food CCC after the pandemic [26]. At the same time, the CCC of food products has special features of temperature modes for HPF storage. Those temperature modes differ from the parameters of ambient temperatures, which are typical for the general FSC.

Food CCC plays a dual role in the context of the COVID-19 pandemic: on the one hand, it helps to ensure food safety and reduce the loss of HPF, and on the other hand, it increases the risk of transmission of COVID-19 due to low temperatures modes.

Several incidents have shown that food at CCC stages can serve as carriers of SARS-CoV-2, including over long distances. For example, the earliest known case of transportation of refrigerated SARS-CoV-2 infected food occurred on June 12, 2020 at the Xinfadi Agricultural Wholesale Market in Beijing, China, where they found a cutting board used to process the imported salmon. This cutting board was infected with SARS-CoV-2. Since July 2020, cases of SARS-CoV-2RNA infection from frozen food imported from countries with an ongoing epidemic have been reported in nine provinces of China [27]. The contaminated food and food packaging imported from areas with active SARS-CoV-2 outbreaks served as the potential sources of COVID-19 outbreaks in previously clear, unreported areas, where not a single case of the disease was recorded for several periods (months) according to an assessment report from New Zealand, Vietnam and China [28].

However, the correlation between temperature and spread of COVID-19 remains unclear and controversial. Thus, researches in 62 Chinese cities found that temperatures rising did not mitigate the COVID-19 epidemic [29], and a study of daily cases of COVID-19 infection in 8 countries found that meteorological factors did not significantly affect the spread of COVID-19 [30].

Meanwhile, several research groups have reported that meteorological conditions yet do influence the spread of COVID-19 [9,31]. Thus, a study of the correlation between infection spread and environmental temperature parameters in 166 countries (excluding China) proved that daily temperature increase for only 1 °C was accompanied with a reduction in the daily number of new COVID cases (by 3.08%) and reduction of daily mortality (by 1.19%) [32].

The impact of temperature on spread of SARS-CoV-2 through surfaces of food and commodities in the CCC was studied too. As a result, it was found that SARS-CoV-2 is able to survive for more than 21 days during HRF storage and transportation at temperatures down to minus 18 °C [33].

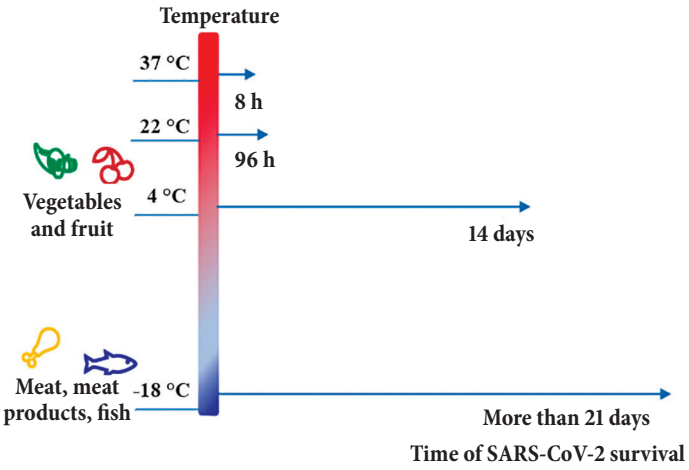

Figure 3. Survival time of SARS-CoV-2 at storage temperatures required for various foods in CCC [34]

The systematic arrangement of the results of assessment of time of SARS-CoV-2 survival on the surface of food at different temperatures shows that SARS-CoV-2 is more likely to be transported through the CCC stages on the surface of frozen meat / fish products compared to fruits and vegetables (Figure 3) [34]. Thus, CCC management practices based on appropriate classification of risks are important to effectively and efficiently reduce the risk of SARS-CoV-2 transmission in FSC.

The results of the analysis of the situation with COVID-19 by foreign researchers show that the future waves of the pandemic (or future pandemics) increase the probability of failures and disruptions for food industry enterprises due to sporadic outbreaks of diseases in their workplaces [12,35].

However, unlike the situation in early spring 2020, there was an opportunity to develop and adapt various preventive procedures afterwards. Thus, the implementation of sanitary and hygienic measures and social distancing at MPPs reduce the risk of infection spread among operation employees, thus helping to protect the health and well-being of workers.

Additional adaptive strategies include automation, robotization and digitalization of production.

The cost-effectiveness of increasing the automation level will depend on the extent to which robotics increases plants productivity, improves quality control, and reduces food safety risks. The pandemic may have contributed a new concern: at the labour-intensive MPPs the production lines should run at slower speeds both to protect worker health and prevent significant loss of revenue should production be interrupted or suspended due to the employees' sickness [15].

Digitization in the FSC is an ongoing trend that can be accelerated by the pandemic also. Technologies that facilitate contactless electronic transactions compared to hard-copies ones are becoming increasingly attractive for population. The development of common standards, for example for exchange of customs data or data on traceability of the goods, can facilitate transactions in cross-border FSC. The System GS1 is an example of a common data standard related to the goods identification, using bar codes, exchanging electronic messages for data collection and their synchronization. The Australian meat industry has developed "MeatMessaging" system basing on GS1 standards as a means of communicating the necessary information about meat products supplied for export. This information enables regulators to verify the authenticity and traceability of meat food [18].

On the territory of the Russian Federation there is a unified information system "VetIS", developed by the Rosselkhoznadzor (RSKhN) in order to create a unified electronic document management system based on digital technologies [36]. It includes several interconnected private systems, including the "Mercury" system, which provides registration of the veterinary examination results and drawing of veterinary accompanying documents; the "VESTA" system, which allows keeping records of laboratory tests, and the other data systems (Figure 4).

Inclusion of the component "Traceability of the HPF temperature modes history" into the "VetIS" system, using the technologies of ERA — Glonass for information monitoring and transmitting, will allow the participants of

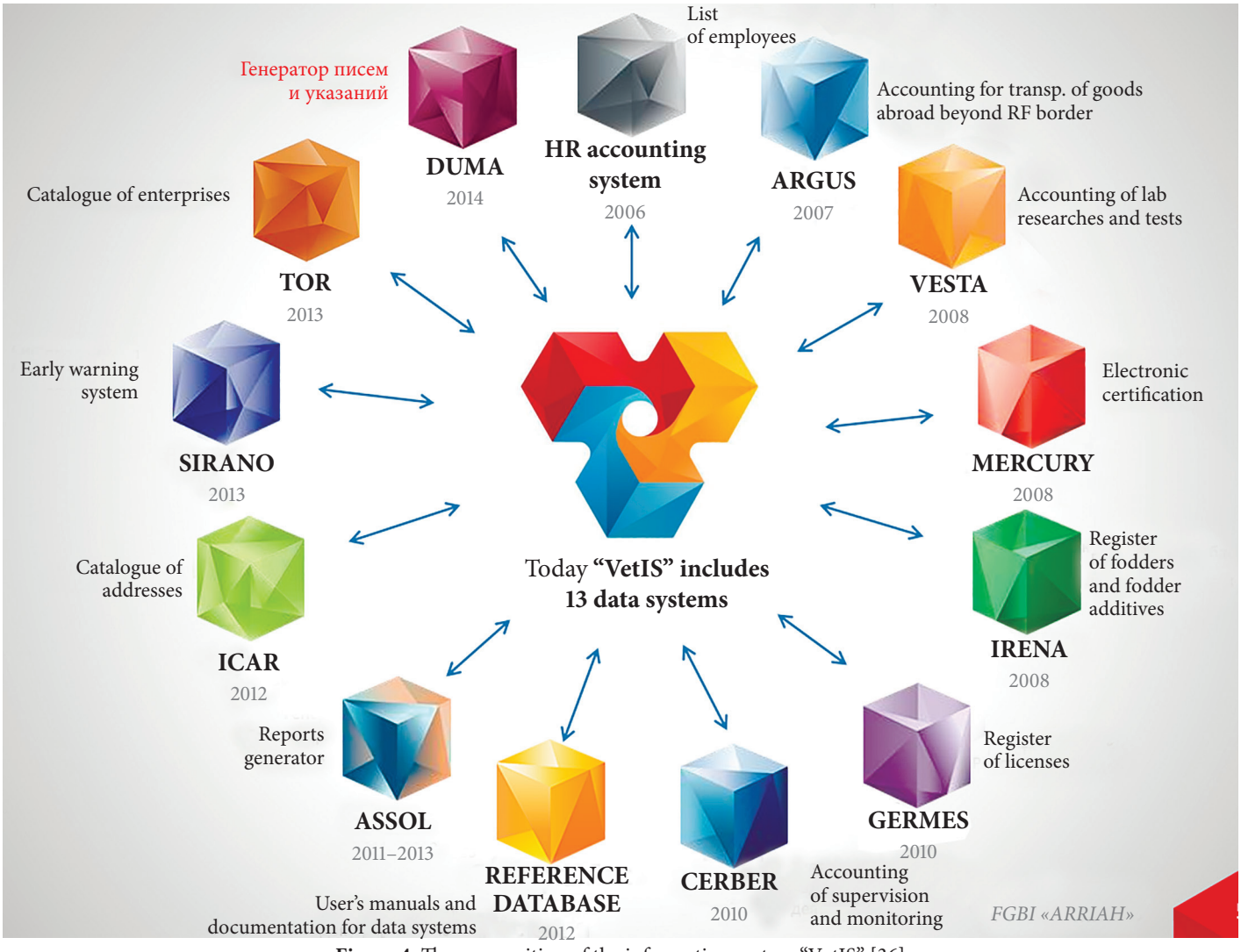

Figure 4. The composition of the information system "VetIS" [36]

the FSC and regulatory authorities receiving data on the actual temperature of the food product when it is exposed to CCC. And in case of violations of the established temperature modes it enables to take proactive measures in order to reduce the risks of food spoilage [37].

The technologies that facilitate transactions in the FSC are likely to be developed further due to increased attention to their resilience and sustainability amid the pandemic. For example, the application of blockchain technology in agricultural food data systems is of increasing interest, because it enables verification of information (including its authenticity), increases food traceability and transparency in the FSC [38–41].

The technology of blockchain is a distributed ledger where transactions are recorded in chronological order to create permanent, unlawful access-secured records between multiple stakeholders [42]. The important point is that once data is added to the blockchain, it cannot be changed by subsequent FSC participants. Therefore, the data that makes up these records must be generated and scientifically validated in order for the blockchain to be useful in facilitating the traceability of food in case of food safety issues, thereby reducing the scale of a problem.

Blockchain technology [43] is not an universal remedy, its application will not be able to prevent fraud with the initial data in the FSC, will not prevent adulteration of food raw materials and distortion of other information, and will not help to eliminate other potential failures in the FSC, for example, a shortage of labor.

The question of whether blockchain technology can increase the responsiveness and resilience of the FSC to external impacts like COVID-19 by increasing the level of interaction within the FSC still remains unsolved. Where FSC bottlenecks arise due to paperwork delays or fragmented procedures, the application of blockchain technologies facilitates the automation of organizational processes and optimizes information flows [42]. The benefits of blockchain in relation to the pandemic are largely to improve the logistics of the FSC (CCC) and improve the cooperation of supply chain participants in case of supply disruptions.

Modern FSCs require breakthrough solutions to increase efficiency and reduce risk. Since the CCC is a segment of the FSC related to products that require strict and continuous temperature control, blockchain technology provides significant advantages for its efficient operation in terms of "temperature modes history" traceability, this way increasing consumer confidence, ensuring the quality and security of HPF. Application of this technology can overcome the problems of information security and ensure transparency when integrating with Internet of Things (IoT).

The analysis and systematization of FSC risks, associated with the COVID-19 pandemic and outlined above, shows that temperature modes control and its traceability through all stages are the key factors in the functioning of the CCC, which contribute to:

- reducing the risk of virus transmission (temperature plays an important role in time of SARS-CoV-2 survival on a surface of HPF);
- improving the safety of HPF (temperature dramatically affects the shelf life of the highly perishable food).

The Internet of Things (IoT) technology is the second most popular information technology today. IoT is used in FSC to monitor food production, processing and storage in real time mode, and it also allows setting up a set of smart production lines and storage lines to ensure the authenticity and reliability of the original data. IoT has proven to be efficient in the supply chains of HPF, ensuring food quality, consumers' health safety, and facilitating a faster reaction to various changes [38]. IoT technologies provide real solutions for monitoring the quality and tracking the food supply chains. Using IoT technology, the necessary data like temperature, humidity and other processing parameters, can be collected and integrated into the tracking system.

Conclusion

The COVID-19 pandemic has highlighted the importance of human health as a key factor in assessing the sustainability of the food supply chain and its major part — the CCC.

Improving the organizational structure of CCC for its proper management is an extremely urgent task, since its proper functioning ensures human health, ensures food safety and prevents the spread of SARS-CoV-2 through contaminated food products.

The COVID-19 pandemic has not only revealed vulnerability of FSC and CCC at certain points, but also determined that an important condition for their medium term and long term efficient functioning, especially under conditions of uncertainty, is their adaptability to external challenges.

The traditional logistics of the CCC features some problems, like actual absence of centralized system for data storage, low reliability of data, ease of forgery and difficulty in finding the responsible employees. These problems lead to the inability to guarantee consumers' rights for food safety, ensure the sustainable quality and security of HPF. To solve these problems, the tracking system of CCC logistics for agricultural products is proposed. This tracking system is based on the technologies of blockchain and Internet of Things (IoT).

It is necessary to adapt the benefits of these technologies in accordance with the current and developing national information systems for ensuring the quality and safety of food products, which will serve to reduce food losses in the country and improve the quality of people's lives.

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WIRELESS PRESSURE SENSOR SYSTEM FOR FISH QUALITY MONITORING

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Keywords: *wireless sensing, pressure sensor, bluetooth communication, fish monitoring, food quality and safety*

Abstract
Food quality monitoring is increasingly important. This paper aims to propose the developed wireless pressure sensor system (WPSS) for fish quality monitoring. WPSS consists of a sensor acquisition module, power supply module, and Bluetooth module. The sensor acquisition module includes a temperature sensor, pressure sensor, and microcontroller unit (MCU). When Bluetooth receives the data collection command from the smartphone, the data of storage temperature and pressure in the food package can be collected by the sensor and transmitted wirelessly to the smartphone through Bluetooth. All data obtained by the system is monitored, stored, processed, and eventually displayed in a smartphone app in real-time to improve temperature, air pressure, and freshness transparency within the food package, ultimately ensuring food quality and safety. The proposed WPSS has potential application in many kinds of food monitoring. It can realize simple and intuitive food quality indications.

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Introduction

Food corruption is an important topic in food processing and transportation [1–3]. Because of the long transportation distance between food production areas and consumers, food corruption is prone to occur [4]. As an essential food in our daily life, meat is becoming more and more important in terms of quality and safety [5]. Among many characteristics of food, freshness is a key factor in food quality [6]. During storage and transportation, food freshness decreases over time with the resulting changes in meat characteristics such as firmness, tenderness, and flavor that affect the taste of food as well as color [7,8]. Reliable monitoring systems are therefore essential for the food industry to track the breakdown of food during storage and instead of as well as transport to avoid harmful problems caused by spoiled food.

A large number of studies have shown that fish can be affected by microorganisms during storage and transportation leading to decomposition of proteins or amino acids and the production of ammonia, amines, as well as other basic nitrogen-containing organic compounds, such as trimethylamine (TMA) and dimethylamine (DMA) [9,10]. These substances are volatile and are collectively known as total volatile basic nitrogen (TVB-N). This is an important indicator to reflect fish freshness, and also an important research direction to realize non-destructive, accurate, and real-time detection of fish freshness [11,12].

The traditional detection methods of volatile organic compounds mainly include the headspace phase spectrum detection [13,14], gas sensor array of the electronic nose [15–17], etc. Headspace phase spectrometry is one of the most reliable methods to measure volatile organic compounds at present, but this method has the characteristics of complex operation and high cost, so it cannot achieve rapid and accurate dynamic detection [18]. Electronic noses can allow quantitative and qualitative detection and identification by a variety of gas sensor arrays, but at present, the gas sensors are still mainly semiconductor metal oxides and electrochemical. The sensors used in these systems are based on metal oxide semiconductor (MOS) mechanisms and require considerable energy consumption. This greatly limits battery life [19]. It is feasible to measure a change in air pressure in food packaging by a pressure sensor based on an increase in air pressure caused by gas emissions from meat spoilage during storage and transportation. The pressure sensor consumes very low power, thus significantly reducing the power consumption of the entire circuit.

Bluetooth communication is an effective method of wireless communication to realize the wireless detection of food quality in packaging [20,21]. At present, Bluetooth is a popular point-to-point or point-to-multipoint communication mechanism for short distances. Among other short-range wireless technologies, Bluetooth has the characteristics of low cost, low power consumption, small size, and

especially strong anti-interference ability, which makes it a versatile and attractive technology. Because of its robustness to interference, Bluetooth is a wireless solution widely used in industrial applications [22,23].

In this study, a wireless air pressure sensing system (WPSS) is proposed. The wireless air pressure sensor system consists of a sensor acquisition module, power supply module, and Bluetooth module. The sensor acquisition module includes a temperature sensor, pressure sensor, and microcontroller unit (MCU). When Bluetooth receives the data acquisition command from the PC, the data on storage temperature and air pressure in a food package can be collected by the sensor and transmitted to the PC wirelessly through Bluetooth. All data obtained by the system is monitored, stored, processed, and ultimately displayed in a PC-side application in real-time to improve temperature, air pressure, and shelf-life transparency within the food package, ultimately ensuring food quality and safety.

Objects and methods

The materials and methods will be presented in more detail in this section, which include the design and implementation of the wireless pressure sensor system, the freshness evolution and the experimental scheme for the actual fish monitoring.

Wireless pressure sensor system

As shown in Figure 1, the wireless pressure sensor system consists of a sensor acquisition module, power supply module, and Bluetooth module (CC2540, Texas Instruments, USA). The sensor acquisition module includes a temperature sensor, pressure sensor, and MCU (ATmega328P, Microchip Technology / Atmel). As shown in Figure 2, the temperature and pressure sensors are integrated on the BMP180 chip (Bosch Sensortec, Germany). The BMP180 has the characteristics of intelligence, small volume, high precision, wide working range, and can output high precision pressure and temperature measurement data. The temperature sensor ranges from minus 40 °C to 85 °C, with an accuracy of ±2 °C and pressure sensor accuracy of 0.12 hPa/m, requiring calibration calculations before operation. The sensor is equipped with a 3.3 V voltage regulator that can be used in conjunction with Arduino. The BMP180 control unit includes EEPROM and IIC interfaces. The temperature and pressure sensors communicate directly with MCU via the internal integrated circuit (I2C) bus. ATmega328P has 32 8-bit general purpose working registers, high performance, and low power consumption. ATmega328P has more interface functions, among which, ADC6 and ADC7 have independent interfaces with a forward analog voltage of 5 V, and the chip has an external reference voltage input interface, AREF. The chip supply voltage VCC is 5 V. The Bluetooth module has the characteristics of low power and excellent cost performance. The chip integrates the microcontroller, host, and application, and is suitable for many practical application directions such as the Internet of Things. Bluetooth modules can be connected to smartphones or devices. When a data acquisition command is received, the storage temperature and pressure sensing data of the food can be collected by the sensor and transmitted wirelessly to the smartphone via Bluetooth.

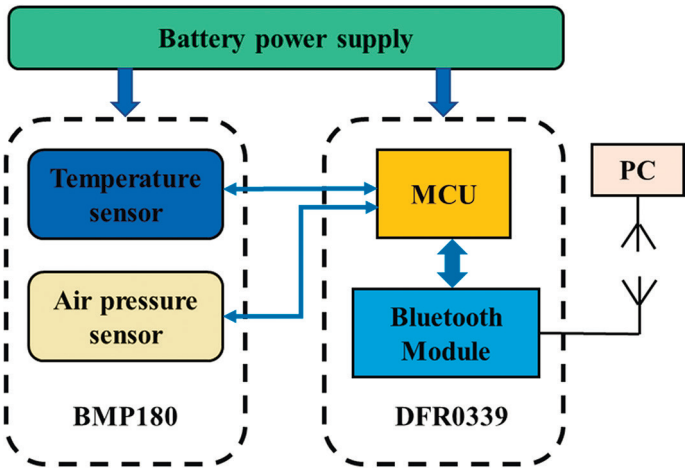

Figure 1. Scheme diagram of the WPSS

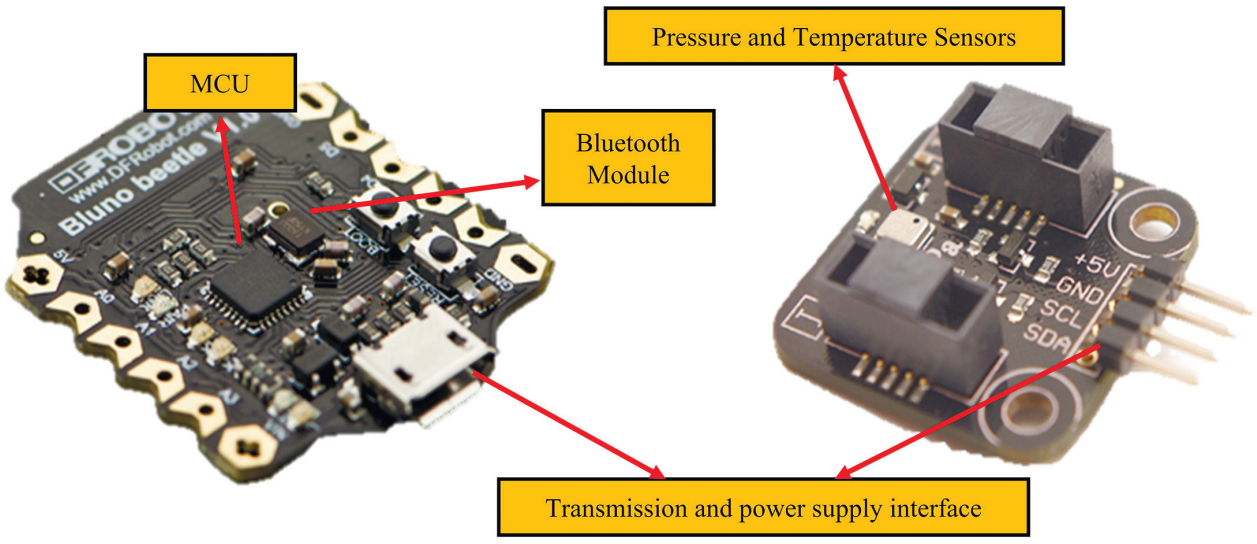

Figure 2. Physical implementation of the wireless pressure sensor

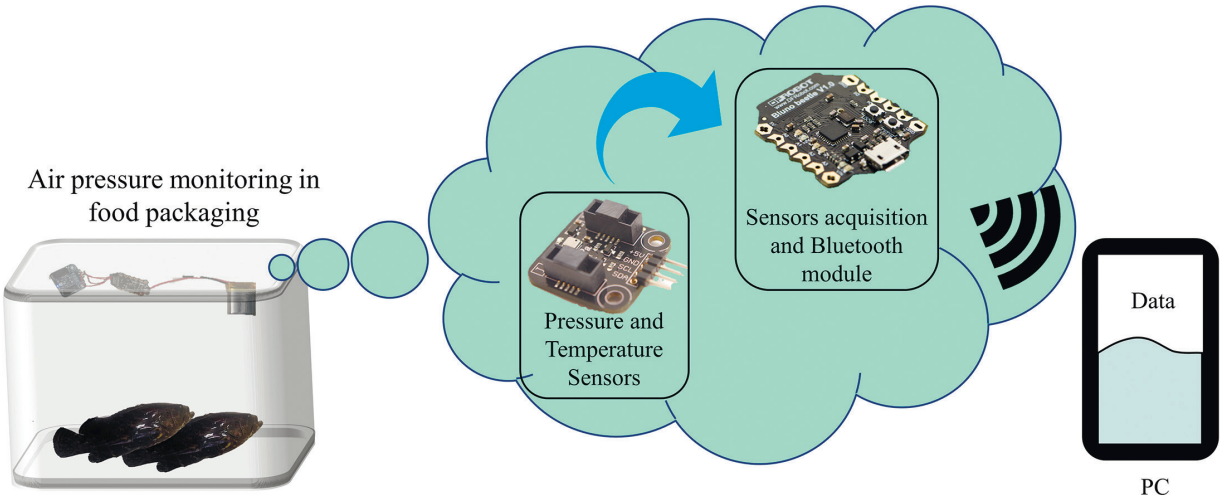

Figure 3. Experimental scheme of the WPSS for fish monitoring

Experimental scheme

Taking gentian grouper meat as an example, the air pressure in the packaging of fish was studied. As shown in Figure 3, the whole monitoring system (development board, sensor, external power supply) is fixed on the wall of the container and does not contact the surface of the chilled fish. The container is sealed with the adhesive tape and plastic film. The container with fish is placed in a constant temperature box, and the temperature is set at 20 °C. The temperature and air pressure in the container measured at intervals of about 3 hours by the sensor are recorded until the fish is completely rotten (there are obvious color and smell changes in the chilled fish, and it is intuitively felt that the chilled fish is rotten). Real-time barometric temperature data can be obtained from sensor data collected on the smartphone.

The same fish samples were tested for the TVB-N content using the Kjeltec 8400 analyzer while the temperature and pressure in the vessel were recorded by the sensors. TVB-N measurement was conducted by the Kjeldahl method identified as Chinese National Standard Method GB5009.228–2016 [24]. The 10.00 g (±0.1 g) homogeneous sample was transferred to the centrifuge tube. The perchloric acid solution was added up to 25 ml and mixed well. Then, the perchloric acid solution was added up to 40 ml. The mixture was filtrated, the supernatant was taken for testing and 20 ml of the supernatant was added to the tube. After adding 3 drops of the phenolphthalein indicator, the digestion tube was placed in the Kjeltec analyzer and the distillation was run on steam (60%) for 6 minutes in 5s delay mode while the boric acid solution absorbed the ammonia from the distillation. The Kjeltec 8400 analyzer analyzed automatically and titrated with standard hydrochloric acid (0.0100 mol/L) to the endpoint grayish blue color.

Data analysis

Matlab R2019a (American Math Works Incorporated) and Microsoft Office Excel 2019 (American Microsoft) were used for processing the temperature sensor data, pressure sensor data, and data on the TVB-N content of fish. The correlation between the pressure in the food package and the TVB-N content of fish was analyzed, and finally, the freshness of fish was judged by the pressure. The WPSS workflow for fish freshness assessment is shown in Figure 4. The smartphone starts scanning the sensor Bluetooth module and then reads the temperature and pressure sensor data after detecting the sensor. The obtained sensor data will be correlated with the TVB-N content of the fish at the same time to further evaluate the freshness. The collected sensor data and food freshness will be monitored, stored, and displayed in real-time in a reader, such as an app on a smartphone.

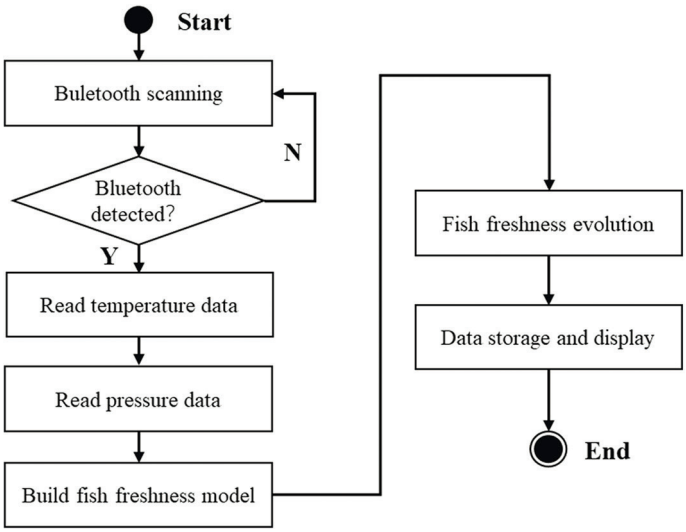

Figure 4. Workflow of the WPSS with freshness evolution of the fish

Results and discussion

The fish freshness evolution and its evaluation using the wireless pressure sensor system will be analyzed and discussed in more detail in this section to explain the application performance of the WPSS.

The performance of the wireless pressure sensor system

Through the actual test of the wireless pressure sensor system for chilled fish, the data on pressure and pressure change in a vessel during storage of chilled fish are

obtained, which can be further analyzed and summarized. As shown in the Figure 5, during the system test, the temperature in the food packaging basically remained at 20 °C with little fluctuation. During the preservation of chilled fish at 20 °C, within 0–15 hours, the change in air pressure caused by microbial activities in the container was only about 100 Pa. Then, during 15–24 hours, the pressure in the container increased rapidly, and the pressure changed to about 200 Pa. After 24 hours, the freshness of chilled fish at this stage could be judged to be poor by artificial senses, and the chilled fish at this stage had no edible value. The pressure increased slowly, by about 100 Pa. The experimental results show that it is feasible to monitor food freshness in packaging by pressure. Compared with other related studies [25,26], although the initial air pressure is different due to the different external environment, the change principle and trend of air pressure in food packaging are the same.

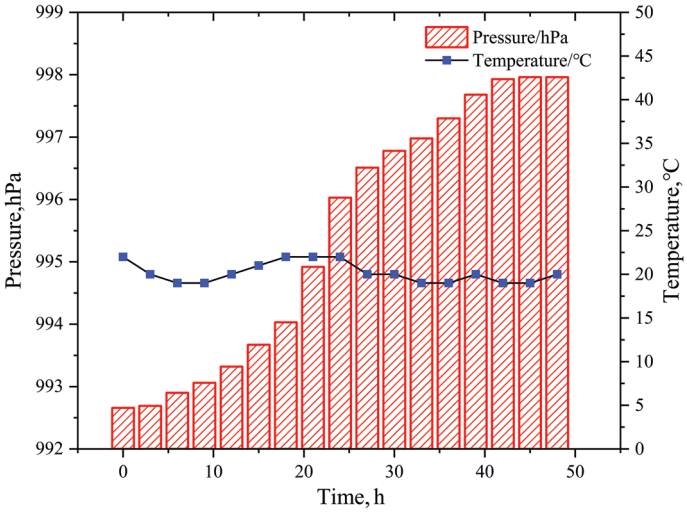

Figure 5. Data on a package pressure increase in the experiments with fish

Fish freshness evolution

The content of volatile base nitrogen (TVB-N) is an important indicator of fish freshness. We further classified foods into different freshness levels according to the TVB-N content of fish. Gentian grouper meat was used to study the availability of this classification. As shown in Figure 6, at a constant temperature of 20 °C, the TVB-N value of fish increased slowly from 9.91 mg/100 g to 15.31 mg/100 g during the period of 0–18 h at the beginning of the experiment. At this stage, the fish was of good quality. After 18–36 h, the content of TVBN in fish began to increase rapidly, from 15.31 mg/100 g to 25.31 mg/100 g. In this case, the freshness of the fish was mediocre, and the use value of the fish decreased and eventually reached the warning status. After 36 hours, the TVB-N content of fish continued to rise for a while until it was completely rotten. At this stage, the fish was completely inedible. The TVB-N of the fish and the pressure in the vessel is monitored simultaneously throughout storage. During this process, the TVB-N content of the fish was compared to the pressure value in the container at the same time to find the internal pressure value of the fish as it changed from one level of freshness to another. The pressure values at these points are called thresholds. Based on the results, the fish is good for the first 18 hours, then classified as normal for the next 18 hours, and the fish freshness warning appeared until the fish was not edible. The thresholds were then used to develop a food classification mobile application.

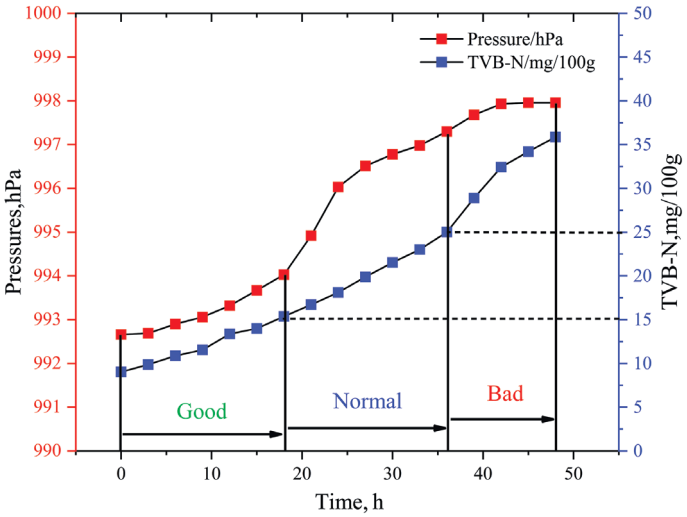

Figure 6. Correlation analysis of pressure and TVB-N of fish

Evaluation of WPSS

WPSS deployment and improved performance were evaluated and discussed (as shown in Table 1 and Table 2). This performance is helpful to improve the efficiency of the system in the practical application of food monitoring and improve the performance of freshness evaluation.

Recommendations to change the WPSS were made by inviting about 10 customers to try out the deployed WPSS. They provided constructive suggestions for WPSS. Table 1 summarizes the improved performance of WPSS.

WPSS can obtain the temperature and pressure sensor data in food packaging to effectively monitor the food environment, and through the pressure in food, packaging to judge food freshness. All data obtained by WPSS is monitored, stored, processed, and ultimately displayed in a smartphone app in real-time to improve the transparency of food temperature, and freshness and ultimately ensure food quality and safety.

Table 1. Deployment performance of the WPSS

ID	Content	Before implementation	After implementation
1	Pressure sensor system	Null	Monitoring in need
2	Freshness evaluation	Null	Predicting in need
3	Sensor deployment	Null	Easy to deployment
4	Monitoring efficiency	Low	Improving with freshness evaluation

Table 2. Improvement suggestions for the WPSS

ID	Suggestion	Suggestion type
1	Improve the stability of WPSS in further	WPSS
2	Reduce the cost and size of WPSS in further	WPSS
3	Improve the flexible deployment possibly in further	WPSS
4	Improve the accuracy of shelf-life prediction model in further	Freshness evaluation
5	Increase the applicability for more fruits or other foods	Food monitoring

Conclusion

The developed wireless pressure sensor system for fish spoilage monitoring is proposed in this paper. The WPSS consists of the sensor module, power supply module, and Bluetooth module. WPSS sensor module includes sensor acquisition module and MCU. Data from temperature and pressure sensors stored in food packaging is sent to Bluetooth module through the MCU. When receiving the data acquisition command of the smartphone, the signal is transmitted to the smartphone wirelessly through Bluetooth. The system takes temperature and pressure sensing data to effectively monitor the pressure inside the food package and judge the freshness of fish by pressure. All data obtained by WPSS will be monitored, stored, and processed in real-time, and finally displayed in the APP on the smartphone to improve the transparency of fish temperature and freshness, and ultimately ensure the quality and safety of fish. This method can display food quality simply and intuitively and has the potential application value in various food monitoring.

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POSTMORTEM STATE OF PORCINE MUSCLE TISSUE DEPENDING ON PRE-SLAUGHTER FASTING TIME

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Keywords: *muscle fibers, contraction knots, myopathy, microstructure, meat quality*

Abstract

Changes in the muscle tissue microstructure lead to changes in meat quality. One of the causes of the myopathy development is animal stress. Pigs experience the strongest stress during pre-slaughter holding. The study of the postmortem meat structure depending on fasting time is a topical task. The objects of the research were samples of m. L. dorsi obtained after slaughter from pigs that differed in fasting time: 4 (group 1), 8 (group 2), 10 (group 3), 16 (group 4) and 18 (group 5) hours (N = 20, n = 4). Investigation of the microstructure and morphometric measurements were carried out on preparations stained with hematoxylin and eosin. Myopathic changes in muscle tissue were assessed using a semi-quantitative method developed earlier. All studied samples were characterized by the uniform condition of muscle tissue. Statistically significant differences between individual groups were observed regarding the number and area of giant fibers, sarcomere length, diameter of muscle fibers and proportion of muscle fibers, which diameter was lower or higher by 1/3 than the mean fiber diameter. An increase in the pre-slaughter holding time reduced the number and area of giant fibers (r = –0.8437 and –0.5796, respectively), as well as the diameter of "normal" fibers (r = –0.5337), which positively influenced pork quality. Groups 1, 2 and 3 were characterized by the presence of signs of moderate and pronounced myopathy. Only one carcass with pronounced myopathic signs was revealed in each of groups 4 and 5. In group 4, one carcass did not have signs of myopathy. Pre-slaughter holding during 4, 8 and 10 hours led to deterioration of pork quality. The recommended fasting time is 16 hours.

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Introduction

From the end of the 20th century, the mass fraction of muscle tissue in porcine carcasses has become an extremely important indicator demonstrating successes of modern pig husbandry. At the same time, the topicality of the problem of pork quality and its technological suitability has grown. The negative correlation between the quantity of muscle tissue in a carcass and pork quality is becoming more and more evident [1]. The genetic progress increased the burden on fast-growing slaughter animals, led to morphological and biochemical modifications of muscle tissue and, as a consequence, to deterioration of consumer properties of meat [2].

In addition to the scientific value, the study of the muscle tissue microstructure is of great practical importance. Muscle fibers are key components of skeletal muscles, which characteristics significantly influence meat quality [3,4]. Histological changes in muscle tissue lead to changes in meat quality [5,6].

Joint histological and sensory studies show that even changes in pork palatability can be explained by characteristics of muscle fibers [7,8]. It is fairly considered that the knowledge of the muscle tissue microstructure with the use of simple methods of its differentiation can be a crucial element of adequate and objective assessment of meat quality [1].

Muscle tissue lesions, in which pathological changes in muscle fibers are observed ranging from degenerative changes to postmortem development of hypertonus giant fibers, are assigned to the main signs of myopathy (Greek: mys, my[os] muscle + pathos: suffering, disease) [2]. All animal species and even insects are prone to myopathy. The causes of myopathy can be different, the main among them are genetics, nutrition and stress. An effect of stress on the development of myopathic changes in porcine muscle tissue is well known [6,9].

Pigs experience the longest and multi-factor stress during pre-slaughter holding (fasting). Fasting is an obligatory measure before slaughtering pigs, which ensures:

- pork safety (visual contamination and microbial contamination of carcasses are reduced) [10];
- pork quality (allow obtaining chilled meat with the optimal pH value and improved technological characteristics) [11,12].

In terms of animal welfare, it reduces the proportion of animals died during transportation [13,14] and stunned with incorrect result [15], and increases heat resistance in pigs [16,17,18].

Pre-slaughter keeping, especially, accompanied by extreme overcrowding, water deficiency, mixing animals from different groups, is a well-known stress factor for pigs [19]. A high level of stress causes behavioral deviations and reduces meat quality. Postmortem redox processes in such pork are characterized by the development of porcine stress syndrome and production of meat with signs of myopathy due to enhanced and prolonged postmortem glycolysis [20]. This meat is characterized by histopathological deviations in muscles and appearance of destructive changes (sarcolemma disruptions), alterations of muscle fiber shape, appearance of atrophied fibers as well as hypertrophied and giant fibers [21].

In our view, it is of scientific and practical interest to study an effect of fasting time on a muscle tissue condition and a degree of the development of myopathic changes.

Previously, the authors developed approaches to classification of porcine carcasses by a degree of manifestation of myopathic changes in muscle tissues into three groups: without myopathy, with signs of moderately pronounced myopathy and pronounced myopathy [22].

The aim of this work was to study a postmortem condition of muscle tissue depending on duration of pig's fasting on the basis of two approaches: analysis of the mean values of morphometric characteristics and scoring of a degree of manifestation of myopathic signs.

Objects and methods

Control slaughter of pigs (n = 100) with an average life weight of 118.1 ± 5.4 kg was carried out in an industrial enterprise slaughtering pigs in an amount of 800 heads per day. Animals for control slaughter were randomly chosen and divided into groups of 20 animals from five different sets differed by fasting time: 4, 8, 10, 16 and 18 hours for groups 1, 2, 3, 4 and 5, respectively.

Animals were slaughtered in the same conditions using gas stunning (CO_2 concentration 88%, exposure time 120 s). Hot carcasses were sent to one-stage chilling at a temperature of 2 ± 2 °C. After 24 hours, four carcasses were randomly selected from each group (N = 20, average weight of selected carcasses was 87.8 ± 2.8 kg) for histological investigations.

For microstructural analysis, samples with a size of 3 × 3 × 3 cm were taken from *m. Longissimus dorsi* (*m. L. dorsi*). Samples were fixed in 10% neutral buffered formalin for 72 hours at room temperature. For the following study, two pieces (1.5×1.5×0.5 cm) with longitudinal and cross orientation of muscle fibers were taken from each sample. The pieces were washed with cold running water for four hours. Then, they were embedded in gelatin in an ascending concentration (12.5%, 25%) at a temperature of 37 °C for 8 hours each.

Serial sections with a thickness of 16 μm were made on the cryostat «MIKROM–HM525» (Thermo Scientific, USA). Three sections were made from each piece. The obtained sections were mounted on Menzel-Glaser slides (Thermo Scientific, USA) and stained with Ehrlich's hematoxylin and 1% aqueous-alcoholic solution of eosin (BioVitrum, Russia) by the conventional method (Romeis, B., 1989). The histological preparations were studied and photographed using an Axio Imager A1 light microscope (Carl Zeiss, Germany) with the AxioCam MRc-5 camera (Carl Zeiss, Germany). The muscle tissue condition (shape of muscle fibers, condition of sarcolemma, striation) and a degree of destructive changes were analyzed.

Morphometric studies were performed using the image analysis system AxioVision 4.7.1.0 (Carl Zeiss, Germany). Packing density of muscle fibers (the number of fibers with the normal diameter (hereinafter, normal fibers)/ 1 mm^2), their diameter, sarcomere length, the number of giant fibers located on 1 cm^2, their diameter and cross-sectional area were measured in the interactive mode. For each section, no less than 100 objects were calculated. A fiber diameter was determined with an accuracy of ±1.0 μm. A sarcomere length was measured with an accuracy of ± 0.1 μm.

Myopathic changes in muscle tissue were assessed using the semi-quantitative scoring method developed jointly by the V. M. Gorbatov Federal Research Center for Food Systems and L. K. Ernst Federal Research Center for Animal Husbandry[1] (Table 1).

Statistical analysis of the experimental data was carried out using the software R (version 4.2.1). Quantitative data are presented as the arithmetic mean (Mean), standard error of the mean (SE), standard deviation (SD), minimum and maximum values (Min/Max), confidence interval (CI) и median. The normality of distribution of parameters of quantitative variables was assessed by the Kolmogorov–Smirnov test. The interrelation of the factor under study with morphometric indices of muscle tissue was determined on the sample of animals by methods of the one-way analysis of variance (ANOVA) and Dunnett's test. Differences were considered significant and the presence of a relationship between parameters was recognized at a probability level of not higher than 0.05.

Results and discussion

In our experiment, pre-slaughter holding was limited to 18 hours due to the practice of industrial enterprises and earlier obtained data showing that longer periods are not economically expedient because of the live weight loss [11]. Moreover, pigs from the same enterprise, the same feeding and age were sent to slaughter. This excluded significant deviations in animal weight (in our experiment they were not more than ±5.4 kg) and did not envisage an effect of live weight on morphometric indices [22].

[1] MR001–00496254/00419779–2021 «Performance of histological investigations on determination of myopathy».

Table 1. Scheme of scoring of manifestation of myopathic signs in analysis of the muscle tissue microstructure

Indicator	Characteristics (value) of indicator/assigned points		
	Without signs of myopathy *	Moderately pronounced myopathy **	Pronounced myopathy ***
Shape of muscle fibers	Slightly wavy, tightly arranged /1	Mainly straight, tightly arranged /2	Straight, located loosely relative to each other/3
Condition of cross-striation	Clearly defined/1	Minute, located closer, smoothened, irregular/2	Minute, located closer, smoothened, irregular/2
Average length of sarcomeres, μm	From 2.0 inclusively and more/1	1.6–1.9 inclusively/2	Less than 1.6/3
Presence of destructive changes in sarcolemma	Not found/1	Individual ruptures of sarcolemma are present /2	Multiple ruptures of sarcolemma are present /3
Presence of giant fibers contraction knots), numbers/1 cm^2	Not found and/or few (up to 10) are found /1	From 10 inclusively to 30/2	30 and more/3
Average area of giant fibers on the cross section, μm^2	Up to 10,000/1	From 10,000 inclusively to 15,000/2	15,000 and more /3
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	250 and more/1	From 150 inclusively to 250/2	Up to 150/3
Proportion of muscle fibers, which diameter is lower or higher by 1/3 than the mean fiber diameter,%	Up to 7 inclusively/1	From 8 inclusively up to 30/2	30 and more/3

Notes:
*** by results of evaluation, samples that did not have a score of three points for any indicator and received no more than 12 points, inclusively, are classified as muscle tissue without signs, with destructive changes corresponding to the normal development of autolytic processes;**
**** samples that received from 13 to 16 points, inclusively, are classified as muscle tissue with moderately pronounced signs of myopathy;**
***** samples that received more than 16 points are classified as muscle tissue with pronounced signs of myopathy.**

All studied samples were characterized by the uniform condition of muscle tissue. On the cross-section, muscle fibers had the polygonal or weakly round shape. The endomysium interlayers were well pronounced; the boundaries between individual muscle fibers were established without particular difficulties. Giant fibers were characterized by a round-oval shape and large diameter.

In the longitudinal section, the main mass of muscle fibers was characterized by the well-defined cross-striation and straightened shape. Individual wavy fibers with longitudinal striation were found, which suggested the presence of contraction zones.

The nuclei in muscle fibers were well stained, had the oval shape and were located directly under the sarcolemma.

The perimysial connective tissue interlayers were wavy, tightly adjacent to bundles of muscle fibers. The nuclei in the connective tissue interlayers were clearly defined on the histological slides. Individual adipocytes or small groups of adipocytes with the typical histological structure were revealed between the bundles of muscle fibers in the areas of perimysium.

In the normal muscle fibers, individual cross micro-ruptures and sarcolemma damage were observed; destruction of myofibrils and ruptures were not found. In the knots of hyper-contraction (giant fibers on the longitudinal section), destruction of sarcomeres and the presence of cracks and ruptures of fibers were noticed.

Results of morphometry of samples are given in Table 2.

The number and size of muscle fibers to a large degree are associated with meat quality [23,24]. Muscle tissue with lower diameter and higher density of muscle fibers is linked with higher meat quality than muscle tissue with higher fiber area and lower fiber density [3].

By the mean values of morphometric indicators (Table 2), group 4 had several advantages, such as:

- normal muscle fibers were characterized by the lowest mean values of the fiber diameter and sarcomere length, as well as the number and area of giant fibers per 1 cm^2;
- muscle tissue was characterized by the highest packing density of muscle fibers;
- proportion of muscle fibers, which diameter was higher or lower by 1/3 than the mean value, was lower than in groups 3 and 5 but comparable with the value of this indicator in group 1;

By the mean values of morphometric indicators, group 5 was close to group 4, but significantly differed from it by a higher sarcomere length and higher values of area of giant fibers.

According to the analysis of the morphometric indicators, short period of pre-slaughter holding led to an increased number of giant fibers per units of section area and an increase in their area, which invariably have to be linked with lower meat quality [23,24].

Statistically significant differences between individual groups were observed by the following indicators: number and area of giant fibers on the cross section, sarcomere length, muscle fiber diameter and proportion of muscle fibers, which diameter was lower or higher by 1/3 than the mean fiber diameter. In terms of packing density of muscle fibers, no significant differences were found between groups.

Assessment of correlation between the studied morphometric indicators and the duration of pre-slaughter holding (Table 3) shows that several indicators have a tendency towards changes with an increase in the duration of pre-slaughter holding:

Table 2. Morphometric indicators of muscle tissue in ***m. L. dorsi*** samples (N = 20, n = 4)

Indicator		Value of indicator for groups				
		1 (4 h)[a]	2 (8 h)[b]	3 (10 h)[c]	4 (16 h)[d]	5 (18 h)[f]
Diameter of muscle fibers, μm	k	600	600	600	600	600
	Mean (SD)	67.33 ± 17.90	68.81 ± 24.13[d]	69.70 ± 22.29[df]	65.74 ± 17.56[b]	66.67 ± 22.87[c]
	Min…Max	18.07…116.42	17.01…180.46	21.88…133.50	25.53…110.45	17.01…140.88
	Median	67.80	67.19	69.17	66.09	67.91
	SE	0.73	0.98	0.91	0.72	0.93
	95% CI	1.43	1.93	1.79	1.41	1.83
Sarcomere length, μm	k	40	40	40	40	40
	Mean (SD)	17.00 ± 0.97[d]	17.14 ± 1.49[d]	16.67 ± 1.04[f]	16.50 ± 1.00[abf]	17.44 ± 0.86[cd]
	Min…Max	15.40…18.71	13.84…19.98	14.80…19.13	14.59…18.43	15.18…18.81
	Median	16.86	17.31	16.85	16.30	17.42
	SE	0.15	0.24	0.16	0.16	0.14
	95% CI	0.31	0.48	0.33	0.32	0.28
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm²	k	12	12	12	12	12
	Mean (SD)	154.17 ± 37.97	161.33 ± 34.60	150.17 ± 19.71	160.83 ± 32.38	158.33 ± 34.10
	Min…Max	104…225	107…207	129…193	102…198	98…198
	Median	146.0	173.5	147.0	167.0	169.5
	SE	10.96	9.99	5.69	9.35	9.84
	95% CI	24.13	21.98	12.52	20.57	21.67
Number of giant fibers, fibers /1 cm²	k	12	12	12	12	12
	Mean (SD)	13.83 ± 6.95[bdf]	9.08 ± 2.15[ad]	11.50 ± 7.55[d]	4.33 ± 2.67[abc]	7.42 ± 6.07[a]
	Min…Max	6…23	6…11	1…23	0…8	0…16
	Median	13.5	10.0	11.0	5.0	7.0
	SE	2.01	0.62	2.18	0.77	1.75
	95% CI	4.42	1.37	4.80	1.70	3.85
Area of giant fibers on the cross section, μm²	k	166	109	138	52	89
	Mean (SD)	15638.2 ± 2877.7[bcd]	18746.7 ± 4329.1[acdf]	16428.2 ± 3310.6[abdf]	12103.6 ± 2869.02[abcf]	15008.1 ± 2409.8[bcd]
	Min…Max	9057.0…26045.4	12441.8…33103.6	10007.00…28412.7	7969.4…18289.1	10656.4…24577.6
	Median	15648,3	17589,2	16001,9	11338,5	14660,3
	SE	223.4	414.6	281.8	397.9	255.4
	95% CI	441.0	821.9	557.3	798.7	507.6
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	k	600	600	600	600	600
	Mean (SD)	23.33 ± 5.52[c]	31.83 ± 12.43	39.00 ± 6.66[ad]	25.33 ± 7.79[c]	32.50 ± 14.06
	Min…Max	18.67…31.33	22.00…50.00	34.00…48.67	17.33…36.00	16.00…50.00
	Median	21.67	27.67	36.67	24.00	32.00
	SE	2.76	6.21	3.33	3.90	7.03
	95% CI	8.79	19.77	10.59	12.40	22.38

Notes:
k — number of observations. Mean — arithmetic mean. SD — standard deviation. Min — minimum value. Max — maximum value. SE — standard error of the mean. CI — confidence interval.
Letters denote values that have statistically significant ($p < 0.05$) differences from the similar value of the corresponding groups.

- packing density of muscle fibers increased, which apparently was a result of the moisture loss by animals (although watering was stopped only three hours before slaughter, not all animals drank water and had a free access to drinkers; apparently, the existing norms of area (0.6 m²/head) are not sufficient for this);
- diameter of "normal" muscle fibers decreased, which corresponded to an increase in their density; these indicators were also characterized by quite a strong correlation (r = –0.5498);
- number and area of giant fibers decreased; these indicators were also interrelated (r = 0.5615).

Analysis of other indicators allowed revealing positive correlations between morphometric indicators.

Table 3. Correlation coefficients (r)

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
x_1	1.0000	-0.5337	0.0626	0.3858	-0.8437	-0.5796	0.1938
x_2		1.0000	0.0040	-0.5498	0.6029	0.8170	0.7208
x_3			1.0000	0.2146	0.1614	0.4586	0.0848
x_4				1.0000	-0.7254	-0.1386	-0.4013
x_5					1.0000	0.5615	0.0679
x_6						1.0000	0.4557
x_7							1.000

Where: x_1 — duration of pre-slaughter holding; x_2 — diameter of muscle fibers; x_3 — sarcomere length; x_4 — packing density of muscle fibers; x_5 — number of giant fibers; x_6 — area of giant fibers on the cross section; x_7 — proportion of muscle fibers, which diameter was lower or higher by 1/3 than the mean fiber diameter.

For example, a positive correlation (r = 0.6029 and 0.8170, respectively) was observed between the diameter of "normal" muscle fibers and the number and area of giant fibers. In other words, an increase in the diameter of "normal" muscle fibers led to a growth in the number and area of giant fibers.

The same relationship was found for a diameter of muscle fibers and the proportion of muscle fibers, which diameter was lower or higher by 1/3 than the mean fiber diameter/"non-standard" size/ (r = 0.7208), that is, with an increase in a diameter of "normal" muscle fibers, the proportion of normal fibers differed to a large degree from the mean diameter increased. To put it otherwise, the heterogeneity of muscle fibers in terms of diameter grew.

In addition, the positive correlation was observed between the sarcomere length and the area of giant fibers (r = 0.4586), as well as the area of giant fibers and proportion of fibers of the "non-standard" size (r = 0.4557).

The negative correlation linked the packing density of muscle fibers with the number of giant fibers and proportion of muscle fibers, which diameter differed by less or more than 1/3 from the mean diameter (r = –0.7254 and –0.4013, respectively). This did not correspond to the concept that giant fibers appear as a result of supercontraction of individual muscle fibers [25,26,27]. Our data more likely confirm a more recent hypothesis that the development of giant fibers occurs from muscle fibers exhausted before slaughter due to animal stress [23,27]. Such fibers have changed metabolism and can experience the very quick onset of rigor mortis, while adjacent fibers continue to be in the relaxed state. In this connection, the negative correlation between the aforementioned indicators can characterize the disproportion in the development of post-mortem changes in muscle fibers.

Therefore, the performed analysis of the mean values of morphometric indicators in the samples taken from 20 carcasses shows that the microstructure of chilled porcine muscle tissue depends on the duration of pre-slaughter holding of pigs. Moreover, an increase in pre-slaughter holding time reduced the number and area of giant fibers as well as a diameter of "normal" fibers. These changes, in turn, influenced practically all morphometric indicators. With that, the sarcomere length practically did not depend on fasting time but showed the dependence on the area of giant fibers.

For transition from the quantitative values of morphometric indicators to values that characterize the qualitative condition of muscle tissue, scoring of each sample was carried out, which allowed making conclusion about the presence and degree of manifestation of myopathic changes (Table 4). For illustration, the final scores (total points and conclusions) are given in Table 5.

Table 4. Results of scoring of morphometric indicators of muscle tissue samples from the control and experimental groups (N = 20, n = 4)

Indicator	Scoring (points) for samples from groups			
	Carcass 1	Carcass 2	Carcass 3	Carcass 4
Group 1 (4 h)				
Shape of muscle fibers	1	2	3	3
Condition of cross-striation	1	1	1	1
Mean sarcomere length, μm	3	2	2	2
Presence of destructive changes in sarcolemma	2	2	2	2
Presence of giant fibers (contraction knots), fibers/1 cm^2	2	2	1	1
Average area of giant fibers on the cross section, μm^2	3	3	3	3
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	2	3	2	3
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	2	2	2	3
Group 2 (8 h)				
Shape of muscle fibers	3	1	2	2
Condition of cross-striation	1	1	1	1
Mean sarcomere length, μm	3	2	2	2
Presence of destructive changes in sarcolemma	2	2	2	2
Presence of giant fibers (contraction knots), fibers/1 cm^2	2	2	1	1
Average area of giant fibers on the cross section, μm^2	3	3	3	3
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	2	3	2	2
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	2	3	2	2
Group 3 (10 h)				
Shape of muscle fibers	1	3	3	3
Condition of cross-striation	1	1	1	1
Mean sarcomere length, μm	2	2	3	2
Presence of destructive changes in sarcolemma	2	2	2	3
Presence of giant fibers (contraction knots), fibers/1 cm^2	1	2	2	2
Average area of giant fibers on the cross section, μm^2	2	2	3	3
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	2	3	3	3
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	3	3	3	3

End of Table 4

Indicator	Scoring (points) for samples from groups			
	Carcass 1	Carcass 2	Carcass 3	Carcass 4
Group 4 (16 h)				
Shape of muscle fibers	3	1	3	3
Condition of cross-striation	1	1	1	1
Mean sarcomere length, μm	2	2	2	3
Presence of destructive changes in sarcolemma	2	1	2	2
Presence of giant fibers (contraction knots), fibers/1 cm^2	1	1	1	1
Average area of giant fibers on the cross section, μm^2	2	1	2	2
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	3	2	2	2
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	3	2	2	2
Group 5 (18 h)				
Shape of muscle fibers	3	3	2	2
Condition of cross-striation	1	1	1	1
Mean sarcomere length, μm	2	2	2	2
Presence of destructive changes in sarcolemma	2	2	2	2
Presence of giant fibers (contraction knots), fibers/1 cm^2	2	1	2	1
Average area of giant fibers on the cross section, μm^2	2	1	3	3
Packing density of muscle fibers (number per unit of cross-sectional area), fibers/mm^2	2	2	2	2
Proportion of muscle fibers, which diameter was lower or higher by 1/3 than mean fiber diameter, %	2	2	3	3

Table 5. Final scoring of samples from the control and experimental groups by a degree of manifestation of myopathy (N = 20, n = 4)

Группы		Scoring of samples			
		Carcass 1	Carcass 2	Carcass 3	Carcass 4
№ 1 (4 h)	Total points	16	17	16	18
	Conclusion	M	P	M	P
№ 2 (8 h)	Total points	18	17	15	15
	Conclusion	P	P	M	M
№ 3 (10 h)	Total points	14	18	20	20
	Conclusion	M	P	P	P
№ 4 (16 h)	Total points	17	11	15	16
	Conclusion	P	W	M	M
№ 5 (18 h)	Total points	16	14	17	16
	Conclusion	M	M	P	M

Notes. W — Without myopathy, M — Moderately pronounced myopathy, P — Pronounced myopathy.

As scoring of samples shows (Table 5), animal groups 1, 2 and 3 were characterized by signs of moderate and pronounced myopathy. Moreover, the highest number of carcasses with pronounced myopathy was in group 3, which underwent pre-slaughter holding for 10 hours. Apparently, compared to groups 1 and 2, animals from group 3 were more strongly exhausted and subjected to stress factors. Only one carcass, which muscle tissue had signs of pronounced myopathy, was revealed in each of groups 4 and 5. With that, one carcass in group 4 did not have signs of myopathy at all. It is possible that increasing pre-slaughter holding for another two hours (from 16 to 18 hours) could negatively affect the condition of muscle tissue after slaughter.

Fasting time along with other pre-slaughter factors can influence meat quality indicators such as slaughter yield of carcasses, pH, color and water holding capacity of muscle tissue [28,29,30]. It was established that long pre-slaughter holding (36–48 hours) [31,32,33] as well as too short (less than 1 hour) [34,35] negatively affected animal welfare and pork technological characteristics. At the same time, optimal duration of pre-slaughter holding of animals without feeding continue to be a subject of scientific discussions. The recommended duration can be from 5 to 12 hours [36], 12 hours [37], from 12 to 24 hours [38].

Recommendations (16 hours) that can be made according to our results of histological investigations are in good agreement with earlier obtained data about the lowest level of cortisol in blood and urine, and therefore, the lowest stress level in pigs fasting for 12–18 hours [39] and more than 14 hours [40].

Conclusion

Microstructural investigations are a useful methodological tool for understanding a significance of an effect of one or another factor on meat quality. The study of the effect of pig's fasting time on the microstructure of chilled porcine muscle tissue, without doubt, confirmed this once more.

Analysis of the mean values of the morphometric characteristics shows that when duration of pre-slaughter holding increases, the number and area of giant fibers can decrease, which undoubtedly positively influence pork quality. The applied semi-quantitative scoring method made it possible to assess the studied samples from each carcass by a degree of manifestation of myopathic signs and confirm the positive effect of longer pre-slaughter holding.

The best results were obtained in case of total pre-slaughter holding time of 16 hours; the further increase in the duration of pre-slaughter holding did not lead to improvement of morphometric indicators of muscle tissue. With that, pre-slaughter holding of animals for 4, 8 and 10 hours led to deterioration of pork quality.

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SYSTEMIC APPROACH IN THE DEVELOPMENT OF FUNCTIONAL FOODS FOR VARIOUS NONCOMMUNICABLE DISEASES

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Abstract
The article presents a hierarchy of requirements necessary for the successful design of food products with given composition and properties considering age restrictions and various diseases. The need for generalization and systematization of scientifically based principles, specific medical and biological requirements for food products, diets for the most common nutritional diseases in the knowledge base is shown. Using the k-means cluster analysis method, 1) meat raw materials were analyzed for inclusion in functional food for gerodietetic nutrition according to the most significant descriptors (protein, methionine + cystine amino acids, tryptophan), 2) spicy herbs and spices were analyzed for inclusion in the Muhammara recipe as natural antioxidant sources according to the descriptor of antioxidant properties. Using the example of the Muhammara recipe change, all stages of a systemic approach in the development of functional foods are shown. The first stage is related to obtaining information from the knowledge base about scientifically based nutritional principles and specific biomedical requirements for the given age group. At the second stage, the clustering of raw materials of animal and vegetable origin is carried out in order to reasonably include in the recipe of food product being developed. At the third stage, a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fraction of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.) is formed. The fourth stage is associated with the establishment of the target function (optimization criterion), and restrictions for recipe and balance. At the fifth stage, the problem is solved using a high-level language in a modern programming environment. At the final (sixth) stage, the nutritional value of the optimal balanced recipe is analyzed considering the target function and the given restrictions. As a result, we receive a modified Muhammara recipe with optimized protein: fat ratio. Mathematical simulation was carried out using the R Studio software with open-source lpSolve and lpSolveAPI libraries.

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Introduction

In recent years, a general trend has been revealed towards the development and production of meat and meat products, which, in addition to nutritional properties, contributes not only to the prevention, but also to the treatment of various pathological conditions in the population. Many different strategies have been developed to improve the functionality of meat and meat products using various functional compounds and modification of live animals [1,2].

It should be noted that the production of functional foods with preventive and biocorrective properties, including meat, should be based on scientifically valid medical and biological principles, progressive and environmentally friendly technologies that contribute to the maximum improvement of the human body, trophic systems, biological communities and the environment [1,3].

Nutrition affects the processes of energy generation in the cell, protein biosynthesis, the structure and functions of cell and intracellular membranes, the activity of enzyme systems, neurohumoral regulation, immunity, biological rhythms, etc. Biochemical indicators of metabolism, the functional activity of various organs and systems significantly depend on the quantity and quality of nutrition. Balanced nutrition is considered as active therapeutic and preventive mean, which contributes to the preservation of physical and mental health, reduces the risk of any pathology and prevents premature aging. With proper organization of nutrition, including knowledge of the effect on health, it is possible to significantly reduce the overall dis-

ease incidence, increase the resistance to adverse environmental factors and life expectancy.

The normal activity of the brain and the body as a whole, and life expectancy depend more or less on the quality of the food consumed. The restoration of the nutrition structure, improvement of its quality and safety is currently one of the most important and priority tasks of the state, which includes a package of measures to ensure that the needs of various population groups in balanced nutrition are met, considering traditions, habits and economic situation.

The modern system of healthy nutrition is formed from many components that depend on biomedical, social, economic, technological and other factors. Failure to comply with the requirements of at least one of the components will undoubtedly lead to a violation of the integrity and balance of the entire system.

Along with the established genetic and environmental risk factors for chronic noncommunicable diseases, modifiable factors associated with lifestyle and diet play an important role in the disease development and prognosis.

With noncommunicable socially significant diseases, proper nutrition is necessary, considering established scientifically based principles and biomedical requirements. In the article, we discuss the principles of nutrition for cardiovascular diseases and gerodietetic nutrition.

Peculiarities of nutrition in people with cardiovascular diseases

Currently, cardiovascular diseases (CVD) are the leading cause of death and account for about a third of all deaths worldwide. In the last decade, CVD mortality in the world has increased by 12.5%. One of the significant risk factors that contribute to their growth is a violation of the nutrition structure in the population. In this regard, encouraging adherence to a healthy diet is important to reduce morbidity and mortality from CVD [4].

Russia is one of the world leaders in terms of morbidity and mortality from this pathology. According to the World Health Organization (WHO), since 2009 the number of deaths from cardiovascular diseases has increased by more than 2 million and reached almost 9 million in 2019. Heart diseases today account for 16% of all deaths in the world. At the same time, a relative reduction in mortality from heart diseases by 15% was noted in the European Region [5].

On the territory of the Russian Federation, this figure is 57.1%, of which CAD accounts for more than half of all cases (28.9%), which in absolute terms is 385.6 per 100,000 people per year. For comparison, the death rate from the same cause in the European Union is 95.9 per 100,000 people per year, which is 4 times less than in our country. The frequency of coronary artery disease (CAD) increases sharply with age: in women from 0.1–1% at the age of 45–54 years to 10–15% at the age of 65–74 years, and in men from 2–5% at the age of 45–54 years to 10–20% at the age of 65–74 [6].

Table 1 presents statistics from 2014 to 2020 in terms of mortality due to coronary artery disease.

Table 1. Statistics of mortality from coronary artery disease [6]

Cause of death	2016	2017	2018	2019	2020
Coronary artery disease	481,780	461,786	453,306	442,328	508,657

According to Heidenreich P. et al. [7, 8], in 2030 the prevalence of CAD will increase by 9.3%. Studies by Scarborough P. et al. [9] show that in 2035, it is possible to expect an increase in the number of myocardial infarctions in English men, while in women an increase in the number of cases is unlikely.

According to modern concepts, the pathogenesis of CAD is based on progressive atherosclerotic occlusion of the coronary arteries, among the main causes of which dyslipidemia, oxidative stress, chronic inflammation, obesity, etc. are considered [4].

Nutrition has always been part of the CVD prevention strategy. It is known that eating disorder may contribute to the development of atherosclerosis and atherothrombosis, both directly and indirectly, by increasing the body mass index, blood pressure, cholesterol and glucose levels in the serum. In 2019, the European Society of Cardiology released a new, third reissue of the guidelines on cardiovascular medicine [10], one of the sections of which is devoted to the contribution of optimal nutrition to the prevention of CVD.

Cardiovascular diseases are characterized by inadequate fat and carbohydrate metabolism, sodium metabolism and enzyme balance, vitamin and mineral deficiency [11,12].

Indisputable importance in the treatment and prevention of these diseases and the main risk factors for their occurrence is given to specialized foods, which include meats, meat and vegetable products (canned products, semi-finished products, ready meals, pates, sausages) intended for nutrition in order to prevent coronary artery disease, atherosclerosis of coronary, cerebral, peripheral vessels, hypertension.

The development of foods for the prevention of cardiovascular diseases is based on the following general scientifically based principles:

- the food product should contribute to improving metabolic processes, restoring the metabolism of the vascular wall and heart muscle, reducing blood coagulation, and have an anti-sclerotic therapeutic effect, which is ensured by a combination of animal and vegetable protein, its balance in amino acid composition, limited energy, salt, cholesterol, along with sufficient protein and optimal fat composition [13,14,15,16];
- the food product should be enriched with vitamins, macro- and microelements at their optimal ratio, polyunsaturated fatty acids, dietary fiber and other specific ingredients that help to prevent the risk of developing cardiovascular diseases [17,18,19,20];

- ingredients containing phospholipids with lipotropic action should be included in the food product to stabilize the solution of cholesterol in the bile and reduce the absorption of cholesterol in the intestine.

When developing the food product recipe, the following specific biomedical requirements must be considered:

- the protein component of the specialized products should combine protein of animal and vegetable origin, since this achieves a more pronounced hypocholesterolemic effect [21];
- the amount of animal and vegetable protein should be approximately equal;
- the content of saturated fats should not exceed 10%, while the ratio of unsaturated to saturated fatty acids should not exceed 1.0;
- the optimal ratio of SFA/MUFA/PUFA should be 1:1:1.

The source of animal protein included in the food product may be beef and pork used in semi-finished products, chicken and turkey meat. As a vegetable protein, it is recommended to use processed soybeans (concentrates and isolates) with a high content of isoflavones, which cause hypolipidemic, antioxidant, hypotensive and thrombolytic effects, as well as chickpeas, cereals.

The fat component is formed by the fat of meat raw materials and vegetable oils as a source of PUFAs: sunflower, corn, cotton oils containing mainly fatty acids of ω-6 class; linseed, soy, rapeseed oils and others rich in α-linolenic acid. PUFAs of ω-3 class especially significantly reduce the hypertriglyceridemia [22,23,24,25].

Among carbohydrates, preference should be given to plant ingredients, i. e. cereals, vegetables, which contain a sufficient amount of dietary fiber (DF). The main representatives of DF are cellulose and pectin. The addition of 15 g of soluble DF (pectin, guar gum) to the daily diet reduces the level of blood cholesterol by 15–21% [26,27,28].

As spices it is recommended to use: parsley and dill greens and roots, celery roots and seeds, marjoram, capsicum, onion.

Nutrition of the elderly and older people

According to the classification of the World Health Organization, the older people range 60 to 75 years old, the category of the elderly is in the range of 75 to 90 years old, and people over 90 years old are considered long-livers [29].

In 2019, people aged 60 and over exceeded one billion, representing 13.2% of the world's total population (7.7 billion). This is 2.5 times more than in 1980 (382 million). Therefore, it is possible to predict the number of older people in the world by 2050. Their number will reach 2.1 billion people. Indeed, in 2020, for the first time in history, the global number of older people surpassed the number of children under 5 years old.

The basis for the development of food products for older people is based on the following general scientifically based principles[1] [30,31,32]:

- energy balance of nutrition, taking into account the actual energy consumption of the body [30,32];
- preventive nature of nutrition, not only in relation to atherosclerosis, but also to other widespread pathologies of old age (obesity, diabetes mellitus, hypertension, cancer, osteoporosis, etc.) [33,34];
- compliance of food chemical composition with age-related changes in metabolism and functions [35];
- diet balance for all essential nutritional factors [36,37,38];
- alkaline nature of nutrition to correct the age-related acidotic features of homeostasis (acidification of the internal environment of the body) [39];
- enrichment of diets with foods that normalize the intestinal microflora of an aging organism [40];
- enrichment of food with substances that have geroprotective properties [41];
- the use of foods that are quite easily subjected to the action of digestive enzymes and assimilation processes [31].

The development of multi-component gerodietetic food products with desired properties is a complicated process, since it is necessary to ensure the entire complex of the above requirements. When developing the composition of a meat-based gerodietetic product, the following specific biomedical requirements must be taken into account:

- the amino acid composition of the product should correspond to the FAO/WHO ideal protein concept [42,43];
- the mass fraction of such amino acid as tryptophan should be at least 1 g per 100 g of protein [42];
- the ratio of lysine mass fraction in relation to the mass fraction of methionine + cystine should tend to be 1:1 [42];
- the ratio of the mass fractions of saturated, monounsaturated and polyunsaturated fatty acids should correspond to 3:6:1, while polyunsaturated fatty acids should include acids belonging to the ω3 group (linoleic, linolenic, arachidonic), which are very important components in treatment and prevention of cardiovascular diseases, as they are able to prevent the formation of cholesterol and triglycerides in the blood; in combination with amino acids such as arginine and glutamine they increase the body's resistance to infectious diseases; improve kidney function; reduce inflammation in the intestines and joints [44,45,46,47,48];
- the ratio of protein mass fraction of to the mass fraction of lipids should be 1:0.8 [42,43];
- the energy value of the finished product should be in the range of 600 to 650 kJ/100 g [30,32];

[1] Guidelines for catering for the elderly and older people (1975). Moscow: Research Institute of Nutrition. Retrieved from https://files.stroyinf.ru/Data2/1/4293855/4293855243.pdf Accessed June 24, 2022. (In Russian)

- the product must contain vitamins E, C, PP and group B vitamins, the presence of which in the product helps to slow down the aging process; minerals, i. e. potassium, calcium, magnesium, phosphorus, iron, selenium, zinc; as well as components that inhibit the processes of lipid membrane oxidation in the body, stimulate peristalsis and contribute to the regulation of cholesterol metabolism [49,50,51,52].

When developing a meat-based gerodietetic product, it is extremely important to choose the type of product from the assortment of meat products. The difficult process of digestion and assimilation of food by the gastrointestinal tract of older people predetermines the fact that this product must be finely dispersed and tender. Based on this fact, pate is the most suitable type of meat products.

The article considers a systemic approach to the development of food products that may be recommended as a nutritional support, by the example of a product for the prevention of cardiovascular diseases and gerodietetic nutrition.

A systemic approach to the development of food products for prevention and nutritional support for various noncommunicable diseases includes the following steps:

Stage 1 — obtaining information from the knowledge base on scientifically based nutritional principles and specific biomedical requirements for a given age group;

Stage 2 — clustering raw materials of animal and vegetable origin in order to reasonably include into food product being developed;

Stage 3 — generating a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fractions of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.);

Stage 4 — setting the target function (optimization criterion), restrictions for recipe and balance;

Stage 5 — solving the problem using a high-level language in a modern programming environment;

Stage 6 — analyzing the nutritional value of the optimal balanced recipe considering the target function and the given restrictions.

Objects and methods

The material of the study was modern data on the contribution of optimal (healthy) nutrition to gerodietetics and the prevention of cardiovascular diseases.

For the analysis of meat raw materials, the Food Products database was used [53]. The analysis was carried out using the k-means method for various indicators (protein content, methionine + cystine, tryptophan, the ratio between protein and fat, etc.). The k-means clustering algorithm involves partitioning objects into classes, which minimizes the differences ("distances") between objects of the same class and maximizes the distances between objects of different classes. The number of clusters is 3. The center of the cluster is the average value of the coordinates of all points included in the cluster (products for this indicator) [54].

Mathematical simulation was carried out using the R Studio software with open-source lpSolve and lpSolveAPI libraries [55,56].

Muhammara was chosen as the object of the study. This is a Syrian pasta with beneficial properties and amazing flavor. Muhammara is usually made with fresh or dried peppers, walnuts, bread, olive oil, onions, garlic, salt, lemon juice, pomegranate syrup, and cumin. Nutritional and energy value of Muhammara: protein — 6.9 g, fat — 27.8 g, carbohydrates — 20.3 g, calorie content — 351.6 kcal.

Results and discussion

Nutrition for cardiovascular diseases

The V. M. Gorbatov Federal Research Center for Food Systems develops functional foods. For example, sterilized canned minced meat "Healthy Heart" for functional nutrition from porcine hearts and aortas — for the prevention of cardiovascular diseases [57].

Sensory and physicochemical parameters of the canned meat "Healthy Heart" must meet the following requirements (Table 2).

Table 2. Physicochemical and sensory characteristics[2]

Parameter	Characteristics and value
Sectional view	Light brown to brown minced meat, without gray spots, voids, without visible inclusions of connective tissue. A small amount of broth is allowed.
Odor and taste	Pleasant, with a pronounced meat flavor, lightly salted, without off-odor and off-flavor.
Texture	Juicy, noncrumbly, dense
Impurities	Not allowed
Protein mass fraction, %	16.5 to 18.0
Fat mass fraction, %	3.5 to 4.0
Salt mass fraction, %	0.3 to 0.5 inclusive
Acid number, mg KOH/g, not more	1.5 to 3.0 inclusive
Calorie content, kcal	97.5 to 108

Porcine aorta and heart are used as the main raw materials as they contain 1) tissue-specific peptides with molecular weights of 809.4 ± 1.0; 776.5 ± 1.0; 765.6 ± 1.0; 739.2 ± 1.0; 710.8 ± 1.0; 229.2 ± 1.0; 162.1 ± 1.0; 156.0 ± 1.0; 148.1 ± 1.0; 140.2 ± 1.0 and 133.1 ± 1.0 kDa; 2) Apo 1 (contributes to the formation of high-density lipoproteins) or 3) pre-Apo A-1 (participates in the inhibition of oxidative stress) [58–60].

Using the example of Muhammara recipe changing, we will consider all the stages of a systemic approach. Enrichment of Muhammara was carried out in order to balance the recipe for the main food nutrients, reduce calorie content, and include ingredients with antioxidant properties to inhibit oxidative processes.

[2] Proprietary standard 00419779–003–2015 "Sterilized canned minced meat "Healthy Heart" for functional nutrition from porcine hearts and aortas". Specifications. — Moscow: VNIIMP. 55 p.

At the first stage, data on nutrition in cardiovascular diseases were obtained from the knowledge base (see Introduction).

At the second stage, the clustering of herbs, spices and vegetables according to the descriptor "Antioxidant activity" was carried out for their reasonable inclusion in the Muhammara recipe. The dendrogram (Figure 1) shows that three clusters were formed. Table 3 shows detailed information about each cluster. The first cluster includes only 2 products (red color on the dendrogram). This cluster contains products with the highest ORAC index — ground cinnamon (ORAC — 314446), ground cloves (ORAC — 267536). Moderate ORAC values are contained in the second cluster (blue color on the dendrogram) ranging from 119929 to 200129 with the average value of 151497. The lowest ORAC values are in the third cluster (32 products) ranging from 821 to 76800 with the average value of 24500.

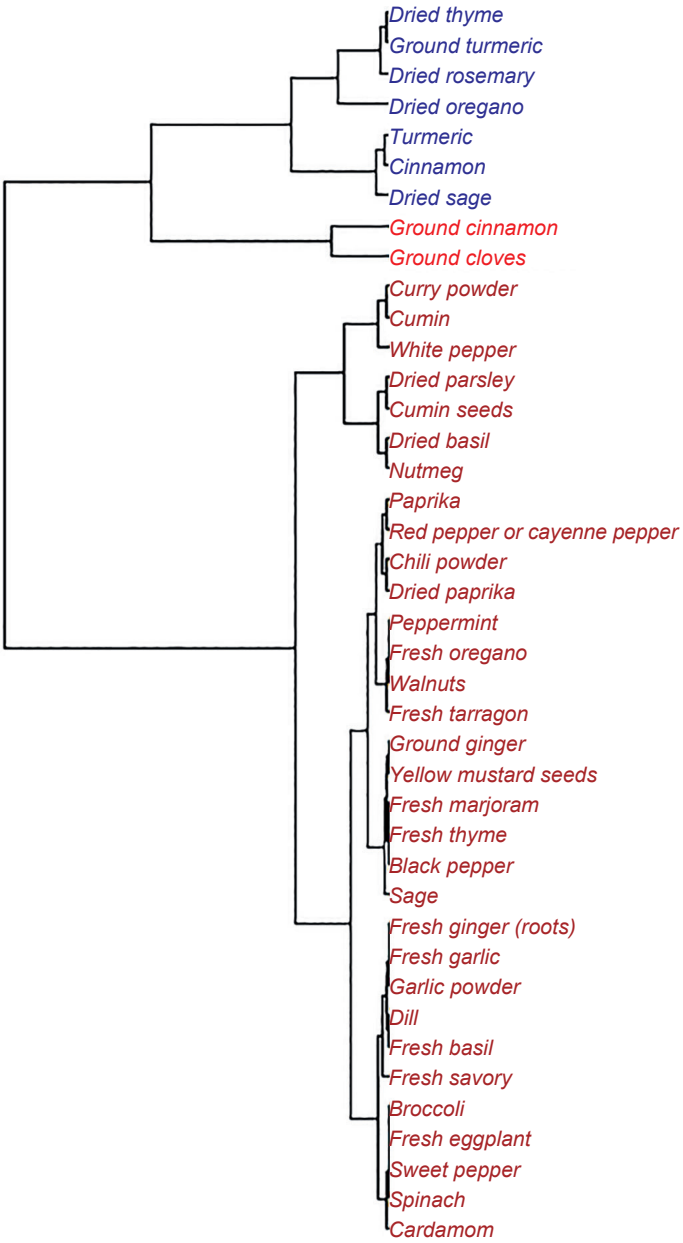

Figure 1. Dendrogram of herbs, spices and vegetables by the descriptor "Antioxidant activity", ORAC (Oxygen Radical Absorbance Capacity)

Table 3. The result of clustering by the descriptor "Antioxidant activity"

Cluster	Number of products in cluster	Mean, %	Min. value for the field «Antioxidant activity»	Max. value for the field «Antioxidant activity»
1	2	290991	267536	314446
2	7	151497	119929	200129
3	32	24500	821	76800

Natural sources of antioxidants were introduced into the recipe: paprika (ORAC — 21932), walnuts (ORAC — 13541), fresh garlic (ORAC — 5770), basil (greens) (ORAC — 4805), as ingredients with antioxidant properties.

As a result, Muhammara recipe was changed. Its dendrogram is shown in Figure 2.

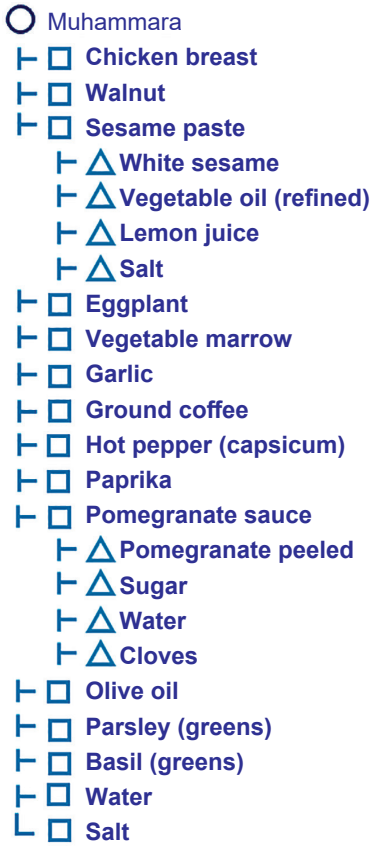

Figure 2. Dendrogram of the Muhammara recipe

Task complexity for a multicomponent recipe is in the fact that it includes many ingredients (more than 5). In our version there are 15 of them. In this case, the calculation of the recipe without the use of modern digital technologies is extremely laborious (with possible human errors). These shortcomings of the traditional method may be successfully solved using modern digital technologies, i. e. computer environments and application packages such as MathCAD, R Studio, MS Excel, Maple, etc. This software saves time for calculations and eliminates the human factor. It also allows the development of functional multicomponent food products with predetermined composition and properties. The basic principle of recipe calculation is the mass conservation law. Its implementation is carried out by solving a system of linear equations by the balance method.

The mathematical technique for solving the classical recipe problem is the simplex method developed by the Nobel laureate, mathematician L. V. Kantorovich [61, 62], and the American scientist, G. Danzig [63, 64].

The third stage is associated with the generation of a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fractions of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.).

Table 4 provides information on the chemical composition (water, protein, fat, essential amino acids and the amount of SFA, MUFA and PUFA) of the ingredients used in the Muhammara recipe.

To perform mathematical calculations, mathematical dependencies were compiled for the protein and fat contents:

$$P = (20.85 \cdot x_1 + 6.5 \cdot x_2 + 13.9 \cdot x_3 + 1.3 \cdot x_4 + 14.14 \cdot x_5 + 1.2 \cdot x_6 + 0.6 \cdot x_7 + 16.2 \cdot x_8 + 18.08 \cdot x_{10} + 3.7 \cdot x_{12} + 3.15 \cdot x_{13}) \cdot 0.99 \quad (1)$$

$$F = (9.25 \cdot x_1 + 0.5 \cdot x_2 + 14.4 \cdot x_3 + 0.44 \cdot x_4 + 12.89 \cdot x_5 + 0.1 \cdot x_6 + 0.3 \cdot x_7 + 60.8 \cdot x_8 + 50.87 \cdot x_{10} + 99.8 \cdot x_{11} + 0.4 \cdot x_{12} + 0.64 \cdot x_{13}) \cdot 0.99 \quad (2)$$

where x_1, x_2, x_3, …. , x_{15} are the mass fractions of the components in the recipe, i. e. chicken breast, garlic, ground coffee, hot pepper (capsicum), paprika, eggplant, vegetable marrow, walnut, pomegranate sauce, sesame paste, olive oil, parsley (greens), basil (greens), water and salt respectively; 0.99 is the preservation of the corresponding food component during heat treatment.

Along with this, an additional ratio between protein and fat is included

$$P : F = 1 : 1 \quad (3)$$

Fourth stage: setting the target function (optimization criterion).

The energy value was chosen as an optimization criterion. Because to reduce the risk of cardiovascular diseases developing and for their dietary therapy, meat-based foods should improve metabolic processes, restore the metabolism of the vascular wall and heart muscle, and have an anti-sclerotic therapeutic effect. This may be achieved by limiting the energy value, salt and fat contents [65].

Fifth stage: solving the problem using a high-level language in a modern programming environment.

The simulation was carried out in the R Studio software using the R programming language. The open-source lpSolve and lpSolveAPI libraries were used.

As a result, the following data were obtained (Table 5).

Nutritional value analysis of the optimal balanced recipe considering the target function and the given restrictions is carried out at *the sixth stage*.

Table 4. Chemical composition of the ingredients used in the Muhammara recipe

	Water, %	Protein, %	Amino acids, g/100 g of protein									Fat, %	Total fatty acids		
			Val	Ile	Leu	Lys	Met + Cys	Thr	Trp	Phe + Tyr	His		SFA	MUFA	PUFA
Chicken breast	69.46	20.85	5.59	5.29	8.93	10.37	3.94	4.84	1.36	8.24	4.02	9.25	3.26	6.48	3.34
Garlic	60.00	6.50	4.48	3.34	4.74	4.20	2.17	2.42	1.02	4.06	1.74	0.50	0.089	0.011	0.249
Ground coffee	7.00	13.90										14.40			
Hot pepper (capsicum)	88.00	1.30	6.15	5.38	8.46	6.92	4.62	5.38	2.31	10.77	3.08	0.44	0.02	0.11	0.11
Paprika	11.24	14.14	5.30	4.03	6.51	4.88	3.04	3.47	0.50	7.00	1.77	12.89	2.14	1.7	7.77
Eggplant	91.00	1.20	5.92	5.08	4.17	4.67	1.67	3.92	1.00	9.17	2.25	0.10	0.03		0.08
Vegetable marrow	93.00	0.60	9.00	7.33	11.83	11.17	5.00	4.83	1.67	12.50	4.33	0.30	0.10		0.10
Walnut	3.80	16.20	7.35	4.75	7.59	2.72	2.65	3.64	1.11	8.33	2.53	60.80	6.20	14.70	40.40
Pomegranate sauce	83.00	0.00										0.00			
Sesame paste	1.60	18.08	5.59	4.30	7.66	3.21	5.32	4.15	2.19	9.49	2.94	50.87	7.12	19.21	22.30
Olive oil	0.20	0.00										99.80	15.75	66.90	13.20
Parsley greens	85.00	3.70	4.65	3.19	5.51	4.89	1.51	3.30	1.22	6.14	1.65	0.40	0.10		0.12
Basil greens	92.06	3.15	4.03	3.30	6.06	3.49	2.03	3.30	1.24	6.57	1.62	0.64	0.04	0.09	0.39
Water	100	0.00										0.00			
Salt	0.20	0.00										0.00			

Table 5. Results of the Muhammara recipe simulation

	Water, %	Protein, %	Amino acids, g/100 g of protein									Fat, %	Total fatty acids		
			Val	Ile	Leu	Lys	Met + Cys	Thr	Trp	Phe + Tyr	His		SFA	MUFA	PUFA
Muhammara	64.27	13.29	5.54	5.05	8.48	9.23	3.76	4.57	1.30	8.02	3.71	13.75	7.72	26.50	15.85
Protein: fat ratio		1:1.03		SFA: MUFA: PUFA ratio			1:3.43:2.05			Energy value, kcal			215		

The chosen ingredient ratios as a result of the execution of the program code in the R language made it possible to obtain the protein: fat ratio of 1:1.03 (recommended ratio 1:1), SFA: MUFA: PUFA ratio — 1:3.43:2.05 (recommended ratio 1:1:1). The energy value of the product is 215 kcal.

The chemical composition of the traditional Muhammara recipe: protein 6.9 g, fat 27.8 g, carbohydrates 20.3 g, protein: fat ratio 1:4.02. Energy value is 351.6 kcal.

The modified and optimized Muhammar recipe is balanced in such a way that, in addition to lowering cholesterol levels, they have a reduced calorie content compared to the traditional recipe.

Gerodietetic nutrition

Another example of systemic approach is the development of products for gerodietetic nutrition.

During the study, meat raw materials, offals and poultry meat were clustered according to important descriptors in the selection of meat ingredients for the recipe of a gerodietetic product being developed: protein content (Figure 3), methionine + cystine content (Figure 4), tryptophan content (Figure 5).

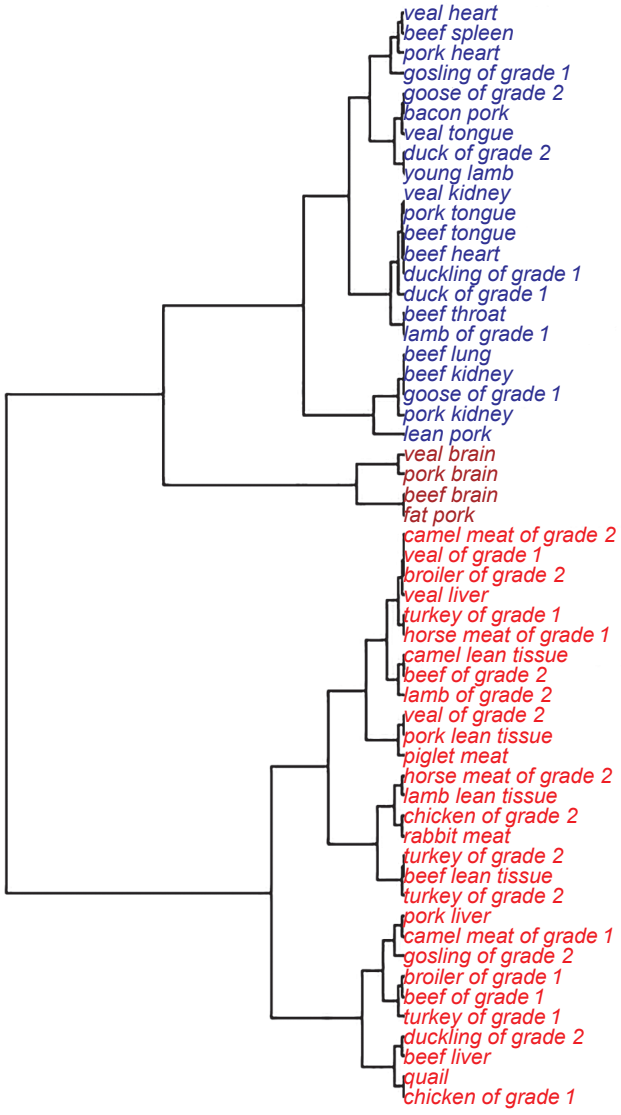

Figure 3. Dendrogram for meat raw materials and poultry meat by the descriptor «Protein content,%»

As a result of clustering, a dendrogram is formed, which visualizes the results of hierarchical clustering. It allows to visually assess the degree of proximity of individual objects and clusters, and also graphically demonstrates the sequence of their combination. Colored areas (red, blue, brown) in the dendrogram visually display the division of products into clusters. Along with the dendrogram, a table is formed with details for each cluster: 1) the number of products included in this cluster; 2) the mean value for this cluster; 3) maximum content in this cluster; 4) minimum content in this cluster. The user can see more detailed information when opening each cluster, i. e. what products are included in this cluster and their value for this indicator (descriptor).

Dendrogram analysis by the descriptor "Protein content,%" (Figure 3) shows that 3 clusters were formed (Table 6) with high, moderate and low protein content. The first cluster (red color on the dendrogram) included 29 items of meat raw materials and poultry meat with a range from the minimum value (17.90%) to the maximum value (21.70%) and an average value of 19.76%. The second cluster (blue color on the dendrogram) included 22 items of meat raw materials and poultry meat with a range from the minimum value (14.3%) to the maximum value (17.2%) and an average value of 16.02%. The third cluster (brown color on the dendrogram) included 4 items of meat raw materials and poultry meat with a range from the minimum value (10.3%) to the maximum value (11.7%) and an average value of 11.05%.

Table 6. Clustering result by the descriptor «Protein content, %»

Cluster	Number of products in cluster	Mean, %	Min. value for the field «Protein», %	Max. value for the field «Protein», %
1	29	19.76	17.90	21.70
2	22	16.02	14.30	17.20
3	4	11.05	10.30	11.70

According to the requirements and restrictions that are set within the framework of his task, the researcher may choose one or more components of the future recipe from the formed samples. If this information is not enough, he can use clustering by different descriptor(s), for example, by the content of the sulfur-containing amino acids, methionine and cystine (Figure 4, Table 7).

Dendrogram and table analysis by the descriptor «Methionine + cystine amino acids content, g/100 g of protein» (Figure 4 и Table 7) shows that the formed first cluster contains 30 types of meat raw materials and poultry meat with a high content of these amino acids. The range of values in this cluster is as follows: the minimum value is 3.48 g/100 g of protein, the maximum value is 4.22 g/100 g of protein, the average value is 3.8 g/100 g of protein.

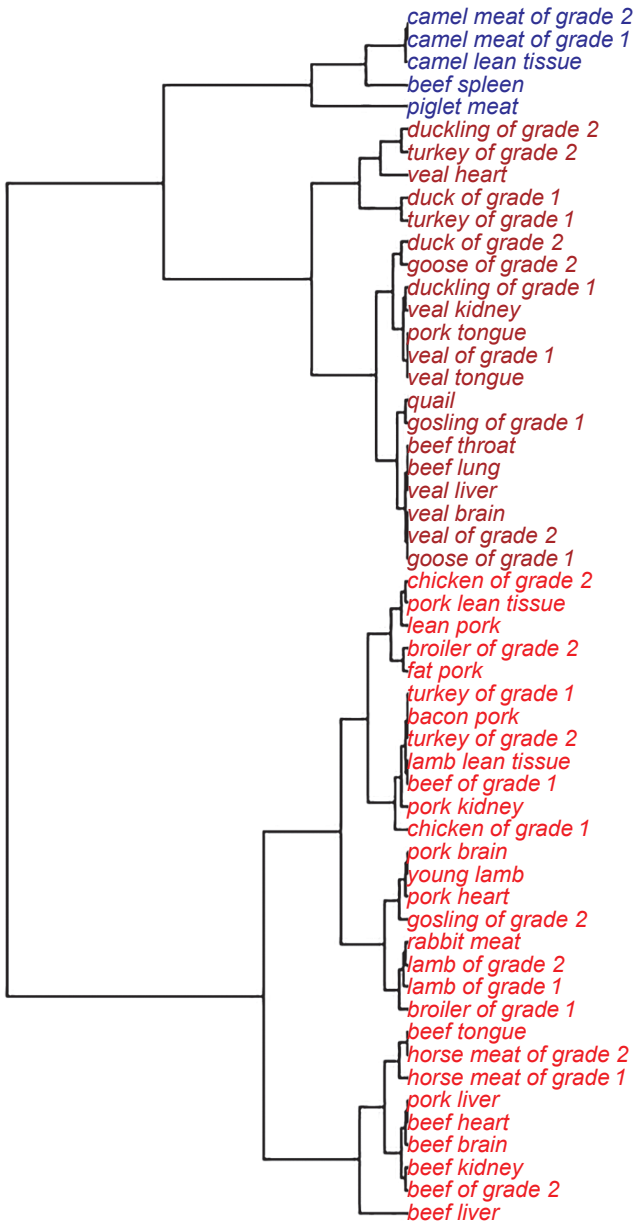

Figure 4. Dendrogram for meat raw materials and poultry meat by the descriptor «Methionine + cystine amino acids content, g/100 g of protein»

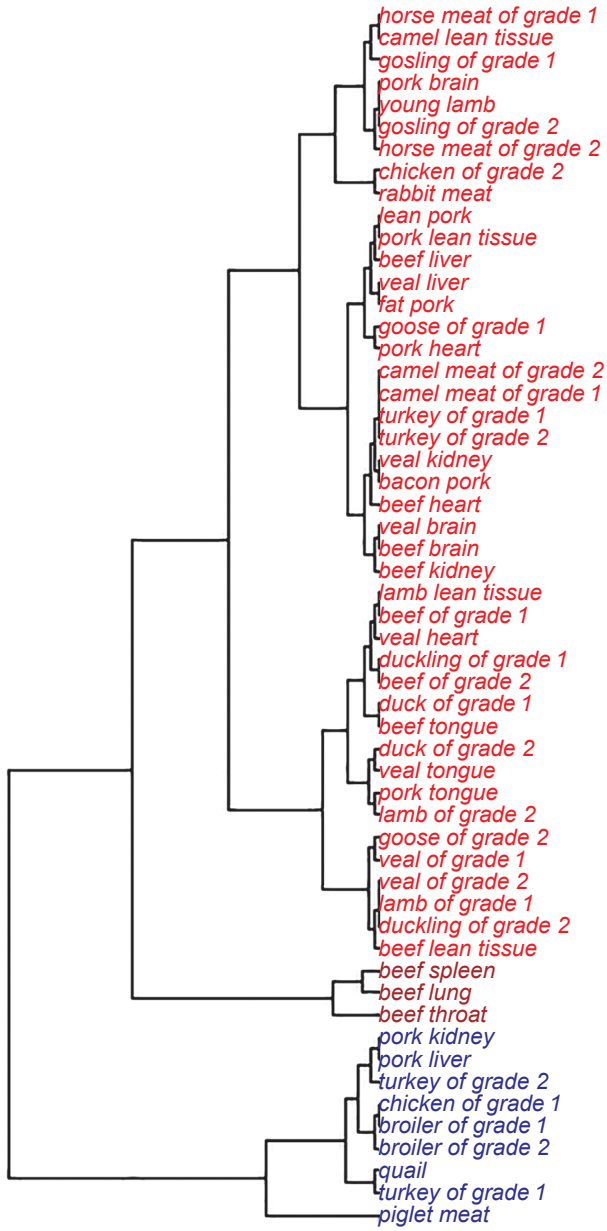

Figure 5. Dendrogram for meat raw materials and poultry meat by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Table 7. Clustering result by the descriptor «Methionine + cystine amino acids content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Met+Cys content», g/100 g of protein	Max. value for the field «Met+Cys content», g/100 g of protein
1	30	3.80	3.48	4.22
2	5	2.49	2.14	2.64
3	20	3.28	2.92	3.41

Along with this, one of the significant indicators included in the medical and biological requirements is the content of tryptophan amino acid. Its value in the product should be at least 1 g per 100 g of protein. Therefore, the clustering of meat raw materials and poultry meat was carried out according to this descriptor (Figure 5, Table 8).

Table 8. Clustering result by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Trp content», g/100 g of protein	Max. value for the field «Trp content», g/100 g of protein
1	43	1.32	1.10	1.56
2	9	1.68	1.60	1.94
3	3	0.89	0.81	0.95

As a result of clustering, three clusters were formed. The second cluster contains 9 types of meat raw materials and poultry meat with the content of tryptophan amino acid ranged from 1.6 to 1.94 g/100 g of protein. These are the highest figures. On the dendrogram, cluster 2 is highlighted in blue. Detailed information about the raw materials included in it may be obtained by opening this cluster (clicking on the "+" icon in the table» (Table 9).

Table 9. Clustering result (detailed information on luster 2) by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Trp content», g/100 g of protein	Max. value for the field «Trp content», g/100 g of protein
1	43	1.32	1.10	1.56
2	9	1.68	1.60	1.94
broiler of grade 1	1	1.61	1.61	1.61
broiler of grade 2	1	1.60	1.60	1.60
turkey of grade 1	1	1.69	1.69	1.69
turkey of grade 2	1	1.64	1.64	1.64
chicken of grade 1	1	1.61	1.61	1.61
piglet meat	1	1.94	1.94	1.94
quail	1	1.70	1.70	1.70
pork liver	1	1.66	1.66	1.66
pork kidney	1	1.66	1.66	1.66
3	3	0.89	0.81	0.95

As it can be seen from Table 9, the highest value of tryptophan amino acid is found in piglet meat (1.94 g/100 g of the product), and poultry meat (quail and turkey of grade 1: 1.7 and 1.69 g/100 g of protein, respectively).

Scientific research and publications by Yudina S. B., a specialist in the field of gerodietetic nutrition, confirm this. In the monograph on gerodietetic nutrition [66], it is noted that the mass fraction of protein in beef (18.5%), rabbit meat (21%) and poultry (chicken of grade 1) (18.2%) is high. The amino acid composition of this raw material is the most balanced in relation to the reference protein and meets the requirements for the nutrition of the elderly and older people.

Beef proteins are high in methionine + cystine (3.79 g/100 g of protein) and low in tryptophan (1.13 g/100 g of protein). Rabbit meat and poultry (chicken of grade 1) also have a high content of methionine + cystine (3.6 and 3.82 g/100 g of protein respectively), and a low content of tryptophan (1.32 and 1.51 g/100 g protein respectively).

In beef and rabbit meat, the protein: fat ratio is ≈ 1:0.8, which corresponds to the nutritional recommendations for older people.

This raw material of animal origin contains a high amount of B vitamins (the content of vitamin B6 in beef is 0.38 mg/100 g of product; in rabbit meat 0.46 mg/100 g of product; in poultry (chicken of grade 1) 0.50 mg/100 g of product), niacin (in beef, rabbit meat and poultry (chicken of grade 1) is 4.7; 6.17; 7.10 mg/100 g of product respectively), and vitamin E (0.51; 0, 50; 0.23 mg/100 g of product respectively).

To obtain products with high nutritional value, it is necessary to use a combination of raw materials of animal and vegetable origin. The use of vegetable raw materials for the production of gerontological nutrition products is predetermined by its high biological properties: an increased content of ballast substances, vitamins, and essential macro- and micronutrients.

Analysis of the data revealed that full-fat flour and chickpeas contain a large amount of protein. The following are distinguished by an increased content of methionine + cystine (g/100 g of protein): chickpeas — 2.93; rice grits — 3.28; soy flour — 6.10; wheat germ — 3.70; white cabbage — 2.34.

For the content of tryptophan, all types of vegetable raw materials meet the requirements for the nutrition of older people.

The lipids of chickpeas, rice grits, full-fat soy flour, wheat germ are rich in polyunsaturated fatty acids, especially linolenic acid.

The choice of meat and vegetable raw materials intended for the production of gerodietetic products, and determination of their chemical composition are important steps in the development of a future product recipe.

The most common diseases in older people are diabetes mellitus, obesity, cardiovascular diseases, atherosclerosis, digestive system disorders, oncological diseases, central nervous system disorders, iodine deficiency and iron deficiency. A special attention is paid to musculoskeletal system disorders. First of all, these are osteoporosis and osteoarthritis. These diseases are leading both in prevalence and in the causes of disability and mortality from complications.

One of the approaches to the prevention of the musculoskeletal system disorders is the introduction of functional foods into diet as they contain essential nutrients in quantities that largely meet the needs of older people.

Sausages are quite popular products for older people. This is due to a number of reasons and specific circumstances: tender texture; a wide range of prices and quality; no cooking is needed. However, these products are not favorable for metabolic, physiological and biochemical processes of the body due to the increased amount of salt and fat, the presence of flavorings and technological additives.

Based on the analysis of data on the physiological needs of older people for nutrients, specialists from the V. M. Gorbatov Federal Research Center for Food Systems together with specialists from the Institute of Nutrition developed scientifically based recommendations for the composition and quality of cooked sausages, which include requirements for the meat raw materials used, protein, fat, vitamin and mineral components and finished product in terms of nutritional value and safety.

When developing scientifically based requirements for functional cooked sausages, deficiencies often found in older people were taken into account, which have the greatest impact on the development of musculoskeletal system disorders (Table 10).

Table 10. Formalized requirements for the composition of gerodietetic products for the prevention of musculoskeletal system disorders

Parameters	Content per 100 g of product	% of daily requirement
Proteins, g, including	10.0 to 14.0	20 to 25
connective tissue proteins, g	4.0 to 6.0	—
Fat, not more, g, including	8.0 to 12.0	20 to 25
vegetable oils	2.0 to 4.0	20 to 25
Carbohydrates, g, including	4.0 to 8.0	5 to 7
dietary fiber, g	3.0 to 6.0	20 to 30
Cholesterol, g, not more	0.06 to 0.012	20
ω6/ω3 ratio	(1 to 7):1	—
Energy value, kcal/100 g	120 to 180	6 to 9
Salt, g, not more	2.0	60
Minerals, mg:		
Calcium	180 to 360	15 to 30
B_1, mg	0.2 to 0.45	15 to 30
B_2, mg	0.27 to 0.54	15 to 30
B_6, mg	0.3 to 0.6	15 to 30
E, mg tocopherol eq.	2.25 to 4.5	15 to 30
PP, mg	3.0 to 6.0	15 to 30
D, μg	2.25 to 4.5	15 to 30

Considering the anti-atherogenic nature of the diet for older people, when developing cooked sausages, raw materials with a low content of saturated fats and a high content of connective tissue (shank meat) were selected. The use of horse meat is due to the high content of α-linolenic acid, linoleic acid, eicosapentaenoic acid and docosahexaenoic acid.

Vegetable oils (rapeseed oil and soybean oil) are important for an aging organism due to the presence of polyunsaturated fatty acids of the ω3 class, as well as phosphatides (lecithin) and phytosterols, which have a beneficial effect on cholesterol metabolism.

To make a functional product, the composition includes dietary supplement developed on the basis of protein hydrolysate with the introduction of a number of food ingredients, including dietary fiber, biologically active substances (chondroprotectors that have a positive effect on the metabolic processes in cartilage tissue), mineral salts and vitamins (B1, B2, B6, B3, D3, E).

Based on the data on the distinctive features of meat raw materials and taking into account the formalized scientifically based requirements given in [67, 68], cooked sausage recipe compositions for gerodietetic nutrition were obtained by computer simulation (Table 11).

The results of amino acid and fatty acid balance assessment are presented in Table 12.

Analyzing the data on the amino acid balance in the resulting sausage compositions, we see the rather high values of the rationality coefficient for the amino acid composition, which is in the range of 0.89 to 0.93, and the comparable redundancy coefficient of 3.1 to 3.12, which indicates a high biological value of the developed cooked sausages. The results of fatty acid balance assessment confirmed the high nutritional value and compliance with the developed scientifically based requirements.

Table 11. Composition of sausages

Sample	Ingredients
Cooked sausage (Recipe 1)	➢ Trimmed beef of grade 1 ➢ Beef shank meat ➢ Pork shank meat ➢ Dietary supplement (inulin, egg albumen, dietary fiber, collagen hydrolysate, calcium, calcium citrate (E333), ascorbic acid, nicotinic acid (PP), tocopherol acetate (vitamin E), pyridoxine hydrochloride (B6), thiamine bromide (B1), riboflavin (B2 E101), cholecalciferol (D3)) ➢ Water ➢ Rapeseed oil ➢ Linseed oil ➢ Salt ➢ Black or white pepper ➢ Nutmeg ➢ Pimento
Cooked sausage (Recipe 2)	➢ Horse meat ➢ Poultry meat ➢ Egg albumen ➢ Rapeseed oil ➢ Linseed oil ➢ Dietary supplement (inulin, skimmed milk powder, egg albumen, dietary fiber, calcium, isolated animal protein, calcium citrate (E333), glucosamine sulfate, chondroitin sulfate, ascorbic acid, nicotinic acid (PP), tocopherol acetate (vitamin E), pyridoxine hydrochloride (B6), thiamine bromide (B1), riboflavin (B2 E101), cholecalciferol (D3)) ➢ Water ➢ Salt ➢ Black or white pepper ➢ Nutmeg ➢ Pimento

Table 12. Amino acid and fatty acid balance of recipe compositions for cooked sausages

Parameters	Cooked sausage		FAO/ WHO reference
	Recipe 1	Recipe 2	
Mass fraction of protein, g/100 g	13.0	13.2	—
Mass fraction of fat, g/100 g	10.25	10.05	
Minimum amino-acid score,%	0.99	0.98	→1
Comparable redundancy coefficient, g/100 g of protein	3.12	3.1	→0
Rationality coefficient, U	0.89	0.93	→1
Fatty acids, g/100 g			
Σ SFA	39.86	38.75	
Σ MUFA	37.31	38.56	
Linoleic fatty acid	14.7	14.8	
Linolenic fatty acid	10.25	9.78	
Arachidonic fatty acid	0.2	0.25	
Coefficient of fatty acid balance R_{1-3}, U	0.82	0.84	
Coefficient of fatty acid balance R_{1-6}, U	0.57	0.58	
ω6: ω3 ratio	1.5:1	1.4:1	

Conclusion

Development of food products with given composition and properties primarily depends on scientifically based information and principles and biomedical requirements for each determined group. This information should be in the knowledge base for the functional foods design system.

Considering these requirements, the choice of the main raw material for the recipe of the future product is carried out by clustering methods according to one or more significant descriptors. This requires a database of the chemical composition of food products and ingredients. Next, the recipe dendrogram and mathematical dependencies for the main food nutrients are generated, taking into account the preservation of the corresponding food nutrient during heat treatment. At the final stage, a complex solution of the equation system using mathematical programming methods and analysis of the nutritional value of the optimal balanced recipe considering the target function and the given restrictions takes place. The example of two products shows the possibility of product simulation, which significantly reduces the time spent on the optimal recipe development and the selection of ingredients. The described systemic approach may be applied for the development of a food product with any properties.

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ATMOSPHERIC COLD PLASMA TECHNOLOGY FOR MEAT INDUSTRY: A BIBLIOMETRIC REVIEW

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Keywords: *Bibliometric analysis, atmospheric cold plasma, meat processing*

Abstract

Atmospheric cold plasma is an innovative, non-thermal technology. It has shown promising results for a broad range of food processing applications. On the basis of those facts, it has prompted growing attention in the scientific community. This paper reviews the literature generation trends surrounding the atmospheric cold plasma technology. A bibliometric analysis was carried out to objectively and analytically uncover the knowledge development in the atmospheric cold plasma technology within the context of meat processing. The research began with querying the Dimensions database for scientific articles published over the past two decades. A total of 105 papers were published during this period. The articles were examined according to several bibliometric metrics such as the year of publication, countries, institutions, sources, authors, and keywords frequency. The results of the bibliometric analysis revealed that researchers are very interested in studying the interface of the atmospheric cold plasma technology and meat processing. In the last couple of years, the number of publications on the topic has been growing. This is the first bibliometric investigation of the atmospheric cold plasma technology in the context of meat processing. To the authors' best knowledge, no similar analysis has been performed before. This paper provides researchers with a better understanding of topic developments. A better understanding can aid future research by closing present knowledge gaps. Hence, the paper provides the continuation of up-to-date technological discussions among researchers.

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Introduction

In the last two decades, a strong increase in interest in the atmospheric cold plasma (ACP) technology has been observed. This novel treatment process is becoming relevant for food processing and new applications are being researched daily. Consequently, in this period, the production of scientific publications has seen the exponential growth. The high rate of scientific production makes it difficult for researchers to remain current with everything being researched and published. Furthermore, the focus on empirical contributions has led to numerous and dispersed research streams [1]. All this results in the data being viewed in isolation, which prevents one from ever seeing the complete spectrum of research. There are several narrative reviews about ACP research as well [2–4]. A few of them are devoted to the particular uses of atmospheric cold plasma in meat processing [5–7]. However, a bibliometric review of publishing patterns in the general research field is still lacking. To our knowledge, a bibliometrics review of ACP research trends in meat processing applications is missing as well. Bibliometric reviews have the ability to introduce a methodical, transparent, and reproducible review process based on statistical measurements of the area and its scientific activity and to give the «overall picture» of existing research [8]. It is outside the scope of this journal and the author's intention to produce a general research field bibliometric review. However, a bibliometric review of research focused on meat processing applications would be beneficial. For scholars, it is valuable to have a deep understanding of the intellectual foundations of the research area and how it has developed. This is crucial for closing the entrance gap for new scholars, who frequently see conducting a thorough review of earlier research as a time-consuming and high-effort activity. Being a bibliometric review this article aims not to explore the advantages, limitations, physicochemical changes, nutritional quality and regulatory issues associated with the application of cold plasma on meat products but to provide a reader with the findings that will aid in area mapping and help steer the future research on meat processing applications of the ACP technology. The paper is structured as follows. Prospects of the atmospheric cold technology and research conducted on possible meat processing applications are discussed first. Then, a description of the study method is given, the review of the content evolution over time is presented and the potential limitations of the review are addressed. Finally, we explore the future and provide some thoughts about how the discipline might develop in the future in the conclusions.

Atmospheric cold plasma

The major disadvantage of vacuum plasma is that it cannot be utilized to process most food materials, since it is only operating under vacuum and most food materials are not compatible with it [9,10]. Plasma operating under atmospheric pressure may provide a novel and highly reliable technique for sanitizing, preserving, and sterilizing food products. The application of ACP is envisioned primarily as a minimal food processing technique and as such should not compromise the protection of processed foods against microbial and chemical risks [11]. Many research papers and studies have concentrated on the use of ACP in food sterilization, microbial inactivation, and mycotoxin breakdown [12,13]. Only recently, investigations on ACP effects on specific products and food nutrients have been initiated. Firstly, effects on fresh produce were investigated and then research expanded to fruit and vegetable products, cereals and cereals products, and almost all types of food products [14–16]. Over the past fifty years, both meat production and consumption have increased, and it is expected that this trend will continue as the demand for animal proteins rises [17,18]. However, because meat and meat products are highly perishable, a variety of preservation and processing techniques have traditionally been used to retain their high quality and prolong their shelf lives [19,20]. In most cases, the application of ACP on meat has been executed as a direct exposure, used on the packaging matrix, or as a means for water treatment that will be used in meat products. This latter case is also termed the plasma-activated water technology but since water treatment also involves plasma excitation in gas for water activation and for the sake of simplicity of terminology throughout this paper, only the ACP term will be used. Numerous studies have concluded that ACP treatment improves the quality of meat [21,22]. Different reactive species constitute plasma, among them are nitrogen (long-lived species) which dissolves as nitrogen oxide (see Eq. 1) and forms nitric acid when water is present. Nitric acid then breaks down into nitrate and nitrite (see Eq. 2).

$$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3 \leftrightarrow NO{-}2 + NO{-}3 + 2H^+ \quad (1)$$

$$2HNO_2 \rightarrow NO + NO_2 + H_2O \quad (2)$$

Plasma-activated brine was utilized by Inguglia et al. to cure beef jerky [23]. According to their findings, air plasma formed more nitrites in the brine solution than N_2 gas plasma, with a residual nitrite concentration of between 26 and 180 ppm. This nitrite depletion is a result of nitrite direct interaction with the proteins in meat. However, they found out that the texture and lipid oxidation of beef jerky were unaffected by this nitrite reaction. Additionally, treatment of the jerky with air ACP, which is regarded as a potential disinfectant on the meat surface, results in a notable decline in the overall population of *Listeria innocua* to 0.85 $\log_{10}$ CFU/g. A significant reduction, ranging from 2.3 to 5.3 log CFU/cm^2, in *Salmonella* Typhimurium was achieved by using CAP in combination with peracetic acid (PAA) in a range of 100 to 200 ppm on the poultry meat, while CAP alone reduced the microbial load by 0.6 to 2.3 log CFU/cm^2 [21]. Furthermore, several studies showed that employing any combination of gas in ACP decreased meat spoilage caused by bacterial contamination [24]. The water activity in meat products is also affected by modifications to the gas mixture. When 25% O_2 and 75% Ar gas combination was used in ACP, a reduction in the water activity (a_w) was seen at an a_w of 0.71 [25]. Low a_w has been proven to be crucial for stopping bacterial development in meat products.

Bibliometric method

Growing attention has been devoted to the bibliometric study of the scientific literature, in recent years. The availability of online databases and the development of effective tools enable one to carry out analysis dealing with a specific domain of research. Since, the primary aim of this review is to examine the domain of the ACP technology in the meat processing domain, we conducted a bibliometric analysis. For this study, we chose to query the Dimensions database due to its certain advantages. The Dimensions database is the most inclusive. It captures the broader list of sources (i. e. journals), increasing our analysis horizon. Dimensions had over than 106 million publications by December 2019 [26]. That is around 30% more than comparable databases. Publications from prominent publishers such as Elsevier, Emerald Insight, Springer, and Taylor & Francis are included [27,28]. Moreover, this database includes publications from numerous small academy-led journals and publishing houses. Access to databases for scientometric purposes is free. Since the authors did not have access to other databases that need a subscription, it was also the only practical choice. The greatest weakness of our choice is incomplete affiliation data. As discussed earlier, the database in some cases lacks the identity of the author's affiliated institutions [29]. Alternative databases for retrieving bibliometric data could be used, for example, Scopus, Google Scholar, Microsoft Academics, Crossref, and Web of Science databases. But each of them also has a set of advantages and weaknesses, just like Dimensions have. In a recent large-scale comparison of bibliographic databases, the strengths and weaknesses of the different data sources are discussed [26].

Selection strategy

All data were extracted through a set of queries. Only bibliographic records published from 2001 to July 31, 2022 were retrieved. To maintain the academic nature and high quality of the literature, the search was limited only to peer-reviewed English-speaking journal articles. Each query was constructed of terms linked by Boolean operators. That way queries aimed to encompass all relevant search fields while still providing adequate selectivity. Hence, only results from the literature connected with our domain of interest would be returned.

The following search fields were defined:

- Keywords;
- Titles;
- Abstracts.

We added all terms that led to the improvement of search results. To identify all publications related to ACP in general, the first query was defined in the following form:

'' Plasma AND (cold OR nonequilibrium OR non-thermal OR non-thermal OR atmospheric OR corona OR "activated water" OR "treated water") AND (food OR cereals OR fruits OR dairy OR beverages OR milk OR meat OR egg OR beans OR fish OR insects OR oils OR nuts OR rice OR wheat OR maize OR barley OR corn OR quinoa OR sorghum OR oat OR juice OR snack OR spice OR "food protein" OR "edible seed" OR legumes OR coffee OR wine OR beer OR cheese OR clams OR juice OR salad OR berry OR flour OR spinach OR lettuces OR oyster OR shrimps OR sausage OR poultry OR pork OR beef OR lamb OR goat)''

To identify all publications related exclusively to the ACP application in food processing, the second query was defined in the following form:

''Plasma AND (cold OR nonequilibrium OR non-thermal OR non-thermal OR atmospheric OR corona OR "activated water" OR "treated water") AND (meat OR sausage OR poultry OR pork OR beef OR amb OR goat) ''

The information about the retrieved record was then exported into Microsoft Excel 2016. Then, several preprocessing methods were applied to improve the quality of the retrieved data:

- Detection of duplicate records;
- Spellings checks of authors' names;
- Screening of records for relevance.

Relevance of records was assessed on the basis of several requirements and all records were manually checked for compliance. The authors screened the titles and abstracts of articles and deemed them relevant if relevance requirements were satisfied. Requirements were defined to include a record in further analysis on the basis that a record was explicitly focused on the application of ACP in food/meat processing when it dealt with at least one of the following topics:

- Effect of treatment on food/meat characteristics (chemical, physical, sensory etc.).
- Effects of treatment on microbial decontamination in food/meat matrix.
- Effect of treatment on packaging material properties tested on food/meat.
- Effect of treatment on chemical decontamination of food/meat samples.

Similarly, requirements to exclude records from the further analysis were defined on the basis that a record was not explicitly focused on the application of cold plasma in food processing, its scope was broader:

- Literature review of several technologies, e. g. of all non-thermal technologies;
- Application of cold plasma in analytic techniques;
- Record was without overlap with Food Sciences categories, e. g. Physics, Materials, Medicine, Microbiology, Non-Food Biotechnologies.

We accepted the use of ACP in all its forms on samples. We also accepted the use of ACP to generate plasma-activated water, which was subsequently used to treat food/meat samples.

At the end of the data preparation process, from 3466 records returned by the first query we ended up with only 1259 articles that satisfied all inclusion conditions. Similarly, in the case of the second query, from 364 records returned we ended up with only 105 articles that satisfied all inclusion conditions.

Data loading and converting

Starting with our final set of records, we loaded the data (i. e., the selected records that matched the inclusion criteria) into an R data frame using bibliometrix [30]. Bibliometrix provides one of the most extensive sets of bibliometric analyses. Bibliometrix is suitable for practitioners through the Biblioshiny addon [31].

Analyses and results

General Information

The main information about the two obtained collections of records is presented in Table 1. In it, an overview of ACP in food processing and ACP with the intersection with meat processing is given. Development dynamics can be used from this overview to provide answers to the questions of this review, i. e. whether the ACP application in meat processing is similar to or differs from the ACP topic in general and what are the most prominent differences. What are the most prominent differences? There were 415 journals that published at least one document about ACP in food processing. Of these, only 44 journals published research articles about the application of ACP in meat processing. It can be easily noticed that published studies about ACP in meat processing are more recent, which is to be expected since it is a subset of ACP research. Looking at the authorship patterns, it can be noticed that only a small number of articles were written) by a single author. Considering the number of times an author appeared in the collection, an average co-authorship value of 5,4 authors per article was obtained for the ACP records. This value is closely matched with 5,28 authors in ACP focused on meat processing. This value can also be seen as a proxy for the average size of research teams.

In order to get insight into the internationalization of the researchers' collaboration, one should look at the values of international co-authorships. It can be seen that the research teams exploring ACP for meat processing appli-

cations are more diverse. This could also explain the notably higher values of the average citations per article and growth rate. Published research about ACP in meat processing should be characterized as more recent since it is only a subset of the ACP research. The timespan and the average age of articles can easily be used to confirm the expected, signaling that the the majority of articles had been written recently.

Table 1. Main information about the collection

Description	ACP — Meat	ACP
MAIN INFORMATION ABOUT DATA		
Timespan	2007–2022	2001–2022
Journals	44	415
Articles	105	1259
Annual Growth Rate %	18.02	15.45
Average Article Age	3.99	4.31
Average citations per article	31.34	26.66
AUTHORS		
Authors	346	4128
Authors of single-authored docs	1	24
Co-Authors per article	5.28	5.4
International co-authorships %	66.67	55.68

The number of articles published is an important indicator for determining whether a topic is attracting the attention of scholars. Analyzing the number of papers published can provide insight into whether the field has seen significant breakthroughs in its development. The foregoing is particularly true for a topic that is a subset of a parent topic. Figure 1 shows the year-wise distribution of articles published during 2001–2022. The earliest published article on the ACP topic dates back to 2001. The first research about the ACP application in meat processing appeared only six years later, in 2007.

ACP: The number of articles on the topic of ACP in general; ACP: Meat the number of articles on the topic of the ACP application in meat processing.

In the mid two thousands, the annual volume of published articles increased barely noticeable. This period averaged 12,1 articles per year. In the last decade, starting from 2012, the number of articles grew more prominently, reaching a value of 219 published articles in 2021, while in the first six months of 2022, 143 articles were published. Extrapolation from the described pattern suggests that the total number of articles in 2022 could also exceed that of the former year. Two main factors explain the observed growth. Firstly, through the maturation of the ACP topic, it is possible that the overall number of studies has increased exponentially, boosting also the number of submissions to the journals. Secondly, the development is fueled by the search for new technologies that provide minimally processed food products to answer the developing tendencies of consumers. However, according to the trend shown in Figure 1, there were no continuous year-by-year publications on the topic of ACP in meat processing after the first article had been published in 2007. In the following year, not a single article was published. This clearly indicates that topic started its development at this moment. In the course of development during the following years, the annual number of articles presented almost a stationary publishing trend. Only in 2019, 12 years after the first article had been published, a noticeable increase in the number of annual publications can be noticed. In that year, there were 19 articles published. After this noticeable peak of activity, we again observe the stationary publishing trend described in the former period. This is quite possibly due to the COVID — 19 pandemic events and the slowing down of research activities. Until sufficient time passes after COVID — 19 pandemic, it is difficult to deduce the reason for our observation with certainty. The above-mentioned numbers show that the topic has been attracting the attention of researchers. This suggests that the topic's concerns continue to have an impact on the academic world, implying that the topic has not been adequately addressed.

Highly contributive journals and articles

There are 44 relevant journals on the topic of ACP applications for meat processing. They represent almost one-tenth of the total number of journals, in which ACP studies were published. Each of the journals published one or more articles in this analyzed set. Figure 2 shows the most relevant journals considering the number of articles. The journal of *Innovative Food Science & Emerging Technolo-*

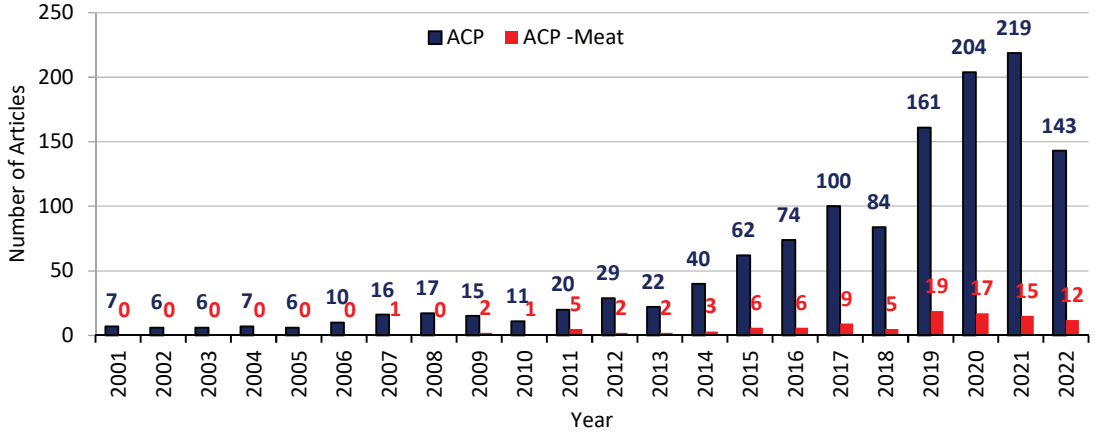

Figure 1. Year-wise distribution of scientific production in 2000–2022 timespan

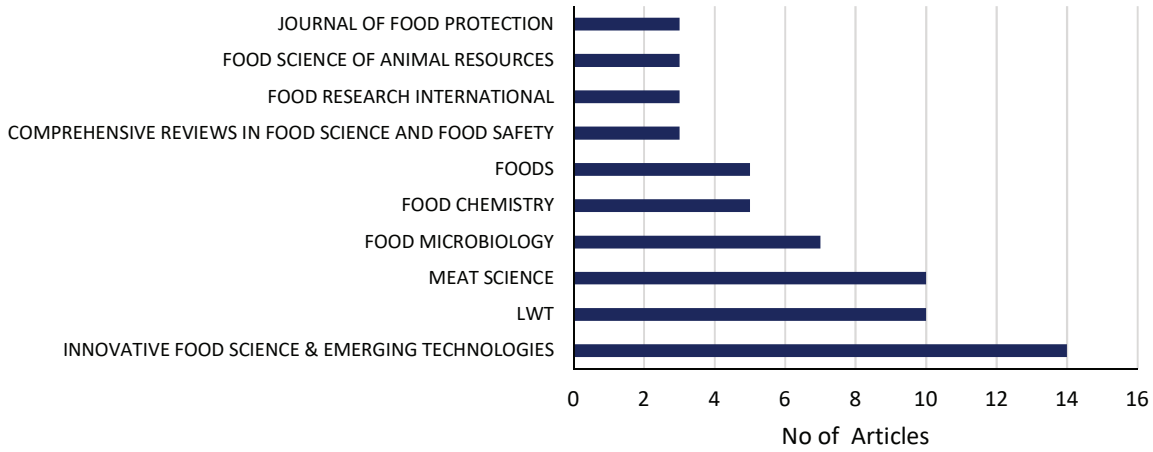

Figure 2. Highly contributive journals

gies is the top critical journal in the field, as it published 14 articles. The *LWT* journal is the second top journal with 10 articles and this number of articles is matched with the number of articles published in the *Meat Science* journal. These three journals are clearly playing a key role in publishing research on ACP in meat processing and hence the development of the topic.

The distribution of research output per journal supports Bradford's law, which says that there is a small set of key journals that account for a significant percentage of publications on the corresponding field or topic [32]. All listed journals involved in publishing articles on the topic of the ACP application in meat processing are well-established venues for publishing in food sciences, hence have adequate bibliometric indicators and professional prestige. This is indicates that the topic of ACP in meat processing is of interest to editors and that the research field is certainly one of the "hot" topics in development. In Figure 3 the most contributing articles to the topic are presented. The contribution was measured as the number of total citations those articles had received. In total, from all analyzed documents in our collection, only 5 articles had 100 or more citations. The most impactful article is an article by Noriega et al published in 2011 in the *Journal Food Microbiology*. This article is closely followed by the other three most impactful articles all published in the same journal and at approximately the same time. From that observation, we can easily extrapolate that the effects of ACP on microbiological safety are the main focus of the conducted studies and that the most important results are in the described line of research.

Authors and Co-authorship productivity

In Figure 4 authors' productivity is shown) through Lotka's Law. In total, there were 3084 unique authors. In accordance with Lotka's Law, 77.5% of authors wrote) just one article, 11.3% of authors wrote) 2 articles, 4.9 wrote) 3 articles, 3.2% authored 4 articles and etc.

In Figure 5, the top 10 countries were ranked by their count of articles published. The gray columns demonstrate the publication rate by corresponding author's country, wherein at least one foreign co-author exits. The black columns represent the number of articles by authors from the same country. These are called Multiple Countries publication (MCP) and Single Country Publication (SCP), respectively. South Korea, China and the USA are considered the top three most relevant countries. South Korea has by far the most international collaboration. Two North American countries, three European countries, three Asian countries, and one country each from Oceania and the Middle East are ranked as countries with the highest number of articles on the topic.

Researchers do not work in isolation, since they are members of a worldwide community working together to provide new insights and inspiration for new researchers to work on the same or related topic. International

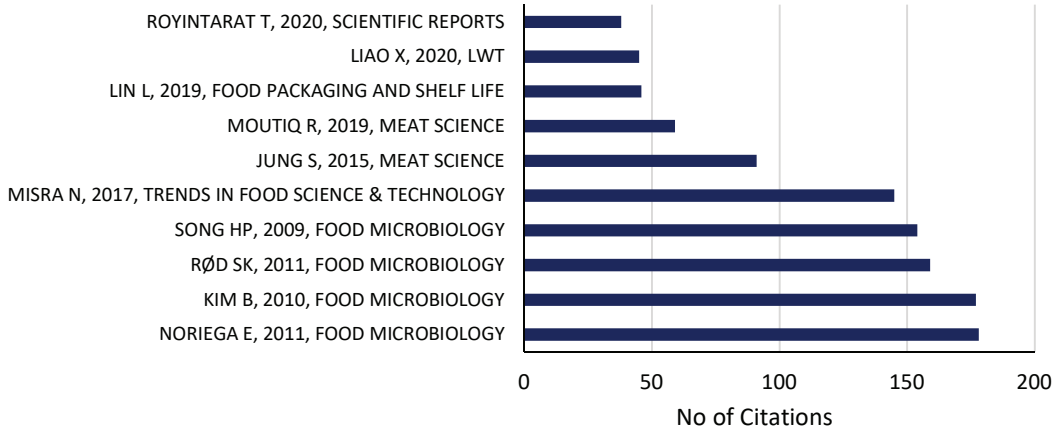

Figure 3. Most contributing articles

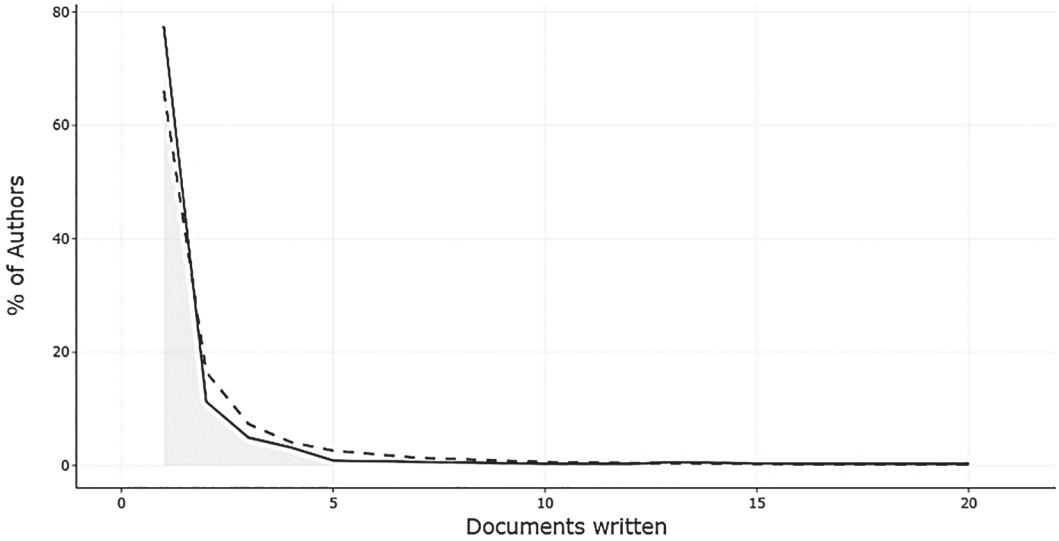

Figure 4. Authors productivity shown through Lotka's Law

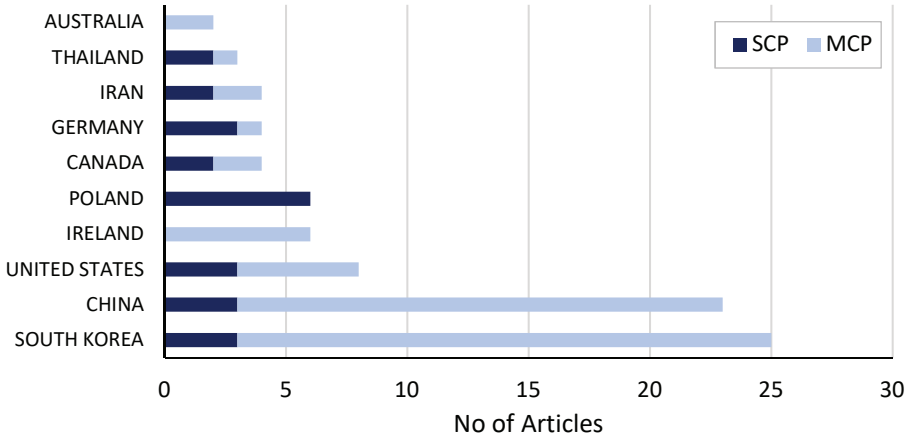

Figure 5. Top 10–Most productive countries (based on first author's affiliation).
SCP — single country publications; MCP — multiple countries publications

co-authored publications are frequently used as a measure to obtain a comprehensive picture of international collaborative works. Co-authorship is the final result of different scientific exchanges that facilitate the acquisition of science undertaken within a community of facts and ideas. It is worth noting that a country we refer to as the author's affiliation is a country indicated at the time of publication.

Keyword Frequency Analysis

The goal of keyword frequency analysis is to identify research hotspots and development trends based on the number of keyword occurrences. [33]. The keywords are derived from the publication's core content; therefore, if a keyword is frequently used in a certain knowledge domain, the topic it represents can be deemed to have garnered substantial attention from researchers and can therefore be regarded as a hotspot in the area [34]. Furthermore, keyword selection follows precise standards, as keywords are frequently used to identify research ideas, define the research field, restrict the scope of the investigation; synthesize research; and discuss the methodology or theory employed in a study [33]. As a consequence, we may find hotspots in certain knowledge fields by analyzing keywords based on their frequency and the meanings they express. Following this approach, we first extracted the most common keywords and conducted a content analysis referring to application of ACP in meat processing. Figure 6 displays the top 10 most often used keywords in our collection of articles.

Overall, all the most frequent keywords listed in Figure 6 suggest that the practicality of the ACP technology is explored mostly in the direction of its use for microbial decontamination of meat products. Beef and chicken meat are most commonly treated and analyzed. It is interesting to note that the most common keyword is nitrite. The importance of nitrite in meat products does not need elaboration. But how to explain its prominence when all other words are connected with microbial decontamination? Simply stated, every use of any other prominent keyword must be followed with the keywords nitrites. So great is its importance for the production of safe meat products. Besides that, outside of the theme of microbial decontamination, there is only one other important theme of the research. This theme is the use of the ACP technology to introduce nitrites into meat products. The process is explored as an easier and potentially more sustainable alternative to the traditional curing process.

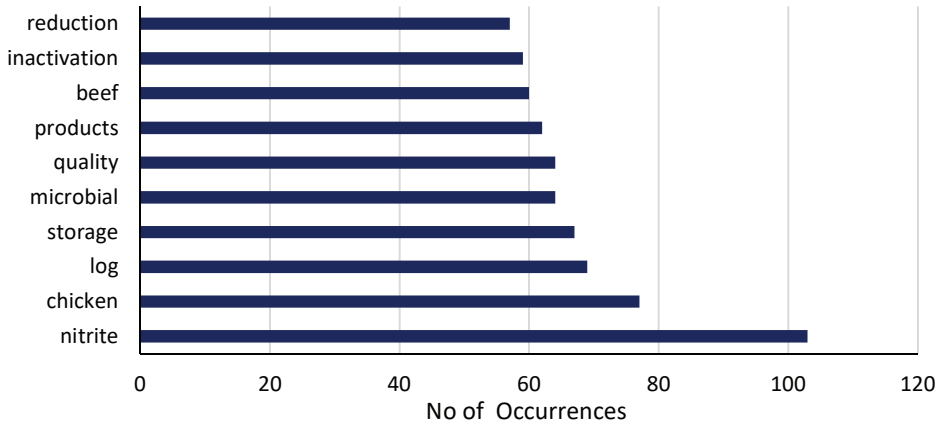

Figure 6. Top 10 most frequent keywords in ACP in meat processing research

Conclusions and Limitations

Science mapping is becoming a vital task for researchers from all scientific areas. As the number of publications continues to grow at an increasing rate and articles emerge with just fragments of knowledge, the process of collecting knowledge becomes exceedingly challenging. The definition of the intellectual structure and the research-front of scientific domains is crucial not only for research but also for policy-making and practice. Bibliometric analysis uses mathematical and statistical methods to evaluate research outputs. Although extensive empirical research has been carried out on the topic of the ACP application in meat processing, there is no study dealing with its bibliometric analysis. This work focuses on the bibliometric analysis of research at the interface of the ACP technology and meat processing through the literature from 2001 to 2022 queried from the Dimensions database. The number of articles has shown a clear increasing trend in the past decade. A great extent of collaboration among different countries, authors, and institutions has been already established. Core journals are identified as well as the list of ten most impactful articles on the topic.

Limitations of Study

This study has several limitations mainly related to the instrument of bibliometric analysis per se. Indeed, there are always false positive and false negative results in any bibliometric research. The first limitation of this study is the impossibility to generate a perfect and all-encompassing research query. The other limitation springs from the fact that the citation analysis represents an objective and quantitative measure of the research but does not provide information about research quality or its influence on the practice. Although we may hypothesize that the more citations an article receives, the greater the impact that article may have on the scientific community, we must be aware that there are many forms of citations. Besides mentioning and supporting, there is also contradicting citation which we could not isolate and quantify with the applied method. Considering all these limitations, the number of articles analyzed in this study might not exactly reflect the entire global research activity on the topic of ACP in meat processing, but the data presented likely provides significant insight into the evolving patterns over the last two decades.

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TROPHOLOGICAL APPROACH IN THE DEVELOPMENT OF NUTRITION THEORIES

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Keywords: *trophology, nutrition theories, perfect nutrition, nutrition culture, allergens*

Abstract

This article presents a trophological approach to the development of nutrition. The evolution of human views on nutrition from antiquity to the present time, including issues of perfect nutrition, is considered. The main concepts of nutrition theories are formulated. The systematized reasoning is useful for new rationale for solutions of challenges related to optimization of nutrition. Within the scope of the development of nutrition theories, the problem of perfect food plays a special role. The article presents a modern vision of perfect nutrition. The designing of trophological nutrition algorithm is based on scientific approaches that both to justify the correct consumption of food products, and also define the most reasonable way of their production, storage, distribution and disposal of food waste. The implementation of the trophological approach in theories of nutrition is also reflected in the concept of the state policy of the Russian Federation in the field of healthy nutrition among the population. This topic is also relevant in light of the sharp increase of food allergies among the various groups of population, because people who suffer from food allergies must follow a special diet to prevent the risk of allergic reactions, which can be managed using a nutritional approach.

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Introduction

Trophology is the science of food that studies the impact of the alimentary factor on the condition of a human body, studies the development and creation of methods for improving health through the alimentary factor. For example, the health can be improved through rational human nutrition, as well as through the improvement and management of food quality. The trophological approach has two bases: biological and evolutionary [1,2].

The founder of the concept of trophological food chains is the Russian scientist Ugolev A. M. Whole range of his works are devoted to fundamental and applied aspects of the problems of nutrition and food digestion, the theory of adequate nutrition and trophology [2–5].

The scientist Lipatov N. N. also contributed to the development of the trophological approach. Lipatov N. N. was the creator of a scientific school that considers the problems of improving the quality of food products as objects of a single exotrophic chain of their production, consumption and digestion of the food nutrients by the human body [6–9].

In scientific works [10–12], a systematic analysis was run. It resulted to defining the main links (operations) of the trophological chain of meat products from the field to the consumer. Through the ongoing collection and analysis of data on the state of raw materials and ready-to-consume food products, their traceability shall be ensured. The traceability is possible via the introduction of a unified information and applying the analytical computer system to identify potentially dangerous or harmful conditions during production and circulation of raw materials and food products; via monitoring the composition and quality of raw materials in their resource zones, as well as monitoring of food products at all stages of its production till their sale to the consumer. The monitoring is especially important when creating functional and specialized food products, since it is necessary to trace the accumulation and preservation of both nutritional elements and xenobiotics.

For formation of this science it is necessary to develop the issue of nutrition. With the help of trophology, it's possible to overcome many difficulties that arise due to different approaches, non-congruence of estimates and experimental methods used in different sciences which study the trophological processes [4,5].

Trophology covers a range of areas: cell trophism and tissue trophism, gastroenterology, nutritional science, dietetics, food production and food turnover. Immunology, microbiology, ecology, assimilatory aspects of almost all biological and medical sciences, as well as many chemical and technological sciences, and certain scientific issues of

agriculture are also closely related to trophology. Trophology combines many links of a single assimilatory chain, artificially broken and divided between different fields of knowledge [4,5,13–17].

Trophology, to a certain extent, is already able to answer the question of what human food should be, taking into account the features of trophic processes in a body that were formed by evolution. Trophological analysis creates more reliable criteria for the formation of optimal agricultural and industrial food technologies. It should be noted that any theory of nutrition is necessarily an important part of trophology [5]. The purpose of the article is to systematize the main concepts of nutrition theories using a trophological approach to substantiate new solutions to issues and challenges related to improvement of nutrition.

In general the evolution of views on the principles of nutrition is presented below in the form of a diagram (Figure 1) [5,18,19].

Basic concepts of nutrition theories

The very first theory of nutrition arose far back in antiquity and was associated with the names of Aristotle and Galen. According to the antique theory, the body is nourished by blood, which is continuously formed from the consumed food substances as a result of some kind of fermentation-type process. In the liver, the blood is purified and then used to nourish organs and tissues. Thus, using our modern terminology, digestion was originally viewed as the process of transforming nutrients into other substances that serve as a source of energy for body and components for tissue building. On this basis, numerous therapeutic diets were created, thus providing an easier conversion of nutrients into the blood [4,5].

The concept of rational nutrition was formulated in 1930 by Professor M. N. Shaternikov in the following form: "In the dynamics of life processes the dominant role belongs to the exchange of substances and forces between the human organism and the external environment. That is the nutrition processes in the broad sense of the word. Growth, development, working capacity and even the very existence of a human being and animals is dramatically dependent on the sufficiency and rationality of nutrition. In other words, the theoretical basis for the development of nutritional standards should be the study of the state of metabolism in the body, depending on the quantity and quality of nutrients consumed by a person [4, 5].

The concept of a balanced diet was set forth in 1964 by academician A. A. Pokrovsky. It is based on six basic postulates as follows (Figure 2) [5,20].

The theory of balanced nutrition enabled to scientifically substantiate the norms of nutrient intake, as well as to overcome many nutritional defects and diseases associated with a lack of vitamins, lack or shortage of essential amino acids, fatty acids, and trace elements. On its basis, various food rations have been created for all groups of the population, taking into consideration the level of their physical activity, environmental climate and other living conditions. All industrial, agro technical and medical measures are based on this theory, which come down to the fact that the improvement of the properties of food products can be achieved by extracting nutrients against the background of a decrease in ballast substances [4,5,20].

However, the balanced approach and the resulting idea of refined, artificially enhanced, ballast-free food also brought significant harm to health. Researchers began to record a surge of diseases — atherosclerosis, diabetes,

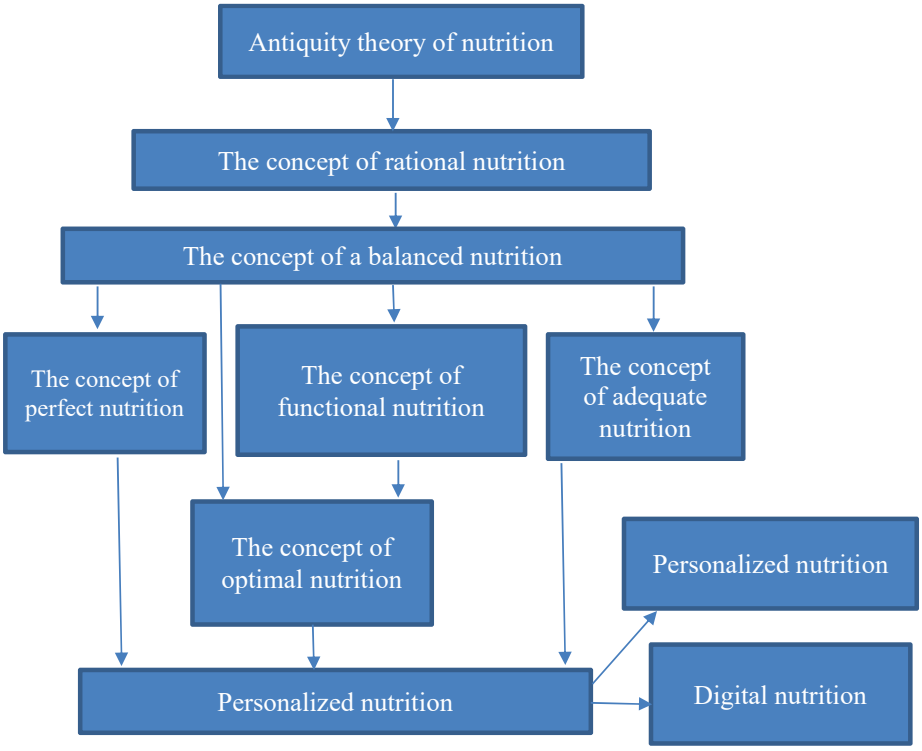

Figure 1. The evolution of views on human nutrition

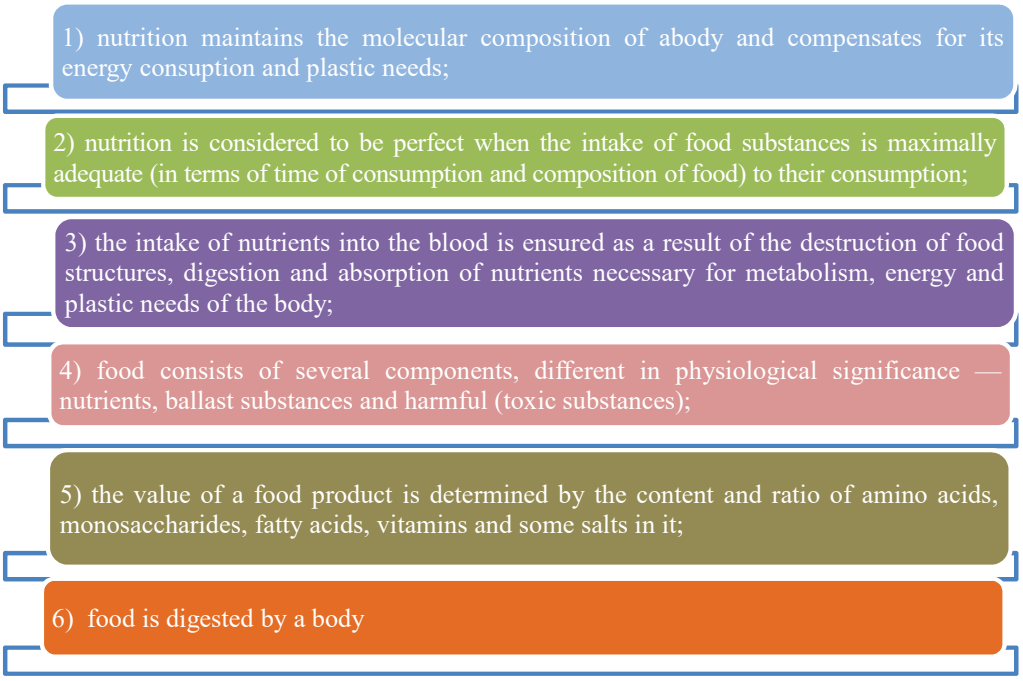

Figure 2. The main postulates of a balanced diet concept

osteochondrosis, osteoarthritis, etc. The production of refined, highly-purified food products turned into emerging of gastrointestinal tract diseases. The dietary regime happened to be no less important. One or two meals a day entailed not only a partial loss of food due to the difficulty of digesting a large amount of food per one intake, but also contributed to emerging of dramatically profound metabolic disorders [4,5,20].

Thus, the main drawback of this theory of nutrition is ignoring the role of dietary fiber and other factors that are not related to nutrients. The theory of balanced nutrition has been re-evaluated. The crisis of this theory stimulated a new scientific research in the field of physiology of digestion, biochemistry of food and microbiology [4,5,20]. All this led to the emergence of a new theory of adequate nutrition. It included every valuable element from the theory of balanced nutrition, but new provisions also appeared [4,5].

In the 80s of the 20th century the Russian physiologist academician A. M. Ugolev formulated the theory of adequate nutrition, which is actually a development of the theory of balanced nutrition, taking into account the latest data on the role of dietary fiber and intestinal microflora in physiology of nutrition [4,5]. The concept of adequate nutrition is based on six basic postulates as follows (Figure 3):

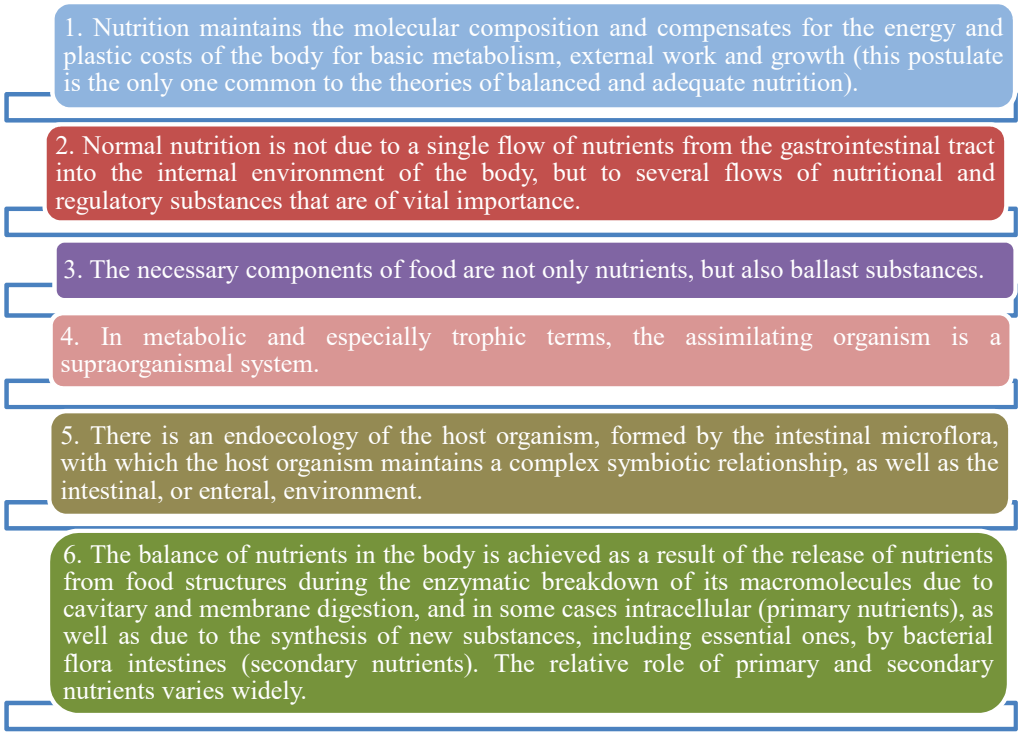

Figure 3. The main postulates of the theory of adequate nutrition

The concept of perfect nutrition is theoretically based on the apparent observance of the laws of nutrition, and in a generalized form it was proposed in 1991 by academician A. M. Ugolev [4]. The main postulate of this concept is as follows: nutrition is primarily a process of maintaining and balancing the molecular composition of a body, i. e. the process of compensating of losses that occur in the body. This concept served as the basis for development of the so-called elemental nutrition, which expediency was not confirmed during the tests [5].

The concept of optimal nutrition is a derivative of the concept of balanced nutrition. This concept converts the recommended norms for energy consumption and nutrient requirements from group values to individual values [5].

Thus, according to the provisions of previous concepts, food was considered mainly as a source of energy and nutrients. Using the deep study of the chemical composition of food raw materials and ready food products and the identification of correlations between the content of individual micronutrients and biologically active substances, as well as the state of public health, a new view of food was formulated as a means of preventing and curing certain diseases.

The concept of functional (healthy, positive) nutrition was first formulated in the early 1980s in Japan [21]. The term "functional nutrition" implies the foods which in case of systematical consuming, benefit human health, increase its resistance to diseases, and can improve many physiological processes in the body, thus allowing a person to maintain an active lifestyle for a long time. Positive nutrition food contains ingredients that provide them with functional properties: dietary fiber, oligosaccharides, amino acids, peptides, polyunsaturated fatty acids, vitamins, antioxidants, minerals, bifid bacteria, and others elements [22,23].

Healthy food products are not medicines and cannot cure; but they help prevent diseases and aging of the body in the current environmental situation. The place of functional nutrition is defined by researchers as an average between the usual way of nutrition, when a person eats what he wants in order to satiate, and the therapeutic nutrition assigned for sick people [22, 24–27].

The basic idea behind perfect food and perfect nutrition is to achieve the best possible manifestation of all the capabilities of the body and its optimal functioning. However, this goal appears to be unrealistic. In fact, some types of food are favorable for high physical exertion, in the same cases where there are significant psychological stresses, a different diet is needed. Moreover, emotional background changes also require corresponding changes in the diet. The types of nutrition in hot and cold climates also differ significantly, and the differences in the nutrition of North and South peoples cannot be reduced down to economic factors only [28]. Finally, to increase life expectancy, low-calorie diets are recommended. At the same time, intensive work requires a sufficiently high level of nutrition. Thus, there are a number of patterns of adequate food and nutrition for different conditions. But none of them are completely perfect [5, 29–33].

First of all modern perfect nutrition is the nutrition of an individual that takes into consideration his/her age, type of build, major and side diseases. That is the personalized nutrition [5, 29, 30, 34–36].

Personalized nutrition is a scientific approach to the individual health of each person. In order to make a person's nutrition really correspond to his personal characteristics, it is necessary to constantly collect and process a large amount of information about his/her body, condition and habits. The study of personalized nutrition is engaged in the science of nutrition [34–37].

Nutrition in its most generalized form can be defined as a part of biology that studies human nutrition and human development, taking into account the conditions and the environment [37]. Nutrition is one of the intensively developing sciences of an integrative nature.

The integration of nutrition with engineering sciences, in particular with food technology, opens up the development of new modern digital methods and techniques for developing products with a specified chemical composition, specialized products, as well as the food for personalizing of diets [18,19].

Today the phenomenon of the emergence of a new scientific direction of "digital nutrition" is being considered, which direction provides for the digital transformation of data on the physiological needs of a person for food, biological substances and energy, as well as the chemical composition of basic foods. It became possible to create software for the development of personalized diets both for a healthy diet and for the prevention and treatment of alimentary-dependent diseases [18,19,38].

It should be noted that merely sufficient food production does not ensure the optimal level of human health. Conscious high culture of food is necessary. Moreover, it is necessary to provide more comprehensive culture, which should be called trophological. In addition to the culture of nutrition the food culture should include the culture of food production (including agriculture, ecology, industrial technology), food distribution and storage. Food culture is a consciously organized, possibly more optimal (adequate) satisfaction of nutritional needs based on achievements of trophology, humanity within the limits of economy and ecology [5,29,30].

The term "trophological culture" means the understanding and using the basic laws of metabolism and nutrition patterns in the daily life of each person and society as a whole. That can ensure the optimal functioning of a body, taking into consideration the actual conditions of life, climate, work, etc. The trophological culture of nutrition includes an understanding not only of the rules of food consumption, but also of all stages of work on food products in agriculture and the food industry (at food industry enterprises) and, of course, in trade. Trophological culture can only be based on the scientific approaches that allow not only justify the correct consumption of food, but also define food production, processing, storage and distribution. Food culture is part of trophology. This is true,

since without a certain level of food culture it is extremely difficult to solve a number of global problems, including the problem of defeating hunger and many diseases (atherosclerosis, cardiovascular diseases, certain malignant neoplasms, diabetes, gastrointestinal tract disorders, food allergies and many others), as well as the problem of struggling against aging of a body [4,5,29–31].

Food allergen management concept

One of the major nutritional problems of the modern world is food allergy, which affects approximately 3 to 10% of adults and 8% of children worldwide [39]. Food allergens affect the health and quality of life of people with hypersensitivity caused by some food components, and such allergens are considered to be serious threat to food safety [40]. To reduce the risk of adverse allergic reactions in food consumers it's necessary to put out certain food allergens from the diet [41,42]. However, the elimination diet like this won't be efficient if food manufacturers fail to inform their consumers reliably on the presence of allergens in food.

The concept of managing food allergens as a food safety threat emerged in the last decade of the 20th century and since then has expanded significantly. Food allergens management has been evolving along with increasing knowledge and understanding of this issue. Initially, little was known about key determinants of risk, such as sensitivity and speed of an allergic reaction in susceptible individuals in response to an allergen. There was virtually no information on the number of affected consumers, even for the most studied allergenic foods such as peanuts [43–47].

As you know, today there is no cure for allergies that guarantees a complete recovery. Until an effective treatment for food allergy becomes available, sensitive consumers should avoid food allergens to prevent an allergic reaction [48]. Successful prevention of consumption of allergenic substances by food allergenic people depends on availability of reliable information among the population about the content of allergens in certain food products. In a number of countries, regulations have been adopted that regulate the requirements for labeling food products containing allergens. Since more than 200 products have been shown to cause allergic reactions in sensitive individuals, regulators in many countries have acknowledged the need to develop labeling rules for food products containing priority allergens. The priority allergens are able to cause the most severe allergic reactions that can lead to significant harm to health and even to death (Figure 3).

In the Russian Federation, the requirements for labeling of food products containing allergenic ingredients are set forth in TR TS022/2011 "Food products in part of their labeling"[1].

In 2020 TC226 "Meat and meat food products" developed the first edition of the draft national standard "Meat industry: procedure for developing an allergen management program", which establishes the procedure for developing a program of food allergen management, provides the general requirements for arrangement and running the allergen management process, describes the method of recording the results of this activity, and method of their analysis at the enterprises of the meat processing industry (Figure 4).

[1] Technical regulations of the Customs Union TR CU022/2011 "Food products in terms of its labeling" (Adopted by The decision of the Council of the Eurasian economic Commission of December 9, 2011 № 881). Moscow, 2011. Retrieved from https://docs.cntd.ru/document/902320347. Accessed May 24, 2021 (In Russian)

Figure 4. Documents defining the requirements for allergens management, applicable in the Russian Federation and the EU

Nutrition Development Legislation

Today, the practical implementation of the trophological approach in the concepts and theories of nutrition is recorded in legislative documents. The strategy for the formation of a healthy lifestyle of the population, the prevention and control of non-communicable diseases for the period up to 2025[2], sets out the goals, objectives and principles of the state policy of the Russian Federation in the sphere of public health. This state policy is aimed at ensuring the national interests and implementing national long term strategic priorities in the sphere of promoting a healthy lifestyle and prevention of spread of non-communicable diseases among the population of the Russian Federation. The legal basis of the strategy is set forth in a range of documents, one of which is the Decree of the Government of the Russian Federation dated from October 25, 2010 No. 1873-r, which defines the foundations of the state policy of the Russian Federation in the sphere of healthy nutrition for the population (Figure 5).

[2] Strategy for the formation of a healthy lifestyle of the population, prevention and control of non-communicable diseases for the period up to 2025. (Order of the Ministry of Health of Russia No. 8 dated February 15, 2020). Retrieved from https://docs.cntd.ru/document/564215449 Accessed September 19, 2022. (In Russian).

Conclusion

According to the requirements of the state policy of the Russian Federation in the sphere of healthy nutrition for the population, the modern scientific approaches to the development of nutrition and food products designing are based on the fundamental principles of rational nutrition, reflected in the basic concepts of nutrition theories.

Taking into consideration all of the above specified, it should be noted that each theory of nutrition makes an important part of trophology and significantly affects a number of criteria for this science.

Trophology provides an opportunity to solve applied problems, which include the issues of perfect food and optimal nutrition in real terms; include development of new criteria for technologies of food production and storage; deal with protection and conservation of natural trophic ecosystems based on trophological analysis; ensure harmonization of natural and industrial food technologies.

The trophological approach in personalized nutrition is a new scientific direction to ensure the normal development of a human body and its vital activity. Individual nutrition is a necessity of today, which sets the task for food industry enterprises to create the food products, food complexes and components that will satisfy not only the basic needs of an individual organism, but will also contribute to the regulation of metabolism in order to preserve and develop the potential of a human body.

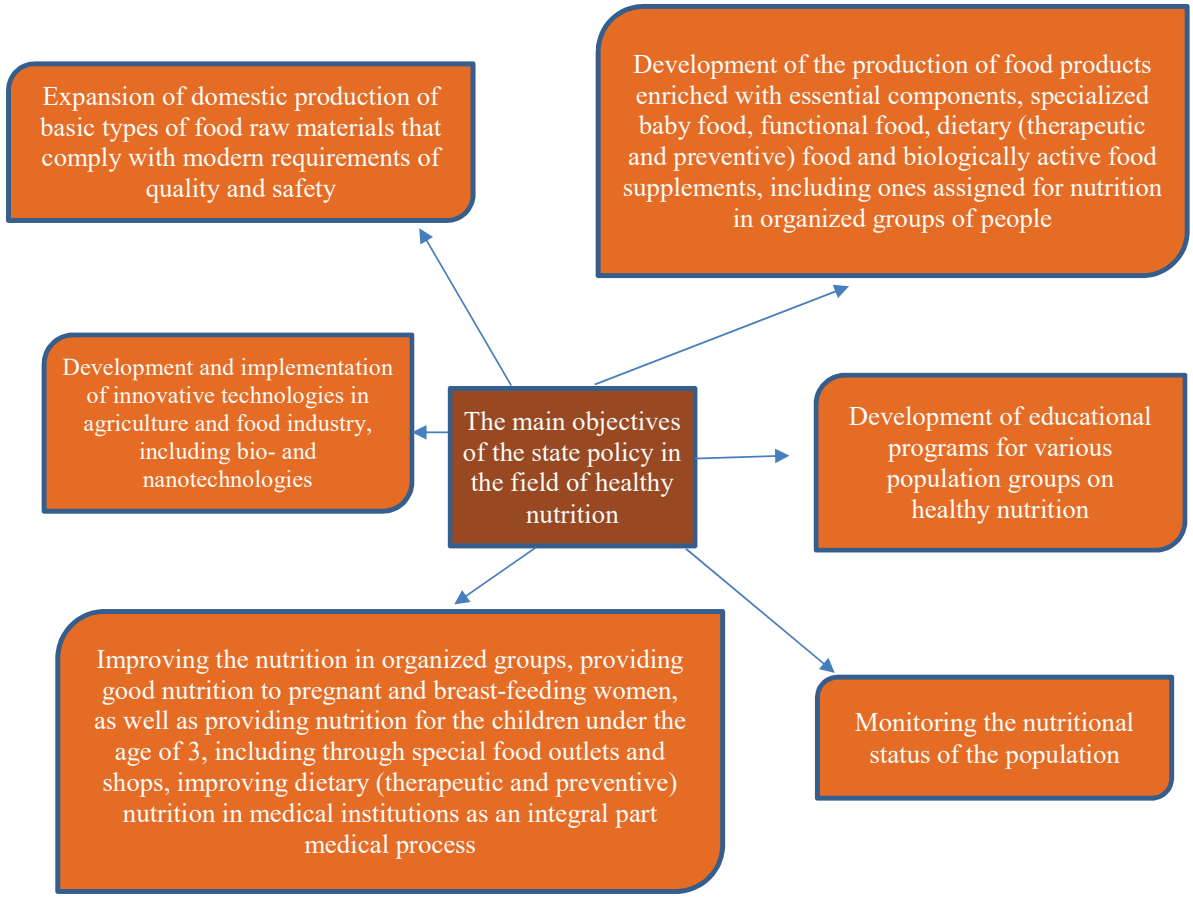

FIgure 5. The main objectives of the state policy in the sphere of healthy nutrition

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CONTRIBUTION OF SOME IMMUNOLOGICAL AND METABOLIC FACTORS TO FORMATION OF PIGLETS' POST-VACCINATION IMMUNITY

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Abstract
The role and responsibility of natural resistance factors, protein and lipid metabolism in the formation of piglets post-vaccination immunity against circovirus is researched. Blood was taken for tests before and on the 15th, 40th and 70th day after the vaccination. The sampled blood was analyzed to determine immunological and biochemical parameters. It was revealed that before vaccination, 31.46% of the studied samples have a positive reaction in ELISA; their number increases to 67.80–71.16% on the 40th and 70th days after vaccination.In the blood of piglets, especially on the 40th and 70th day after the vaccination, the total count of leukocytes, monocytes and lymphocytes increases by 1.21; 2.28 times and 1.48 times, but neutrophils reduced by 1.74 times along with the phagocytic properties activation. The anabolic directivity of protein metabolism is defined by the synthesis of globulin proteins. At the same time albumin-synthesizing activity in a liver decreased and "cytolysis reaction" of hepatocytes was detected. In the lipid profile of piglets' blood, the content of LDL-cholesterol increased by 1.44 times, while that of triglycerides decreased by 2.64 times. X-ray spectral analysis revealed the correlation between the formation of post-vaccination immunity and two factors: the factor of the principal component (PC) 1, which is predominantly associated with indicators of natural resistance, and PC2, which is associated with metabolism indicators. The research results show that in order to increase the efficiency of formation of post-vaccination immunity in piglets, it is necessary to combine vaccination with hepatoprotective drugs.

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Introduction

Vaccination is the main way of struggle against the most infectious diseases, including porcine circovirus of type 2 (PCV2), which is possible due to the availability of specific vaccines [1]. The vaccine, after being introduced into the body of animals, stimulates the immune system due to the "launch" of the humoral and cell-mediated immune response. In this case the humoral immune response is provided not only by the synthesis of antibodies, which neutralize the virus, but also is stipulated by antibodies that stimulate the complement system and antibody-dependent cellular cytotoxicity. Cellular immunity factors activate cytotoxic T-cells and macrophages [2].

However, vaccination does not always provide a sufficient level of "herd immunity" necessary to protect animals in large industrial farms due to the quick "moving" of the animals during the technological cycle, as well as due to the low immunological response of pigs, caused by flaws and drawbacks in technology of their managing and feeding, but most importantly — by the circulation of viruses in industrial premises as the viruses feature high resistance in the environment.

Therefore, despite regular vaccination, the infectious agent still circulates in the farm facilities, thus reducing the immune response of animals. At the same time, various respiratory co-infection very often joins the virus and initiates the symptoms complex, known as "the disease associated with porcine circovirus" [3,4]. Piglets are most sensitive group of animals to this complex of porcine respiratory diseases during the period of growing up till fattening period [4]. The joint disease provides a negative impact on the rate of growth and development of the animals, rate of feed digestion; it increases the rejection rate of animals, leading to economic losses of the farms [5,6,7,8]. So, the research of the patterns of formation of post-vaccination immunity in piglets is one of the urgent and relevant issues in pig breeding.

Most researches on this issue represent the results of testing the efficiency of vaccines against the virus [4,9,10]. Meanwhile, the number of researches that reveal the mechanisms of formation of post-vaccination immunity against

PCV2 is quite insignificant. In particular, it was found that in the body of vaccinated pigs, the humoral and cellular immune response factors feature the greatest variability. At the same time, cytotoxic T-cells, T-helper cells of the 1st (Th1) and 17th type (Th17) are most strongly activated, reducing the viral load on the body of vaccinated pigs [11]. It was noted in studies [11,12] that vaccination is a stress factor for the animal's body. Therefore, during the post-vaccination period the changes, typical for alert stage, develop in the body of animals. These changes are accompanied by fluctuations in proteins levels during the acute phase of inflammation, variations of glucocorticoids content in the blood [12,13], immunosuppression [14], changes in antioxidant activity and metabolism of lipids and proteins [15], thus affecting the "quality" of the forming immunity. At the same time, the immune memory is modulated by the influence of a large number of factors, which diversely contribute to maintaining the titer of specific antibodies [16,17]. Thus, according to the research [18], the efficiency of formation of post-vaccination immunity is associated with such a parameter as the growth rate of piglets, which correlates with the degree of lung damage. As is known, the intensity of growth processes is interrelated with the metabolic status of the body, which provides the cells of the body with macronutrients and energy [19,20]. Therefore it is possible to form an "adequate" immune response after vaccination in conditions of maintaining the activity and usual metabolic processes in the growing body of piglets.

In addition, it has been established that due to the "antigenic drifting of circulating viruses", most vaccines need constant renewal. Only in this case they provide sufficient protection of the animal organism after its vaccination [2]. However, renovating a vaccine is quite a labor-consuming process; it cannot keep up with the rate of emergence of circulating strains of viruses, especially in the specific conditions of a region and the certain enterprise. Therefore, vaccines against most animal respiratory diseases are remade very rarely, which does not provide complete protection against the current type of infection [21]. For these reasons, it is important to expand the body's immune response to vaccination, and for this it is necessary to study the patterns of formation of the post-vaccination immunity, including not only immunological, but also metabolic parameters. This will enable us to form a "vaccination strategy" that maximizes the efficiency of post-vaccination immunity.

The purpose of this research was to assess the contribution of natural resistance factors, parameters of protein and lipid metabolism in the body of piglets in the formation of post-vaccination immunity against circovirus.

Materials and Methods

Ethical statement

This study was planned and run in accordance with the recommendations of the bioethics committee of the South Ural State Agrarian University (Chelyabinsk region, Russia), and was also agreed upon with the veterinary service of the agricultural company.

Animals, Study Design

The on-site part of the research was run in 2022 at the agricultural company "Ariant" LLC (Chelyabinsk region). An experimental group (n = 3618) of suckling piglets was taken at the one of the pig farms of the agricultural company. This pig farm specializes in growing of commercial young pigs, which were vaccinated with the Ingelvak CircoFLEX vaccine (Germany) against circovirus on the 21st day of life in accordance with the vaccine manufacturer's recommendations. At the age of 23–24 days, the piglets were taken away from their breeding sow and transferred to the nursery. There they were kept in group cages of 20–25 heads each. The cages were equipped with freely accessible automatic feeders and waterthroughs. The technology of feeding and managing the animals complied with recommendations of *Genesis*. The nutrients of regional origin were used for the compound feed production.

Data collection

To conduct immunological and biochemical studies in 5% of the animals of the experimental group, blood samples were randomly taken from the *vena cava cranialis* with the help of VACUETTE vacuum-smart tubes (9ml, 16x100mm), Zhejiang Gongdong Medical Technology Co. Ltd. (9 ml,16x100mm), with the double ended blood sampling needles 14Gx3–1/4 (2.1x80mm).

Whole blood was used to determine: 1) the number of leukocytes, lymphocytes and monocytes on a Mindray BC2800 Vet hematological analyzer (China) with species-specific settings for pigs; 2) phagocytic activity of neutrophilic granulocytes. To obtain leukocyte suspension, blood samples were incubated at 37 °C at an angle of 45° for 40 min, this way initiating spontaneous sedimentation of erythrocytes. As a microbial test object, a suspension of a day-aged culture of *Escherichia coli* was used (1 billion cells in 1 ml of the suspension). Microbial suspension and leukocyte suspensions were mixed in strips at a ratio of 1:1, and incubated in a thermoshaker (Elmy, Latvia) at 37 °C for 40 minutes and centrifuged. The smears were prepared from the precipitate on defatted glass slides and stained according to the method of Romanovsky-Giemsa. The result of phagocytosis was assessed on 100 cells with an immersion system of a light microscope and a magnification of 10x90. Phagocytic activity of neutrophils (PAN,%) was calculated as a percentage of phagocytic cells in reference to their total number (100 cells); phagocytic number (PN, c. u.) was calculated as an average number of phagocytosing microbes captured by one active neutrophilic granulocyte; phagocytic index (PI,%), as a percentage of the average number of phagocytosed microbes in reference to the total number of neutrophilic granulocytes (100 cells).

Blood serum obtained after blood clot sedimentation was used: 1) to determine specific antibodies to circovirus

using CIRCOSerotest kits (LLC Vetbiokhim, Russia) by immunoenzyme method. The analysis was run in accordance with the instructions for the test kit provided by the manufacturer. The result was expressed as a percentage. If the ratio of conjugate binding (Rcb,%) with blood serum antibodies exceeded 20%, then it was considered positive; 2) to determine biochemical parameters (total protein, albumin (A), urea, ALT and AST activity) using a Super Z biochemical analyzer (China). Additionally, the calculation method was used to determine the concentration of globulins (G = Total protein (g/l) — albumins (g/l)), ration of proteins (albumins (A, g/l) / globulins (G, g/l)), ratio between total protein (g/l) and urea (mmol/l).

Statistical analysis

Statistical analysis was run by the software Statistica 6.0. The significance of the differences was set at $p < 0.05$. All laboratory data were expressed as mean (X) and standard error of the mean (Sx). The principal component analysis (PCA) was used to determine the blood parameters, most significantly associated with the titer of antibodies to virus antigens [22]. The correlation of those parameters was judged by the values of the correlation indices determined by Spearman method between the indicator and its load on the principal component (PC). The number of principal components was determined by the graphical method of Cattell's scree [23].

Results and discussion

Vaccination against PCV-2 reduces the viral load on the body of piglets and prevents specific damage to lymphoid tissue due to production of specific antibodies [24]. The formation of an immune response in the organism of animals was tested by the seropositivity of the piglets, determined by ELISA kit (Table 1).

Table 1. Results of detection of antibodies (IgG) to PCV-2 by enzyme-linked immunosorbent assay

Age of the piglets	After vaccination, days	Number of piglets with a positive ELISA test, %	Rcb, %
19 days	Before vaccination (background)	31.46	39.34 ± 0.64
35 days	15 days	33.63	41.56 ± 1.29
60 days	40 days	67.80	78.54 ± 1.85
90 days	70 days	71.16	24.35 ± 0.68

The results of our research showed that 31.46% of suckling piglets had a positive ELISA test before vaccination. The count of IgG antibodies, estimated by Rcb, was equal to 39.34 ± 0.64% (Table 1).

In the post-vaccination period, the number of animals in the experimental group with a positive ELISA test increased, and in the period 40–70 days after vaccination, it fluctuated in the range of 67.80–71.16% of their total number of studies performed.

However, the dynamics of detection of positive ELISA samples did not correspond to the results of quantitative analysis.

So, on the 15th day after vaccination the Rcb practically did not differ from the background values; its peak was observed on the 40th day, exceeding the background value by 2.00 times (78.54 ± 1.85%). By the end of the rearing period, the Rcb decreased to a borderline value, although the number of piglets with a positive ELISA test remained practically unchanged.

To define the responsibility of some blood parameters in the formation of post-vaccination immunity, we researched their dynamics during the growing period, as this period is the most "critical" in terms of animals' rejection in the pig-breeding complex environment.

It is possible to judge indirectly on the status of cell-mediated immune responses in the body of piglets in the post-vaccination period by the variability of indicators of the natural resistance [25]. Thus, the total number of leukocytes in the blood of animals, which characterizes the immune potential of the body, increased systematically in the post-vaccination period, reaching its maximum in piglets of 60- and 90-days old (Table 2). At the same time, the main changes in their group were observed on the 40th day and 70th day after vaccination. At the control point — "the 40th day after vaccination" — the changes were most profound in comparison with the background; they manifested themselves in the form of a sharp increase of lymphocytes number (by 1.48 times, $p < 0.05$) and neutrophils decrease (by 1.74 times, $p < 0.05$), and on the 70th day we observed an increase in the number of lymphocytes (by 1.17 times, $p < 0.05$), monocytes (by 2.28 times, $p < 0.05$) and neutrophils (by 1.25 times $p < 0.05$). < 0.05).

The phagocytic properties of neutrophils weren't correlated with changes in their number in the blood of piglets. The absorption function of cells, assessed by the phagocytic activity of neutrophils, phagocytic number and phagocytic index, was profound on the 40th and 70th days after vaccination, exceeding the values "before vaccination" by 13.11–20.12; 67.51–83.24 and 31.22–39.29%, respectively (Table 2).

The performance of the vaccine immunogenic properties was also represented in the metabolic status of the growing piglets. In our research we assessed the protein and lipid metabolism, most of the indicators of which in the post-vaccination period were varying within the normal range. Thus there was a trend towards building-up the total protein concentration in the piglets' blood by 17.52% (Table 2) due to an increase of globulins share (by 33.99%) and a decrease of albumins share (by 9.92%). This way the ration of proteins (A/G) decreased by 33.33% ($p < 0.05$). The positive age-related dynamics of total protein value was caused by systematic decrease of urea level in the blood by 36.39%. This fact proves retention of protein nitrogen in the body of piglets and shows an increase in ratio of total protein/urea by 1.84 times ($p < 0.05$). However, AlAT

Table 2. Immuno-metabolic parameters of piglets' blood (X ± Sx)

Parameter	Age of the piglets / time period after vaccination, days			
	19 / before vaccination	35/15	60 / 40	90 / 70
Indicators of the natural resistance				
Leukocytes, 10^9/l	19.31 ± 0.87	21.31 ± 0.98	23.19 ± 0.77*	23.38 ± 0.46*
Lymphocytes, 10^9/l	12.22 ± 0.61	13.81 ± 0.94	18.15 ± 0.37*	14.34 ± 0.60*
Monocytes, 10^9/l	0.66 ± 0.02	0.45 ± 0.11*	0.69 ± 0.07	1.51 ± 0.11*
Neutrophils, 10^9/l	6.01 ± 0.37	6.44 ± 0.56	3.75 ± 0.55*	7.53 ± 0.24*
PAN (phagocytic activity of neutrophils), %	40.04 ± 0.90	42.81 ± 0.79	48.10 ± 0.42*	45.29 ± 0.31*
PN (phagocytic number), c. u.	1.97 ± 0.12	2.21 ± 0.25	3.61 ± 0.12*	3.30 ± 0.22*
PI (phagocytic index), %	2.85 ± 0.17	3.01 ± 0.25	3.97 ± 0.32*	3.74 ± 0.26*
Metabolic indicators				
Total protein, g/l	64.50 ± 1.50	65.30 ± 1.99	69.40 ± 0.70	75.80 ± 0.49*
Albumins (A), g/l	24.20 ± 1.30	22.70 ± 1.01	22.40 ± 1.10	21.80 ± 1.80
Globulins (G), g/l	40.30 ± 0.54	42.60 ± 0.49	47.00 ± 0.32*	54.00 ± 0.61*
A/G, c. u.	0.60 ± 0.03	0.53 ± 0.06	0.48 ± 0.05*	0.40 ± 0.03*
Urea, mmol/l	5.66 ± 0.78	4.67 ± 0.34	3.96 ± 0.23*	3.60 ± 0.21*
Total protein/urea, c. u.	11.39 ± 1.20	13.98 ± 0.36*	17.52 ± 0.56*	21.06 ± 1.10*
AsAT, mmol/l · h	1.57 ± 0.08	1.44 ± 0.10	1.29 ± 0.11	0.66 ± 0.13
AlAT, mmol/l · h	1.53 ± 0.12	2.19 ± 0.15*	2.11 ± 0.11*	1.63 ± 0.15
Total lipids, g/l	2.93 ± 0.15	2.67 ± 0.12	2.27 ± 0.07*	2.42 ± 0.16*
Cholesterol, mmol/l	2.61 ± 0.14	2.37 ± 0.13	2.41 ± 0.11	2.87 ± 0.17
LDL-cholesterol, mmol/l	1.10 ± 0.10	1.26 ± 0.08	1.49 ± 0.07*	1.58 ± 0.14*
Triglycerides, mmol/l	0.37 ± 0.04	0.31 ± 0.03	0.34 ± 0.03	0.14 ± 0.01**

Note: * — $p < 0.05$ to the "before vaccination (background)" value.

activity increased by 1.36 times ($p < 0.05$), exceeding the limits of the norm, and AsAT, on the contrary, decreased by 2.37 times ($p < 0.05$), but corresponded to its limits. This means that the body of piglets in the post-vaccination period demonstrated an imbalance in the synthesis of proteins and the directivity of amino acids participation in metabolic processes.

More significant changes were noted in lipid metabolism (Table 2): the concentration of total lipids and triglycerides in the piglets' blood decreased by 1.29 and 2.64 times ($p < 0.05$), but the level of total cholesterol and LDL cholesterol increased by 1.21 and 1.43 times ($p < 0.05$).

To determine the parameters of the sampled blood which are most significantly associated with the process of immunity formation in the post-vaccination period, we used the principal component analysis (PCA) [26]. While "compressing" the identified multidimensional correlations using the method of Cattell [23], two most significant factors were determined: the main component 1 (PC-1) and the main component 2 (PC-2), which components determine more than 70% of variance of features in the statistical matrix. Further, the identified correlations were ranked in the context of the main components according to the strength of the relationship during the post-vaccination period (Table 3).

At the same time, GC-1 had a predominant associativity with indicators of natural resistance, and GC-2 — is associated with metabolic indicators, which content in the blood is directly or indirectly related to liver functions [19]. Consequently, the process of formation of post-vaccination immunity in the body of piglets is determined not only by changes in its immunological status, but by their metabolic status too.

Table 3. Associativity of the main components with blood parameters

Parameters	Age of the piglets / time period after vaccination, days					
	35/15		60 / 40		90 / 70	
	PC1	PC2	PC1	PC2	PC1	PC2
Indicators of natural resistance						
Leukocytes, 10^9/l	++	+	++	+	+++	+
Lymphocytes, 10^9/l	+++	+	+++	++	+++	++
Monocytes, 10^9/l	+++	+	++	+	+++	+
Neutrophils, 10^9/l	+++	+	+++	+	+++	++
PAN (phagocytic activity of neutrophils), %	++	+	++	+	++	+
PN (phagocytic number), c. u.	++	+	++	+	++	+
PI (phagocytic index), %	++	+	++	+	++	+
Metabolic indicators						
Total protein, g/l	+	++	+	++	+	
Albumins (A), g/l	+	+++	+	+++	+	+++
Globulins (G), g/l	++	++	++	+++	+++	+++
A/G, c. u.	+	++	++	+++	+	+++
Urea, mmol/l	+	+++	+	+++	+	+++
Total protein/urea, c. u.	+	++	+	+++	+	++
AsAT, mmol/l · h	++	+++	+	+++	++	+++
AlAT, mmol/l · h	+	+++	+	+++	++	+++
Total lipids, g/l	+	++	+	++	+	++
Cholesterol, mmol/l	+	++	++	+++	+	+++
LDL-cholesterol, mmol/l	+	+++	+	+++	+	+++
Triglycerides, mmol/l	+	+++	+	++	+	++

Note: the significance of correlations intensity of between the parameters: "+" — r=0.3–0.5; "++" — r=0.5–0.7; "+++" — r=0.7 and more

The global trade of breeding pigs, semen, and pork products has contributed to the worldwide extension of PCV-2 [5]. In order to prevent the disease the animals undergo the vaccination. For vaccination various commercial vaccines are used. In our research we used the vaccine Ingelvak CircoFLEX (Germany), which contributed to the emergence of antibodies in the body of animals. These antibodies bind and neutralize the virus and prevent its further spread [24]. We found that 31.46% of suckling piglets had specific antibodies to PCV-2 before their vaccination as a result of their passive immunization under conditions of a controlled subclinical course of infection [27]. The presence of the antibodies in the first 15 days after vaccination inhibited the formation of a humoral immune response. This inhibition was caused by their influence on the cell-mediated and antibody-mediated mechanisms of immunity in the body of piglets [28]. Studies [29] also confirmed the low PCR-positivity of piglets in the early stages of the post-vaccination period. However, on the 40th day after vaccination, the ration of conjugate binding by antibodies increased dramatically from 39.34 ± 0.64 up to 78.54 ± 1.85%, although the number of samples with a positive ELISA sample was 67.80% of the total number of studies performed. Consequently, passively acquired antibodies influenced the formation of a post-vaccination immune response in piglets [27]. Therefore, the number of positive samples on the 70th day after vaccination practically did not change (71.16%), and the value of Rcb decreased to 24.35 ± 0.68%, that is, almost to the threshold value of a positive test in the ELISA method used.

In general, it can be stated that the number of positive samples in the post-vaccination period systematically increased as a result of the development of specific antibodies to PCV2, but the intensity of post-vaccination immunity formation was related to presence of antibodies against the virus in the body of animals before immunization.

Post-vaccination variability of leukocyte cells in the body of piglets was determined by their participation in the processes of opsonization, transfer and phagocytosis of antigenic particles [30]. Thus, the increase in the total count of leukocytes proved the increase of the body reactivity. The redistribution of cells in the leukocyte pool, especially in 40 days after vaccination, indicated the activation of leukocytes proliferation processes and their release from the organs of leukopoiesis into the bloodstream [31]. At the same time, the variability of lymphocytes corresponded to fluctuations of monocytes, which was consistent with coordination of the mechanisms for formation of their pool in the piglets' blood after vaccination [32]. Meanwhile the functions of lymphocytes and monocytes in production of neutralizing antibodies were reflected both in the count of circulating neutrophilic granulocytes and their phagocytability.

Currently there are a row of researches that have revealed the effect of vaccination on the metabolic status of the liver [33], which is related to the hepatodepressive effect of the vaccine. Meanwhile, the antigenic components of the vaccine and the products of their seroconversion are found not only in the organs of immunogenesis, but are also found in the liver [34] as the central metabolic organ [19,20].

Blood proteins play an important role in the homeostatic balance of the body. In the post-vaccination period the count of total protein in the piglets' blood increases due to globulin fractions, which contain significant share of gamma globulins, involved in the formation of the body's immune response [19]. However, under the conditions of the anabolic directivity of protein metabolism in the blood, the count of albumins, synthesized only in liver cells and being a marker of its protein-synthesizing function, decreased [35]. At the same time, AlAT activity increased as a result of intensification of hepatocytes cytolysis reaction [20]. Consequently, in the post-vaccination period metabolic changes were observed in the liver. Those changes are probably associated with lymphocyte-mediated immune responses of cytolysis [36], or vaccine-induced or mediated immune response of hepatocytes to administration of antigen [37].

During the post-vaccination period the blood lipid profile of piglets also changed. The peak of changes was found in level of LDL-cholesterol and triglycerides. It determined the risk of cardiovascular changes in the body of an animal [38], as well as it testifies on mutation in directivity of lipid metabolism in liver cells.

Based on the fact that the body of a piglet is a multi-parameter system [39], we tried to minimize the amount of initial laboratory information by excluding data that are not directly related to the formation of immunity after vaccination. Using the PCA method, we determined two priority factors: the principal component 1 (PC1) and the principal component 2 (PC2), in the context of which the associativity of blood parameters was determined. Thus, in the post-vaccination period in the context of PC1, the indicators of natural resistance turned out to be interrelated and mutually correlated variables. Their variability was directly associated with the formation of the animals' seropositivity [28]. As far as PC2 is concerned, here, on the contrary, associativity with metabolic parameters was revealed, which parameters should be attributed to "indirect" blood parameters, reflecting both the metabolic functions of the liver and the adaptive potential of the animal's organism [19]. Consequently, the efficiency of immunological reactions is not only associated with factors of cellular and humoral immunity, but also with factors that determine the provision of immune processes with macronutrients.

Conclusion

The results of the work showed that before vaccination, 31.46% of blood samples of piglets have a positive reaction in ELISA. After vaccination, their number increases to 67.80–71.16%, although the quantitative expression of the conjugate binding coefficient is 78.54 and 24.35%, respectively. In the post-vaccination period, the indicators of the body's natural resistance change in accordance with its role in immunological reactions and

manifest themselves most intensively on the 40th and 70th days after the vaccination. Meanwhile, the total count of leukocytes in the animals' blood increases by 1.21 times ($p < 0.05$), of monocytes by 2.28 times ($p < 0.05$), lymphocytes by 1.48 times ($p < 0.05$), especially on the 40th day after the vaccination, but the count of neutrophils decreases by 1.74 times ($p < 0.05$), although phagocytic properties increase (phagocytic activity of neutrophils, phagocytic count and phagocytic index by 13.11–20.12; 67.51–83.24 and 31.22–39.29%, respectively). In the post-vaccination period the protein metabolism has an anabolic directivity due to synthesis of globulin proteins. At the same time, there are the signs of inhibition of albumin-synthesizing activity in liver cells (albumin in the blood decreases by 9.92%) and their "cytolytic reaction" (AlAT activity increases by 1.36 times ($p < 0.05$) and exceeds the normal range). In the blood lipidogram of the piglets, the amount of LDL-cholesterol increases by 1.44 times ($p < 0.05$) and level of triglycerides decreases by 2.64 times ($p < 0.05$), thus determining the probability of developing cardiovascular damage. The method of X-ray spectral analysis revealed the associativity of post-vaccination immunity formation with two factors: PC1 had a predominant association with indicators of natural resistance, and PC2 was associated with metabolic indicators.

The obtained results show that in order to increase the efficiency of the formation of post-vaccination immunity in the body of piglets, it is necessary to combine vaccination with hepatoprotective drugs. However, this assumption still requires experimental verification.

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All authors made an equal contribution to the work.

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ASPECTS OF LIFE CYCLE IN ITS PROJECTION ONTO PRODUCTION OF MEAT AND MEAT-CONTAINING CANNED FOOD: SYSTEMATIC REVIEW

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Keywords: *meat and meat-containing canned food, life cycle model, life cycle terminology, retrospective, perspective*

Abstract

While choosing one or another product from a wide variety on the market, we intuitively focus on the quality of the food product, we pay attention to its source, raw material and how this food is made. At the same time, the same questions are being asked by food manufacturers as they want to be sure of the quality and safety of purchased raw materials and ingredients. In both cases, decisions should be based on the consequences they could entail. It must be acknowledged that any failure in the field-to-shelf chain system may harm the consumers' health, as well as may lead to disruptions and losses in the food industry. Producers and consumers are increasingly concerned in the terms of life cycles. The life cycle is the most expressive and comprehensive approach to achieve the highest usefulness of the made decisions. The fact is that life cycle problems can be solved, and product life cycles can be managed, controlled and regulated. This is widely applied, for example, by the use of life cycle methodology in solving environmental problems highlighted in this article. However, in the meat processing industry the standards of the ISO 9000 series are not supported by this methodology. It was necessary to find and define the problem-exposed stages from the full life cycle of production of meat and meat-containing canned food within the system "from the field to the shop shelf". Those problem-exposed stages are responsible for safety and quality of canned food and responsible for maintaining the safety and quality of ready-to-eat food products, as the most relevant stages in the meat processing industry. Here the author proposes for consideration three stages of the life cycle of canned meat and meat-containing food, including its pre-production, production process and post-production. It is assumed that the impacts at certain limited stages of the canned food production cycle will be representative in terms of consequences of applied decisions.

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Introduction

The phrase "life cycle" is widely used in the natural sciences, in the humanities and social studies. However, it can be considered that the "life cycle" in relation to food products is not actually "life" one, since the food product does not belong to living organisms and is not a "cycle" in the classical interpretation of this word [1–7], since it is not closed like real cycles. The application of this term in various spheres of knowledge or in regulatory documents has a number of features. It is interesting to analyze the terminology and the possibility of its application in terms of its projection to meat and meat-containing sterilized canned food. The results of this research will determine the vector of development of the scientific direction in the food canning industry.

For the first time in economics the term "cycle" was used by K. Juglar. Being a physician by his education, he established the length of economic cycles equal to 7–10 years long [8–10], and divided them into periods or stages as presented below in the Figure 1.

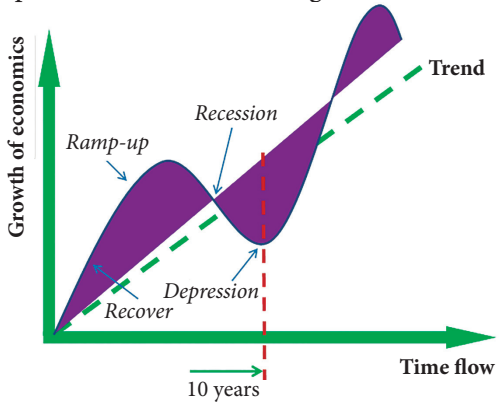

Figure 1. The economic cycle after K. Juglar (based on the materials of K. Juglar [9])

In Soviet engineering V. Burkov and V. Irikov defined the term "full life cycle model" as follows: "The full life cycle model of an individual object is a description of the sequence of all phases and stages of its existence, starting from its conception and appearance ("birth") to its disappearance ("dying off")" [11,12].

In the field of systems and software engineering the standard of series ISO/IEC24748 gives the modern interpretation gives the following definition of the term "life cycle model" and "system life cycle":

- "life cycle model: Structural base for the processes and activities related to the life cycle, which also serves as a common reference for communication and mutual understanding between the parties";
- "system life cycle: Development of the system under consideration in time, starting from its conception to its decommissioning".

The model, being a specific object under regulated conditions, shall remain unchanged. And thus, each specific model of the life cycle (LC) of an object is nothing more but just a projection of the full LC onto a certain type of human activity. The number of life cycle stages (LC) in various fields of science for objects varies. Life cycle models attract the attention of not scientists only, but of practitioners also.

Objects and methods

The object of research was the life cycle of sterilized meat and meat-containing canned food.

When studying the object, an analytical method was used from the standpoint of epistemics, which allows clarifying the concepts of "life cycle of meat and meat-containing canned food" and "stages of the life cycle of meat and meat-containing canned food" for the sterilized canned food.

The prijection of the "life cycle" methodology onto the production of meat and meat-containing canned food is a new problem. Therefore, the research used the works of scientists in the field of economics, management, ecology and regulatory documents as the theoretical foundations. The first stage in the sphere of this research was the selection of relevant publications on the information platform *Elsevier*, the national information and analytical portal eLIBRARY.RU for the period 1999–2022. The design of a systematic review, based on the principles of the PRISMA Guidelines (Preferred reporting items for systematic reviews and meta-analyses), is presented below in the Figure 2.

The following were selected as criteria for inclusion: (1) compliance with the research topic by reference points: life cycle, life cycle stages, life cycle model, food product, canned meat; (2) areas of knowledge, enveloped into food production; (3) original research results and reviews in peer-reviewed journals.

The following were selected as criteria for exclusion: (1) research conducted in the sphere of social studies and sciences; (2) research conducted in the sphere of natural sciences (chemistry, physics, biology, geology); (3) research conducted in the sphere of technical sciences; (4) research conducted in the sphere of social sciences and humanities (except for economics).

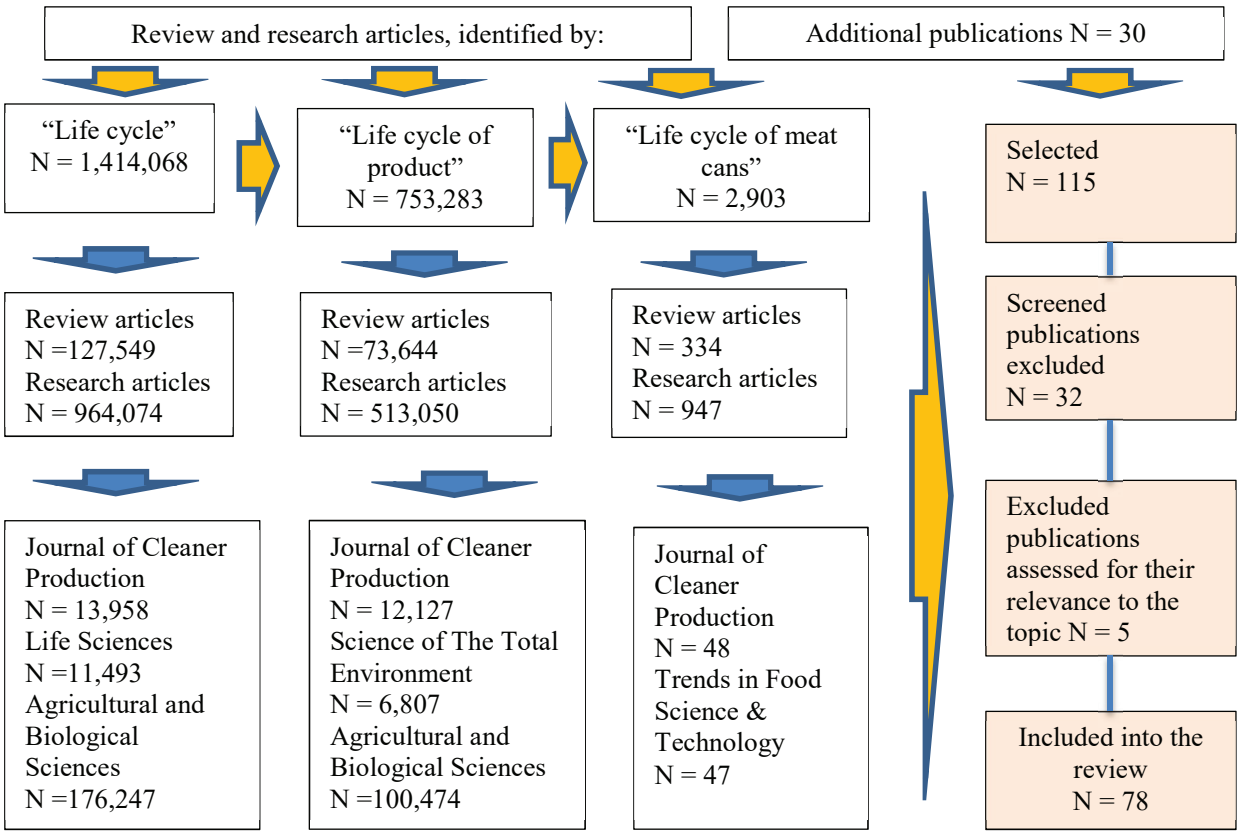

Figure 2. Design scheme of systematic review

Retrospective of the use of the life cycle method in different fields of knowledge

Aspects of the life cycle of enterprises / organizations

In order to define priority directions for development of an enterprise or organization, it is possible to assess its target state at each specific point in time. Five successive stages of the life cycle are arranged along in the popular model of L. Greiner [13]. These are: creativity, directive management, delegation, coordination and cooperation. In this case, each stage takes place after the "revolution" which stems from a crisis. The "revolution" is explained by strategic changes in the organization's management, which are confronted with active internal resistance. This leads to the fact that managerial decisions that lead the organization out of the crisis, at the next stage, will become the cause of this crisis [13]. The works of L. Greiner on determining the stages of the life cycle are based on theoretical approaches, like most similar works.

According to Yu. Ovanesova [14] there are relatively few researches focusing on the development of empirical life cycle models. These include, for example, the researches of H. Hanks. H. Hanks and co-authors [15] defined four stages of organization growth and defined life cycle stages as a unique configuration of variables related to the situation which the organization is located in, and its structure.

The Russian scientist G. Shirokova applied different approach, but consonant with H. Hanks's one, to creation of an empirical model of the life cycle of an organization [8]. It defines the stage of the life cycle of an organization as follows: "the configuration of internal variables that characterizes the specific state of the organization at a specific point in time and that changes during the transition to the next stage of development". For Russian companies that started their activities "from scratch", the author defines three stages — the stages of formation, growth and formalization (bureaucratization) [16, 17].

Not all proposed models of the life cycle of an organization feature stage of recession or crisis.

One of the first scientists who introduced the stage of a company's extinction, was I. Adizes, the largest business consultant in the field of management. He identified ten stages in the life cycle of an organization: courtship, infancy, go-go, adolescence, flourishing, stability, aristocracy, early bureaucratization, bureaucratization, death (Figure 3). Quoting [18] I. Adizes: "I believe that each system, "breathing" or not, has its own life cycle. We know that living organisms — plants, animals, people — are born, they grow, get old and die. The same thing happens with organizations". So we come to the conclusion that he acknowledges the organization as a living organism, therefore, the stage of extinction or death is also inherent to the organization, but unlike a living organism, the organization has the opportunity to get out of a crisis situation. But for a living organism death is inevitable [19]. In accordance with I. Adizes's concept, a company is able to start a new life cycle after attracting the attention of large investors at the moment of its financial attractiveness.

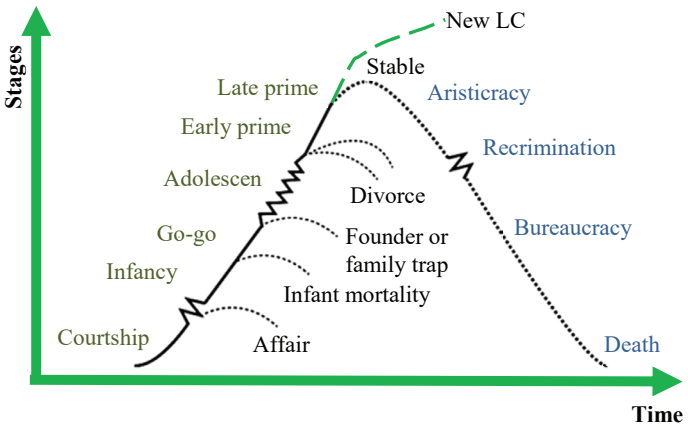

Figure 3. Stages of the life cycle of an organization (according to I. Adizes's materials of [18])

From the financial side, the life cycle of an organization is reviewed by V. Dickinson. He specifies five stages with unequal ratio of funds obtained from various types of company's activities: its emergence, growth, maturity, turbulence and decline [20].

It's necessary to change style of managing a company at each stage of the life cycle, and the same is applied to the sources of its funding. This assumption was put forward by M. Scott and R. Bruce in their work "Five Stages of Small Business Growth" [21].

Basing on the financial parameters at each stage of the life cycle, I. Ivashkovskaya and D. Yangel [22] proposed an aggregate indicator of company's growth. As for the parameters of the life cycle stage, a specific weighting value was defined, which determines the significance of the parameter and the degree of its influence on the company's growth rate. The calculated index is obtained by multiplying the specific weight and the actual value of the chosen parameter, which in total gives the integral value of the growth factor related to the period corresponding to the stage of the life cycle.

Thus, it allows tracing the value of both the financial approach and strategic management in modeling the life cycle of a company. Both approaches are important for practice and for the theoretical analysis of company's management. The relevance of empirical research for development of new models of the life cycle is obvious.

The life cycle of an organization directly depends on the life cycle of the product and the resources used.

Product Marketing Life Cycle Aspects

T. Levitt, who published the concept of the product life cycle, states that the product exists on the market only for a certain period of time, and sooner or later will be replaced by a more perfect product [23]. Just as an organization goes through certain stages in its development, the concept of the product life cycle describes the stages of the emergence of an idea (concept) of the product, and its introduction to the market until its production is stopped (Figure 4).

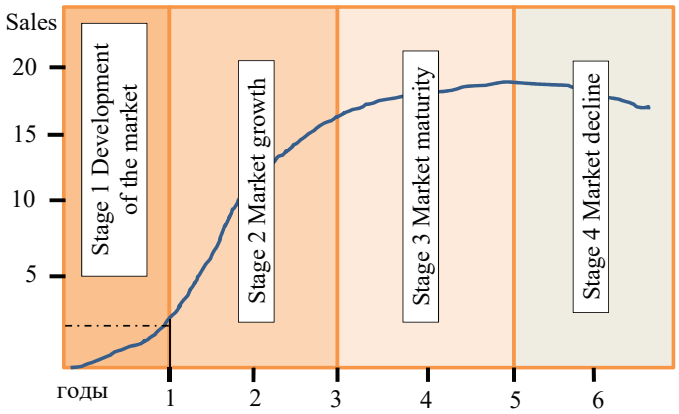

Figure 4. Product life cycle — the entire industry (according to T. Levitt [23])

T. Levitt [24] also identified four reference points in planning of marketing researches, which are presented below in the Figure 5.

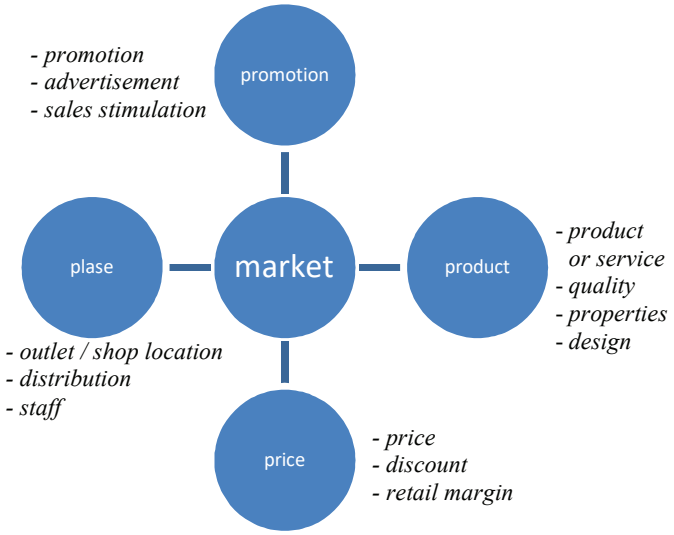

Figure 5. Benchmarks of Product Marketing Planning (Based on T. Levitt)

As a concept the product life cycle guides managers to analyze the activities of the enterprise, forms a strategy at each stage of the product life cycle.

The marketing company *Nielsen* noted that 76% of consumer goods released in the period from 2011 to 2013 did not last more than one year on the market [25]. When developing new food products, the companies used consumer-oriented approaches. These consumers' response tests [26,27] took into account new food trends that influenced consumers' choice. At the same time, demographic, economic, sociocultural or technological preferences of the consumers were taken into account. However, at the present stage, the question often arises of how consumers' preferences are taken into account after the product is launched on the market, i. e. at the stages of the product's life cycle. The scientists aimed to clarify what interests of consumers and at what stages of the product life cycle were taken into account by European companies. Based on the conceptual model, the frequency of using demographic, economic and technological factors at the development stage and stages of the product life cycle was shown. The results are shown below in the Figure 6 [28].

The researchers conclude that there is a lack of consumers' involvement at the stages of the product life cycle. It is proposed to use computer modeling to integrate consumers' preferences of all sphere and directions.

The result of consumers' preference research conducted by Ingredion showed that approximately 2/3 of consumers read labels to get to know the ingredients when buying, for example, cosmetics and 50% expect to see the composition without "unnecessary" ingredients [29]. Manufacturers start to take into account the sources of the used ingredients, the capacities of production, emissions, and the potential capacity of packaging [30]. So, to reduce water

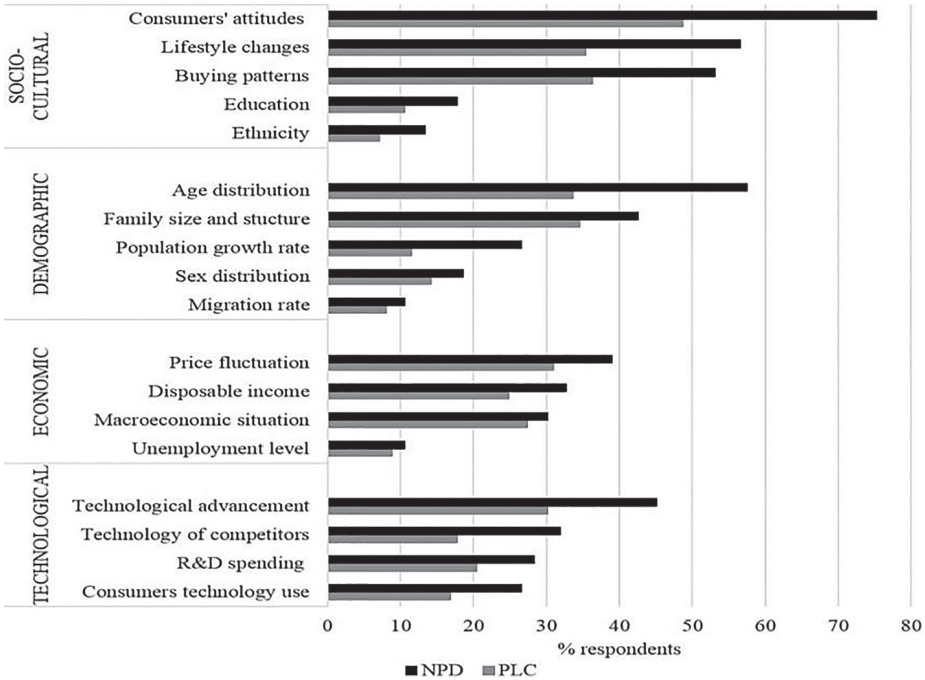

Figure 6. Frequency of using the various environmental factors (sociological, cultural, demographic, economic and technological) in new product development (NPD) and product life cycle (PLC) [28]

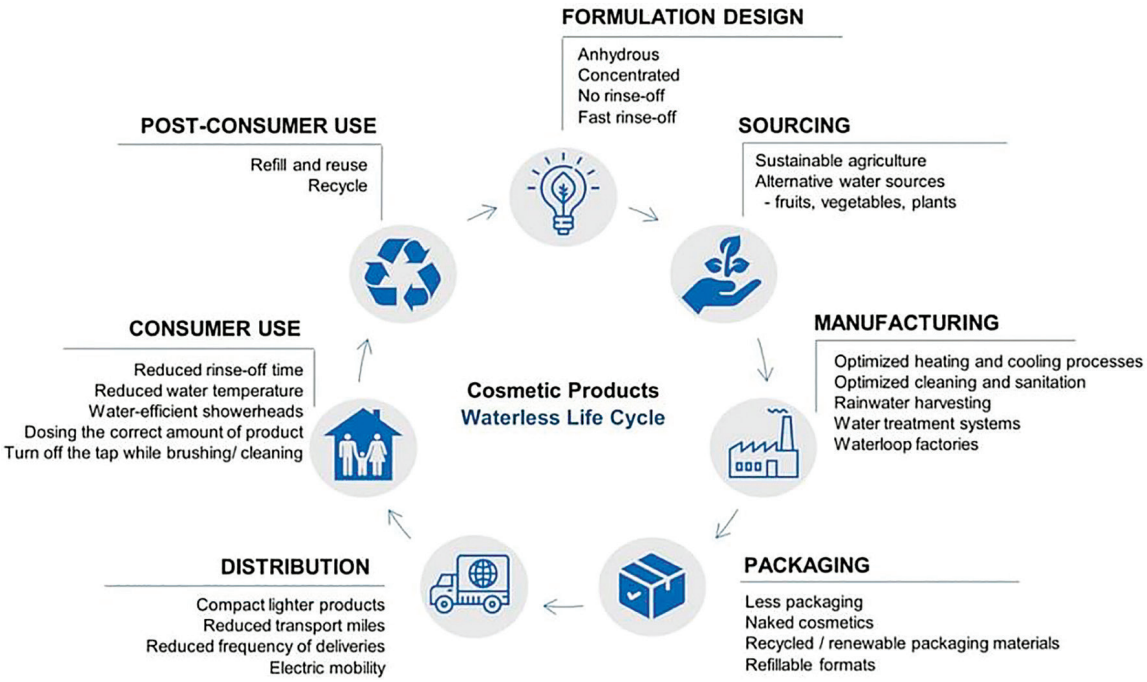

Figure 7. Anhydrous life cycle of cosmetic products [31]

consumption in the cosmetic industry, it is proposed to reduce its amount in the product composition; it is also proposed to use additional insulation in heating systems to avoid energy losses [31]. Figure 7 shows the sustainability of a water resource, used during the life cycle stages of cosmetics. In addition to changing the composition of the product, manufacturers keep looking for raw materials, ways of packaging, ways of its promotion, method of use and disposal of the product.

Standardization specialists, in order to help the competencies of employees of Russian enterprises and companies responsible for product management processes, have developed the standard GOST R58537[1]. This standard helps focus on problems and develop new solutions along the life cycle of the product. Meanwhile this standard determines the following:

— "product life cycle": <in the context of its stages> The cycle, that covers four main stages of the product — "launch", "growth", "maturity" and "decline" — and that is associated with the active marketing of the product in the market.

Note: Sometimes the product life cycle is based on a process which includes five stages — launch, growth, maturity, saturation and decline";

— "product life cycle: <in the context of time> The time from the observation stage (including the stage of a product creation) till the stage of bringing the product to market. This time includes, in addition to the stage of market observation, designing of idea, development of the product and its productions that precede marketing, including the phase of the product's leaving the market that follows the stage of active marketing.

[1] GOST R 58537-2019 "Product management. Fundamentals". Moscow: Standartinform, 2019. — 23 p. Retrieved from https://docs.cntd.ru/document/1200167818 Accessed August 25, 2022. (In Russian)

Although the recommendations of the standard apply to technical products, they can be useful in the sphere of food production.

Aspects of the life cycle in ecology

The ecological state of the planet makes the scientific community worry for a while already. Ways to address global threats to humanity are being actively discussed. The agricultural sector consumes a significant share of water and energy resources at all stages of the life cycle of manufactured products, which has a significant impact on the environment. To satisfy the vital needs of the modern population without reducing the opportunities for the future generation is a model of sustainable development [32]. A systematic approach to the analysis of the ecological state of the production process throughout its entire life cycle underlies the method of LCA (Life Cycle Assessment). The negative impact of some production processes on the environment served as prerequisite for the development of the method (Figure 8).

At the first time life cycle of food products was assessed in the early 1990s. Since then, life cycle assessment has been used as an environmental performance tool to determine

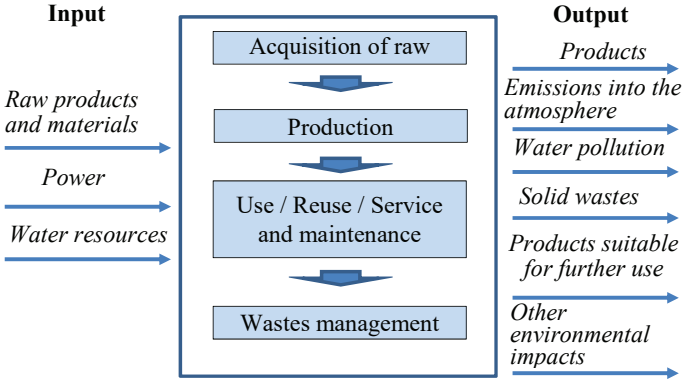

Figure 8. Functional model of the production system in the method LCA [32]

the stages of the product cycle that make the greatest negative impact on the environment.

International standards of the series ISO 14000 contribute to the implementation of the LCA methodology. More than one product has been assessed in reference to the requirements of these standards. Milk [33, 34], animal and vegetable oils [35, 36], bread [37], meat [38, 39], chicken [40], eggs [41], alcoholic beverages [42, 43].

Thus, the ecological attributes of pork have been studied in almost all European countries [44, 45, 46]. Scientists in Portugal focused their attention to the life cycle of pork production, since this type of meat makes up 45% of the country's total production [47]. And they focused their research on the cradle-to-gate segment of the life cycle (Figure 8). They excluded the stages of packaging, retail, consumption and disposal from the system. The boundaries of the system under research are shown below in the Figure 9 [48].

The life cycle of pork production has been divided into three main stages: growing crops and production of forage (S1), livestock production (S2) and slaughter (S3).

The results of the studies showed that among three stages of pork production life cycle, it is forage production (S1) that makes the greatest contribution to the environment. This is attributed to the peculiarities of growing crops like wheat, barley, corn and soybeans. In order to reduce the load onto the environment, the authors proposed to find alternative sources of protein, for example — to use the leguminous crops in the forage. The livestock stage (S2) was characterized mainly by on-farm emissions and emissions related to manure management. The activities at this stage have potentially contributed to climate change, eutrophication and acidification, respectively 30%, 40% and 75% of livestock stage emissions.

The complexity and global nature of environmental problems makes it impossible to understand quickly and easily all the details of the problems and challenges. Anthropogenic activities, among other things, increase the concentrations of greenhouse gases in the atmosphere, which persist for a long time [49, 50].

Quite few studies have been published on processed and ready-to-eat foods.

The food industry is developing now, and according to some authors about 20% of global greenhouse gas emissions come from the food industry [51]. According to the Australian Department of Industry, 21% of the entire food industry accounts for the production of meat and meat products in the country. It is the production and consumption of meat, according to Troy and Kerry [52], which are associated with climate change and exert the influence on the environment. In Australia the popularity of the life cycle assessment method keeps growing [53].

Canon Foods products were examined with the help of the Life Cycle Assessment method. The research was aimed to determine the categories of environmental impact: carbon footprint and embodied (operational) energy. Frozen, pre-baked, ready-to-eat "Swedish meatballs" (beef) and "Chicken breasts with crispy garlic" were analyzed. Figure 10 below shows the system life cycle boundaries for "Swedish meatballs". Similar boundaries are defined for "Chicken breasts with crispy garlic" [54].

The solid-lined boxes in the Figure 9 indicate that the data is obtained from surveys and consultations with manufacturers. The dashed-lined boxes indicate that the data is obtained from the key reference literature and widely acknowledged databases.

The global warming impact of 1 kJ equivalent caused by production of Swedish meatballs produced by *Canon Foods* and delivered to Barrow Island, is estimated at 1.09 g CO_2 eq/kJ carbon footprint and 4.15 kJ embodied energy [54]. At the same time, it was found that beef (the

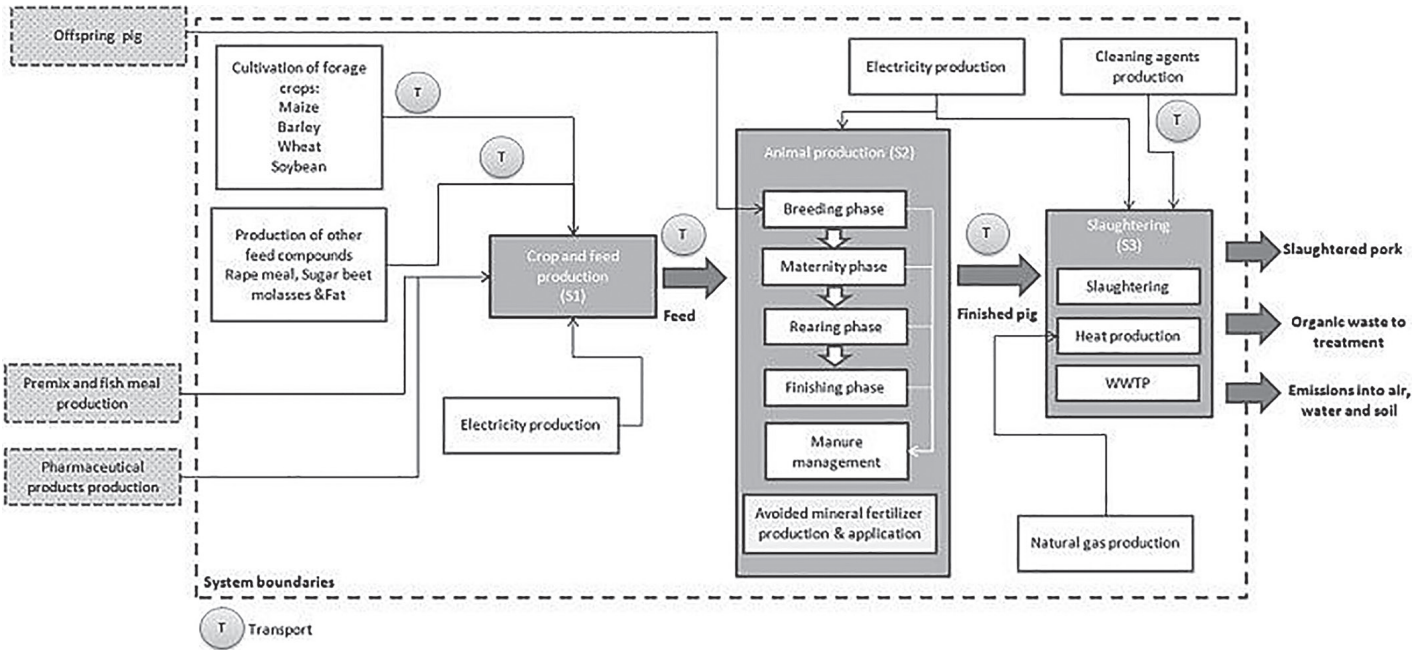

Figure 9. Boundaries of the Portuguese pork production chain system (reference script).
The dashed rectangles correspond to processes excluded from the assessment [48]

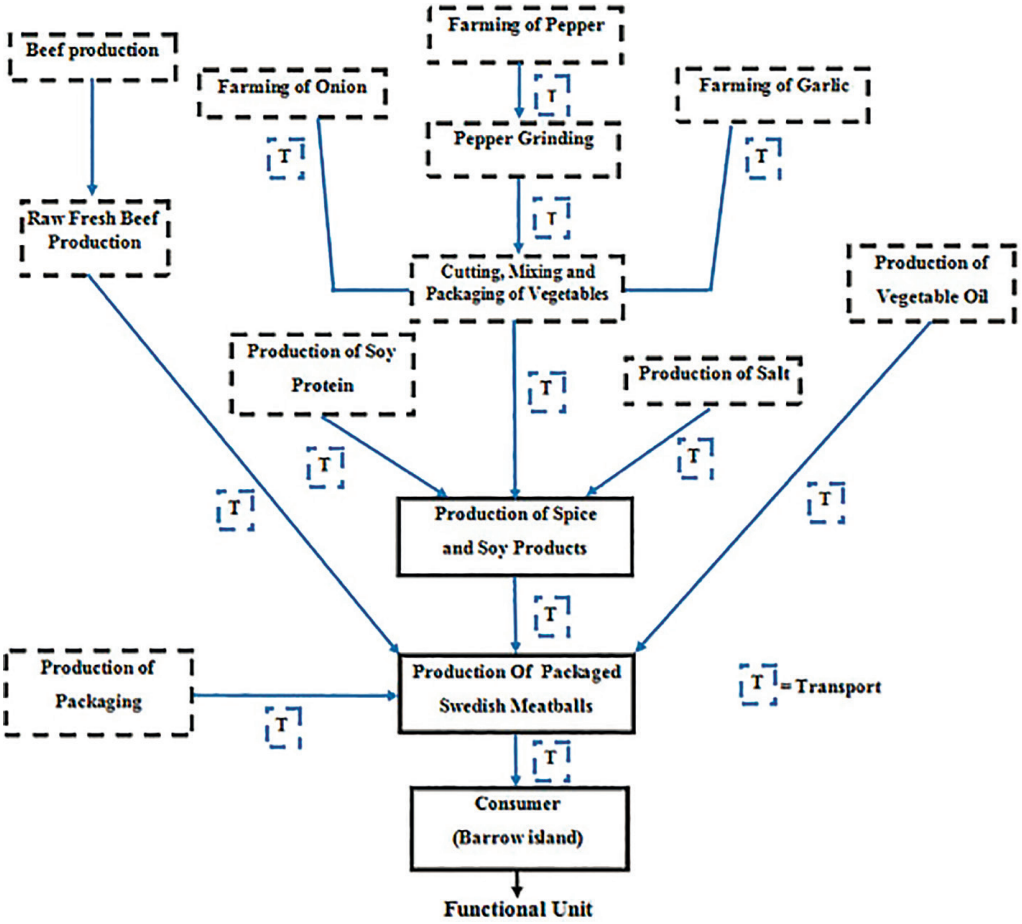

Figure 10. Visualization of the system boundaries for the "Swedish meatballs" life cycle [54]

ingredient of meatballs) accounts for 91% of the total carbon footprint. It is followed by 4% — transport, 2% for electricity and 2% for packaging, and <1% vegetable oil. The rest of the carbon footprint caused by the production of spices and soy mixture, as well as process water. 48% of the total embodied energy also comes from beef, 22% comes from transport, 11.4% each from packaging and vegetable oil, and 7% from processed-related electricity.

There are publications on the study of processed food products that have undergone heat treatment, i. e. sterilization: various types of legumes, seafood, products that include raw meat.

For example, studies have been conducted on food produced from beans, peas and chickpeas, packaged and sterilized in glass jars and metal cans [55]. The reviewed system included the stages of the supply chain, starting from the cradle till the gates of a factory, as well as disposal of primary packaging, presented below in the Figure 11.

According to the life cycle, the environmental impact of sterilized canned beans was assessed in terms of non-renewable energy requirement (NRED), global warming potential (GWP), water scarcity index (WSI), human toxicity potential (HTP) and freshwater aquatic ecotoxicity potential (FAETP).

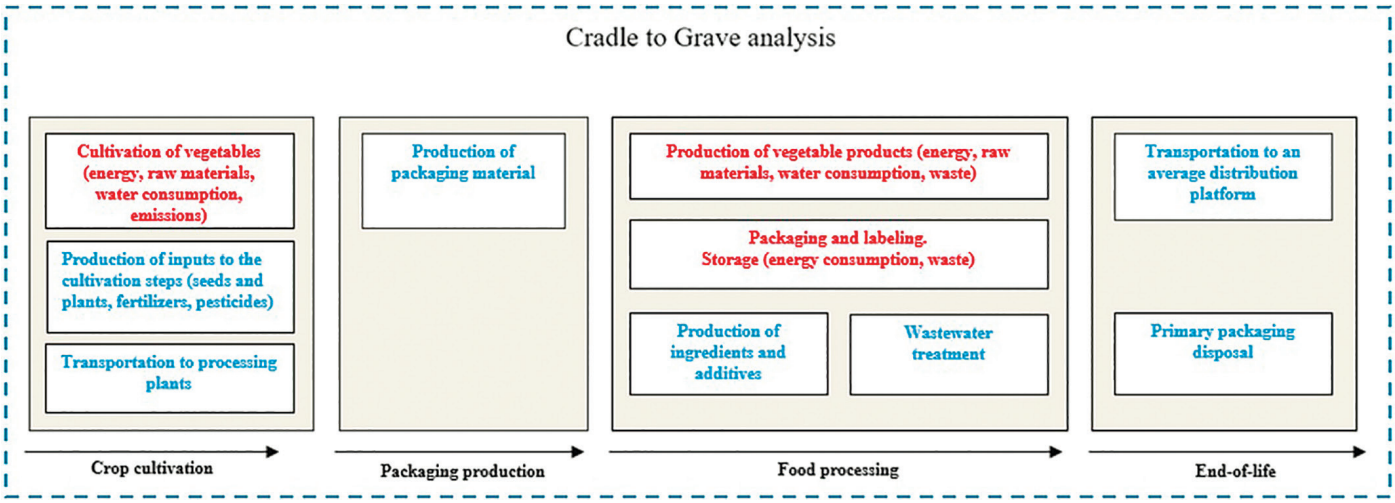

Figure 11. Life cycle system boundaries [55]

The comparable results were obtained for the stages of the product life cycle in terms of non-renewable energy and global warming potential. It is shown that the production of the food package accounts for more than 70% of the total negative impact on the environment. High energy consumption in the production of metal and glass packaging leads to high emissions of CO_2. It was noted in the metal package under review, the largest weight of the negative impact lies on packaging made of chrome-plated tin. The authors proposed to switch to less energy-consuming materials like paper or plastic package and change the format of food package. By the way, chrome-plated tin is prohibited in the meat canning industry in Russia.

The experience of the method of assessing the seafood life cycle in the analysis of their impact on the environment happened to be interesting. Previously this method was justified to be relevant [56]. In a further study, the authors focused on the comparative ecological properties of the life cycle of fresh and canned mussels. As for the canned food, the authors emphasized the potential danger to the environment of fuel production and electric power generation in the process of food canning, as well as during the transportation of ready canned food. The special significance of mussel cultivation in the ecological situation is emphasized as well. Based on the obtained results, the authors summarize the prospects and importance of using the method of assessment of the life cycle in the production of mussel food [57].

Among other types of seafood, tuna is one of the most widely available canned foods on the market. There is information about the assessment of this product from the point of its environmental properties. In particular, the recycling stage was noted as the largest contributor to the environmental impact. The important and the least environmentally friendly aspects of production are production and transportation of tinplate. Tinplate is the main material for cans production. In order to reduce the impact on the environment, the authors proposed to use the alternative package, for example, plastic. However, the consumers were not ready for these changes in their habits. It took some efforts of the professional marketing companies to introduce the obtained results of the research into practice [58].

The authors who studied the environmental load of anchovy canned food, came to the similar conclusions in the context of production diversification. The system under research was divided into stages of the life cycle, conventionally named Cradle to Gate, Gate to Gate and Gate to Grave [59]:

- from cradle to gate, including anchovy harvest, energy, water and fuel used, ingredients used and packaging (consumer and transport), transport of raw materials, ingredients and packaging;
- door-to-door, including the production of canned anchovies and the management of sewage and fish waste;
- from the gate to the grave, including the distribution of the finished product and its use.

The results of studies on canned anchovies showed an increased demand for natural resources in production of aluminum cans, which is 8 times higher than the cost of food being canned with sauce. In addition, the production of olive oil requires a large amount of water for growing olive trees. These stages of the life cycle require appropriate measures to be taken. Like in tuna production, the authors suggest replacing metal package with plastic package, but there is a problem of deterioration in quality of the product and its rejection by the consumers. Replacing olive oil with sunflower oil also raises a number of questions. Sunflower oil production is energy intensive and has more negative environmental impact due to the use of pesticides and herbicides in cultivation.

In the few publications on the evaluation of the life cycle of the processed and sterilized product, the following studies can be distinguished regarding meat and meat-and-vegetable canned food. A characteristic was given from an environmental point of view of the stages of production of canned food "Lean pork" and "Meatballs with peas" [60]. The system included all stages of the product life cycle: production of meat — manufacturing of product — product distribution — product consumption — waste disposal. Canned food life cycle diagrams are shown below in the Figures 12 and 13.

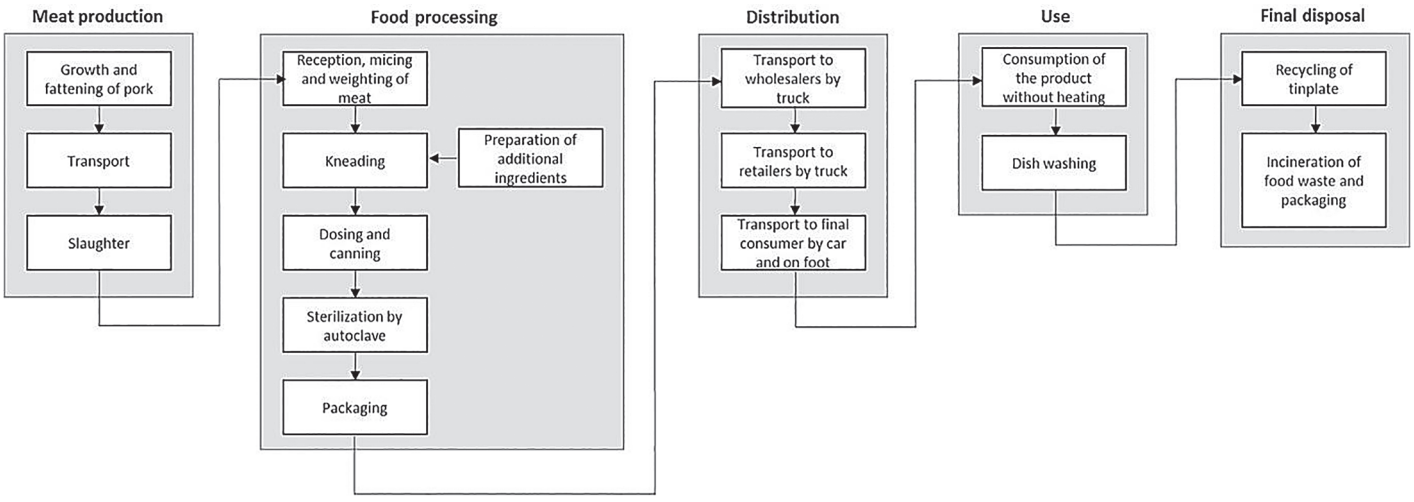

Figure 12. Scheme of the life cycle of canned food "Lean pork" [60]

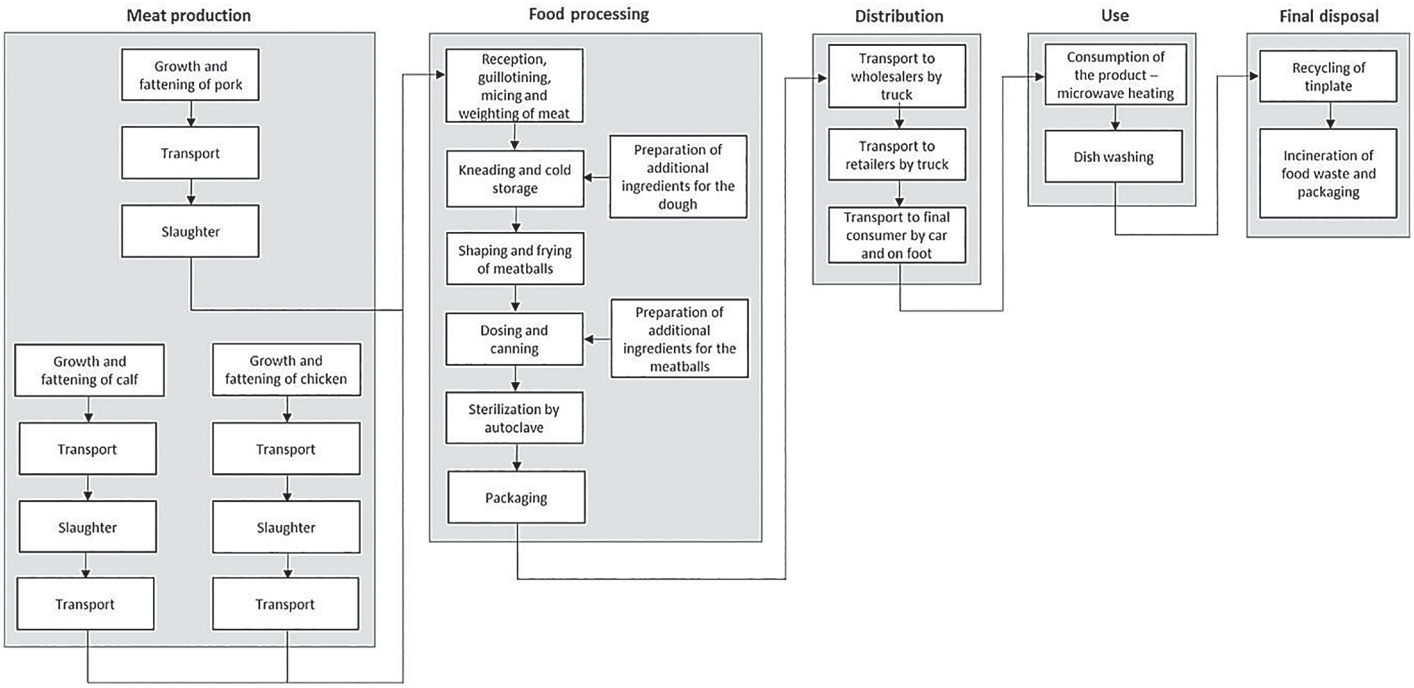

Figure 13. Scheme of the life cycle of canned food "Meatballs with peas" [60]

The assessment of potential environmental impacts of canned food were assessed in 18 categories: climate change (CC), ozone depletion (OD), land surface acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), human toxicity (HT), formation of photochemical oxidants (POF), formation of particulate matter (PMF), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), ionizing radiation (IR), agricultural land use (ALO), urban land use (ULO), natural land conversion (NLT), water depletion (WD), metal depletion (MD), and fossil depletion (FD).

The main conclusion based on the results of studies on canned food "Lean pork" was made by the authors in relation to the greatest environmental impact of dosing and sterilization processes. These two stages together accounted for 75% of the impact across all categories, and over 90% in 15 categories. The reason for this is the production of tinplate cans and high consumption of steam and electric power respectively.

The authors came to the same conclusions regarding the production of "Meatballs with peas". But in the production of this product, an additional contribution is made by the preparation of herbal ingredients. Additional ingredients are important contributors in the categories of terrestrial ecotoxicity (TET) and natural land conversion (NLT) with a contribution of 57.7% and 69.2% respectively. In addition, the used ingredients affect the category of agricultural land employment (ALO) with its contribution of 66.7%.

Having set the goal of becoming the first environmentally neutral continent by 2050, the European Union included the target of reducing greenhouse gas emissions by 55% by 2030 [61]. Therefore, the search and development of alternative food products with a lower environmental impact will be important for the EU [62].

The farmed meat was subjected to a life cycle assessment taking into account the need for nutrients during experiments on the proliferation and differentiation of muscle cell line cultures [63]. The boundaries of the system under study included the acquisition of raw materials and the production of muscle cells. According to the results of the research, it was revealed that the production of amino acids provides the greatest impact on the environment. Theoretical studies of scientists have demonstrated scripts for the production of farmed meat with the potential to reduce environmental impact, for example in relation to the production of canned beef food.

Thus, life cycle assessment as a tool for determining the environmental sustainability of agricultural products, processed food products or various technologies is widely applicable [64, 65, 66]. Criteria in food development and food system selection should be minimal environmental impact and efficient use of natural resources. Steps are also being taken to apply the life cycle assessment methodology, which does not have a standardized form for food products [67].

In the early 2000s, the standards of the ISO 14000 series were adopted in Russia, but these standards were not appropriately developed and applied, perhaps due to the lack of the necessary relevant information and a methodological basis for assessing the life cycle of products. But the standards provide concepts and terminology that can be used in further research work or can serve as a basis. So, in accordance with GOST R ISO 14040 the following terms have the following meaning:

- "life cycle: The successive and interrelated stages of a product life cycle system from its acquisition or its production from natural resources or raw materials to its final disposal in the environment";
- "system boundary: The set of criteria defining unit processes that are part of a product life cycle system";

- "product system: The set of singular processes with elementary flows and product flows, which perform one or more certain functions, and which models the life cycle of a product".

The forerunners in application of the process approach to managing an organization or evaluating the environmental profile of products were the standards of quality management standards — series ISO 9000. The process is managed through the Deming cycle Plan-Do-Check-Act (PDCA), and it is recommended to apply risk-based thinking when developing the process controls. The process approach of quality management is illustrated below in the Figure 14.

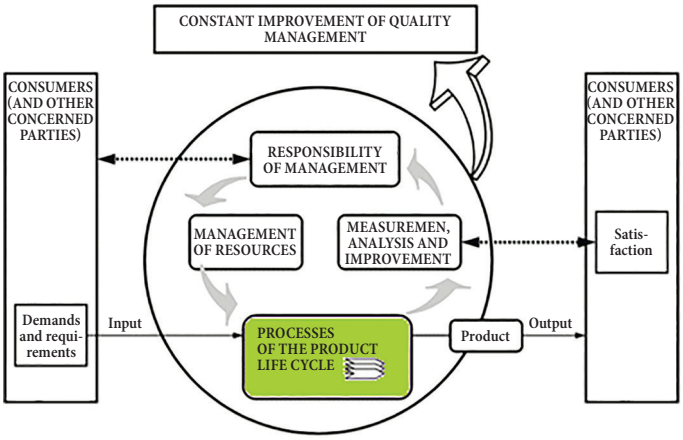

Figure 14. Model of a quality management system based on a process approach (GOST R ISO 9000)
→ — value-adding activity; ⇢ — data flow.

However, the process approach of ISO 9000 series quality systems does not provide for either product life cycle models or life cycle analysis, which is important and efficient in problems solving.

Perspective of the life cycle method in the projection of the production of meat and meat-containing canned food

The life cycle, being a complex system, is applicable in various fields of knowledge. Of all the many models and concepts of the life cycles of objects or systems, none of them has been used in analyzing or studying certain aspects of the production process of meat and meat-containing canned food. The environment is changing, business media is changing, political and economic situations constantly keep changing, legislation is also changing, consumer expectations are changing, suppliers are being replaced by imposed sanctions, and all this does not have the best effect on the targets of enterprises. It is necessary to promptly and correctly respond to all changes — external and internal. The epistemological approach to aspects of the life cycle made it possible to judge how correctly the term "life cycle" is applicable to the production of canned food. The term "cycle", mentioned in explanatory and encyclopedic dictionaries, is a certain period of time after which phenomena or processes are repeated in the same order. Or, according to the philosophy terminology, "cycle" means "…reproduction of the structure of changes that repeat with a certain periodicity. For example, cycles of economic development, solar activity, seasons, etc. The cyclic changes, left unattended, maintain the existence of their beings in a certain balance. Emergence of a new quality in result of development can break the previous circles (cycles) and give start to new cyclic structures" [68]. In the natural sciences, the life cycle is understood as a set of stages of development, after which the body gives rise to a new generation, closing the life cycle. Thus, any terminology regarding the life cycle, adopted in different fields of knowledge, reveals semantic coincidences and enables us to speak of the life cycle as a temporal function of an object from a set of arguments. In the context of this approach, the canned food as an object has its own life cycle. There is no cyclic repetition, of course. But canned food has a beginning of its production and its final consumption.

The life cycle of any object requires a systematic approach during the process of its study. The use of a systematic approach to assessment of canned food technology has previously made it possible to define the issue of getting a safe and stable product quality as multifaceted and systemic issue [69]. But it is not possible to cover the entire system from the field to the shop shelf or to review the entire life cycle of canned food within the framework of one research; though it is not required at this stage of research. It is known that the more indeterminates in a problem, the more difficult it is to solve. It is necessary to determine the boundaries of the system under review, adopting the experience of environmental management. Or in other words, it is necessary to develop a model of the life cycle of canned food, which is part of the system, and which will cover a range of criteria that define singular processes.

While moving in this direction, it is necessary to clarify some generally acknowledged and regulated formulations in the standards, projecting them onto meat and meat-containing canned food.

Let's accept that:

- Life cycle of meat and meat-containing canned food: The cycle of successive and interrelated stages of pre-production, production process and post-production, changing and shaping the state of canned food;
- Stage of the life cycle of meat and meat-containing canned food: The part of the life cycle of meat and meat-containing canned food, characterized by an aggregate of implemented activities and their final results.

We clarify that:

1. The pre-production stage is a prerequisite for solving problems to meet the goal set for the company. This stage includes: the idea and concept of the product, research and development (R&D) — analysis of existing developments; development of the composition and technological production chart; feasibility study, justification and development of heat treatment modes, taking into account the shelf life of the products in certain storage conditions; production of a prototype, its revi-

sion if necessary; analysis of marketing research results; drawing of necessary documents; development of technical specifications.

2. The stage of the production process is a complex process of the combined actions of people and tools for transformation of raw materials, ingredients, resources and other items into finished products. In its turn the technological process is a part of the production process that contains purposeful actions to change and (or) determine the state of the object of labor.
3. The post-production stage is a set of storage and transportation processes that maintain and preserve the quality and safety of the finished product. This stage requires thorough attention, including the cases of unforeseen challenges that require quick solution.

Author of the book "System coaching of organizations. Organization under the microscope. View from within" O. Weinberg [70] graphically visualizes the problem (Figure 15). In his diagram the degree of the problem understanding is stretched along one axis. The other axis defines the degree of understanding how to solve the problem. The problem as a whole, according to the author, is divided into the "known" part, i. e. this part is understandable, the organization can realize what it is; and the "unknown" part, when the organization sees and understands the negative consequences and manifestations of a problem, but it has no idea of what exactly the problem is. The author defines the problem as a kind of mismatch, a gap between what we want and what we really have [70]. This definition is quite fair and applicable to the canned food technology. The model of the life cycle of canned food in a visual form can be shown in the Figure 16. Preserving the safety and quality of canned food in various situations remains a problem everywhere in the modern world. Each stage of the life cycle of canned food has a certain problem that needs to be solved on the basis of a structured study that does not have an unambiguous solution. The analytical way of presenting information as a source for finding solutions is a feature of the problem-oriented approach.

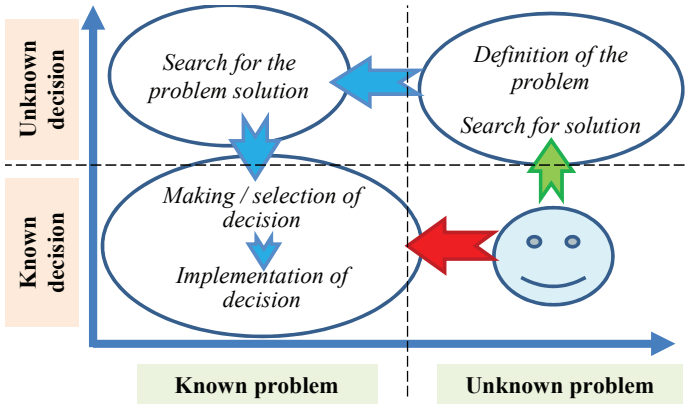

Figure 15. Matrix of problem solution (based on materials [70])

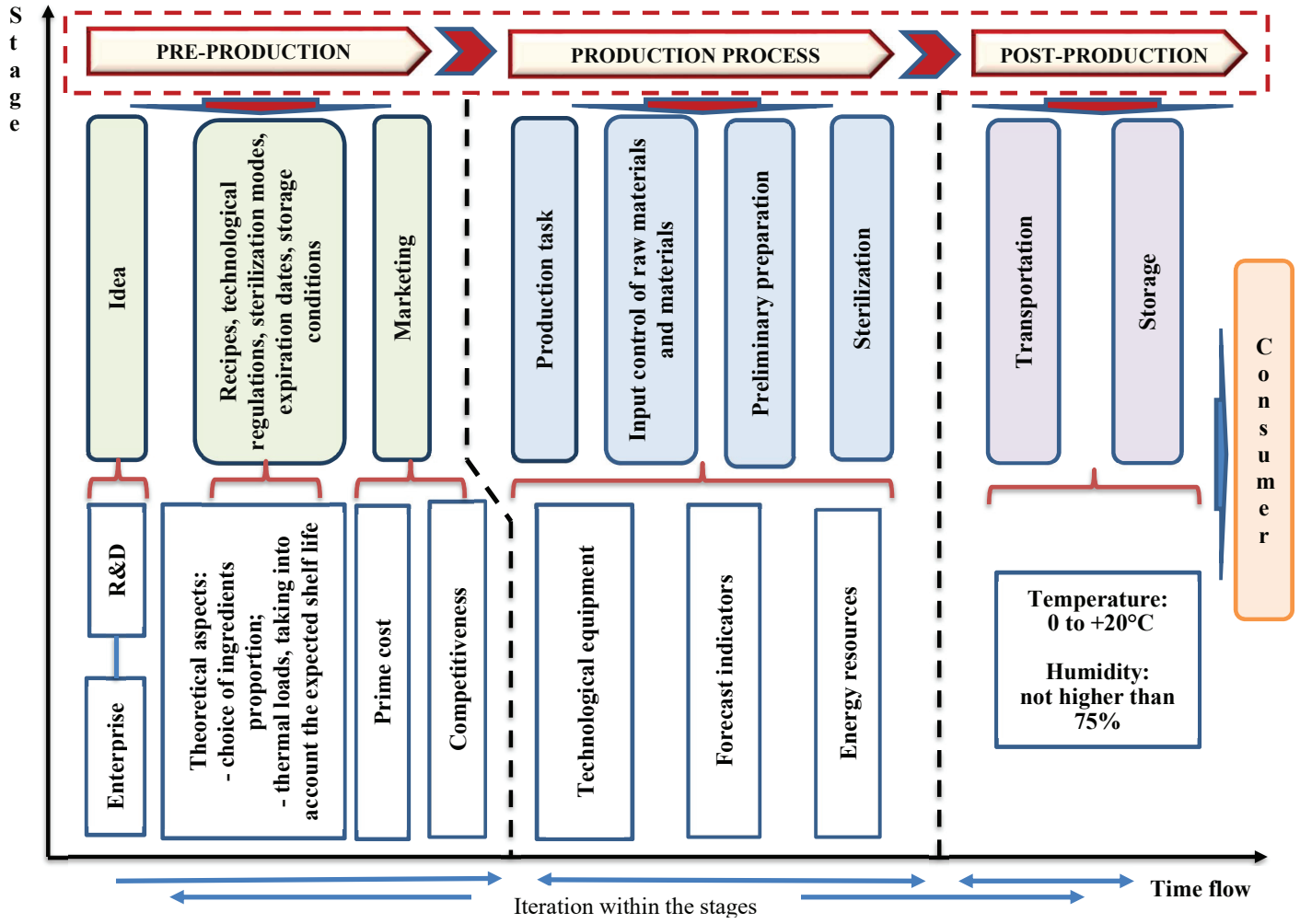

Figure 16. Model of problem-oriented stages of the life cycle of canned food

Thus, pre-production is the stage where ideas are born; the market and the target audience are studied, the main characteristics of the product are determined, technological regulations and recipes are developed, heat treatment modes and patterns are substantiated and tested, the shelf life of products is defined. At this stage, it's necessary to run the maximum number of iterations of canned food production in order to make it innovative and competitive. To competently rank the new products by groups and types at the pre-production stage, to lay down the correct ratios of ingredients when designing a recipe on the basis of a deep analysis of technologies and regulatory documents for the first time in the food canning industry has developed two types of standards of the general technical conditions for homogeneous groups of meat and meat-containing food products: GOST 34177[2] "Canned meat. General technical conditions" and GOST 32245[3] "Meat-containing canned food. General technical conditions". These standards supplement technical regulation TR TS034/2013[4] "On food safety of meat and meat products" in terms of terminology. For each type of canned food the important parameters like "mass fraction of meat ingredients" are regulated by normative documents. In addition, the range of food packages today is quite versatile. Based on the results of both research activities and verification in course of canned food production, a modern version of the GOST 13534[5] "Package, marking and transportation" standard has been developed. This version of standard provides for requirements for both classic types of packaging and for modern ones as well: polymeric and combined ones. And this is a small part of preventive measures aimed at solving the problem of canned food quality and safety formation.

Conclusion

In the food industry nowadays insufficient attention is paid to those production processes that affect formation of quality and safety of finished food products. And hardly any attention is paid to the stage of maintaining quality and safety of food products. Inconsistency and lack of continuity in the regulatory framework, scattered nature of practical skills for appropriate decision-making in conditions that go beyond the normalized values revealed the necessity of a unified methodological basis for identifying and applying preventive measures in the problem-oriented production stages, which ensure production of competitive products. To solve problems based on a systematic approach and the life cycle method, the innovations of various nature (technological, organizational, etc.) and of various scales (from elementary scale to system-wide) shall be developed and implemented. The formation and preservation of food quality and safety at production stages and at post-production stages of the canned food life cycle will be the subject of further publications. Yet the measures covered in this article, taken in due time at the stage of pre-production, allow fixing, eliminating and avoiding serious and costly mistakes in the evolution of meat and meat-containing canned food.

[2] GOST 34177–2017 "Canned meat. General specifications" Moscow: Standartinform, 2018. — 23 p. Retrieved from https://docs.cntd.ru/document/556309635. Accessed September 27, 2022. (In Russian)

[3] GOST 32245–2013 "Meat containing cans. General specifications" Moscow: Standartinform, 2019. — 14 p. Retrieved from https://docs.cntd.ru/document/1200107342 Accessed September 27, 2022. (In Russian)

[4] TR CU034/2013 Technical Regulations of the Customs Union "On the safety of meat and meat products" Retrieved from http://docs.cntd.ru/document/499050564. Accessed August 15, 2022. (In Russian)

[5] GOST 13534–2015 "Meat and meat containing cans. Packing, marking and transportation" Moscow: Standartinform, 2019. — 11p. Retrieved from https://docs.cntd.ru/document/1200133272 Accessed September 27, 2022. (In Russian)

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Completely prepared the manuscript and is responsible for plagiarism.

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