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## Chemical composition of sausages processed with starter cultures *Lactobacillus curvatus* and *Lactococcus lactis* subsp. *lactis* during storage in vacuum packaging

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Sausages belong to the category of cooked meat products with a short shelf life, which is associated with their rapid spoilage and unsuitability for consumption. One of the ways to extend the shelf life of sausages is the use of biopreservatives, including cultures of lactic acid bacteria. The aim of the study was to determine the chemical composition and organoleptic characteristics of "Juicy" sausages processed with a starter culture of *Lactobacillus curvatus* or a mixture of starter cultures *Lactobacillus curvatus* + *Lactococcus lactis* subsp. *lactis* before vacuum packaging and storage in a chilled state. Storage of sausages in the control variant in vacuum packaging in a chilled state for up to 18 days did not affect the moisture, protein, fat, and ash content, but on the 21st day, their spoilage was observed in the form of appearance of cloudy juice, sliminess, sour odor, and delamination of the vacuum packaging. Processing sausages with a starter culture of *Lactobacillus curvatus* or a mixture of starter cultures *Lactobacillus curvatus* + *Lactococcus lactis* subsp. *lactis* before vacuum packaging did not affect the moisture, protein, fat, and ash content up to 30 days of storage in a chilled state. On the 36th day, spoilage of sausages was observed in both variants of treatment with lactic acid bacteria cultures, characterized by the appearance of cloudy juice, sour odor, and delamination of the vacuum packaging. The pH value of sausages in both variants of treatment with lactic acid bacteria cultures decreased throughout the storage period and reached a level of 6.05 and 5.91 units on the 30th day. Processing sausages with either a single culture or a mixture of lactic acid bacteria cultures extends their shelf life in a chilled state by 12 days. The obtained results may justify the use of microbial biopreservatives for the production of cooked sausage products, which will help reduce losses due to spoilage during storage in vacuum packaging in a chilled state. The use of a mixture of lactic acid bacteria cultures for processing sausages requires further research and may be effective in case of detection of aerobic spoilage microorganisms.

**Keywords:** sausage products; shelf life; sensory indicators; spoilage; pH value.

### Introduction

Sausage products, including sausages, diversify the daily diet and are an important source of protein, amino acids, minerals, and vitamins for humans (Vivar-Vera et al., 2018; Bui et al., 2024). The main raw materials for making sausages are animal slaughter products: fatty and semi-fatty pork, beef, and poultry meat (Khodayari et al., 2019; Ruiz-Capillas & Herrero et al., 2021; Pérez et al., 2023). Food safety and stability of meat cooked products such as sausages during storage are important and necessary conditions for both consumers and producers, depending on many factors (compliance with sanitary and hygienic requirements for the production of main and auxiliary raw materials, hygiene of workers, sanitary condition of technological equipment, packaging conditions, and storage of the finished product). As known, sausages have a limited shelf life, which depends on the microbial contamination of the mince and sausage casings and packaging (Luong et al., 2020).

Foodborne pathogens, including *Listeria monocytogenes*, *Staphylococcus aureus*, pathogenic serovars of *Escherichia coli*, *Clostridium perfringens*, *Campylobacter* spp., and *Vibrio* spp., cause a large number of human illnesses worldwide, causing significant harm to health and the economy of countries (Shevchenko et al., 2019; Babenko et al., 2022). According to the World Health Organization (WHO), food products contaminated with pathogens, toxins, and allergens cause up to 600 million cases of foodborne illnesses and approximately 400,000 deaths worldwide each year (Lee & Yoon et al., 2021). Meat and meat products

are not only important sources of nutrients for humans, being a source of protein, essential amino acids, vitamins, and minerals, but also a nutritious environment for spoilage microorganisms or foodborne pathogens.

Spoilage can not only shorten the shelf life of meat products such as sausages but also lead to a decrease in their attractiveness to consumers (Bogdanović et al., 2023; Stangierski et al., 2023). Among the most important sensory characteristics of sausages that attract consumers' attention are changes in external appearance (consistency, secretion of mucus or exudates), varying degrees of color deterioration, or the appearance of off-odors (Zhu et al., 2022). These signs of spoilage typically have different mechanisms of development. Spoilage of meat products can be caused by natural processes in the meat, such as lipid oxidation or autolytic enzymatic reactions in the animal's muscle cells after slaughter (Vovkotrub et al., 2023). However, the main cause of spoilage in cooked meat products is inevitable contamination by microorganisms (mostly bacteria) during meat production and processing, followed by their growth and metabolic processes during storage. Each stage of meat and auxiliary raw material processing can affect microbial contamination, and storage conditions can shape the structure of bacterial communities, thereby influencing the onset of microbial spoilage over time (Odeyemi et al., 2020). Traditional researches on microbial populations found on meat and in meat production environments associate meat spoilage with a wide range of representatives from different groups of microorganisms, including Proteobacteria (genera *Actinobacter*, *Pseudomonas*, *Moraxella*, *Psychrobacter*, *Shewanella*, and some members of Enterobacteriaceae), Bacilli (*Bacillus*, *Brocothrix*,

*Carnobacterium*, *Kurthia*, *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Pediococcus*, *Staphylococcus*, and *Weissella*), and Bacteroides (*Bacteroides* and *Flavobacterium*). Despite these microorganisms occupying a diverse phylogenetic space, they share the common ability to grow at refrigeration temperatures (psychrotrophic growth) and utilize glucose, lipids, and amino acids, which are abundant in mixed products containing fresh ground meat, forming the basis of sausage filling (Benson et al., 2014).

The problem of preventing spoilage and extending the shelf life of cooked meat products such as sausages is most often addressed by adding chemical preservatives to their composition. However, due to potential health risks for humans, chemical food preservatives require constant control in finished products and reduce their attractiveness to consumers (Campêlo et al., 2019).

A significant amount of research on extending the shelf life of sausages is related to the complex use of high-barrier packaging materials and active packaging elements aimed at increasing product protection from external factors (Song et al., 2021).

Overall, consumers prefer minimally processed meat products and the use of natural food additives such as annatto, saffron, rosemary, paprika, and astaxanthin (Schilling et al., 2019), as well as natural food preservatives such as pediocin, natamycin, lactoferrin, thyme (Carballo et al., 2019; Karam et al., 2019), and antioxidants (Munekata et al., 2021; Bellucci et al., 2022). Therefore, the production of safe (Bayer et al., 2017, 2019) and high-quality meat products using natural food additives and preservatives is attracting increasing interest in the food industry (Mohammadpourfard et al., 2020; Munekata et al., 2020).

Among natural food preservatives are also cultures of special strains of microorganisms, which, along with their antagonistic effect on spoilage-causing microorganisms, including those in cooked meat products such as sausages, lower the pH of the environment, creating unfavorable conditions for pathogenic and conditionally pathogenic microorganisms (Chaillou et al., 2022).

One of the effective ways to extend the shelf life of cooked sausage products in vacuum packaging, such as sausages, is their processing with starter cultures of microorganisms *Lactobacillus curvatus* and *Lactococcus lactis* subsp. *lactis*, which involves evaluating their chemical composition and organoleptic indicators during storage in a chilled state. There is a limited amount of such research, and their results do not fully reflect the objective picture of changes in sausages during storage in a chilled state, which is associated with the different recipes of cooked meat products, types of casings, and packaging.

Therefore, the aim of the research is to determine the chemical composition and organoleptic characteristics of sausages processed with starter cultures of *Lactobacillus curvatus* and *Lactococcus lactis* subsp. *lactis*, stored in vacuum packaging under refrigeration, and to select effective strains of starter lactic acid microorganisms capable of reducing the intensity of spoilage processes and extending the shelf life of sausages.

## Materials and methods

For the study, a batch of "Juicy" sausages of the first grade was produced at a meat processing plant in the Zakarpattia region. The recipe used was as follows: main ingredients (kg/100 kg): fatty pork – 20, semi-fat pork – 34, poultry meat – 30, pork skin emulsion – 10, dry milk – 3, potato starch – 3, water (ice) – 25; auxiliary ingredients (kg/100 kg): kitchen salt – 2.30, sodium nitrite – 0.0075, food additive Emulin (guar gum thickener, mixture of milk proteins, sodium tripolyphosphate stabilizer, kitchen salt) – 2, food additive Parovka kombi (spices: white pepper, mustard, celery), spice extracts (cardamom, paprika), dextrose, yeast extract – 1, food additive Ham flavor (black pepper, garlic, coriander, maltodextrin, soy protein hydrolysate, yeast hydrolysate extracts) – 0.2, food additive milk enhanced (spices and spice extracts: cardamom, nutmeg, garlic, meat flavor and aroma, blood hemoglobin (color fixative), milk proteins, carriers (dextrose, rice flour, kitchen salt) – 1.

For the research, 60 vacuum packages of "Juicy" sausages weighing 200 g each were used, divided into 3 variants: control and two experimental ones. The experimental variants of sausages were treated by spraying a suspension of starter cultures of lactic acid bacteria according to the scheme shown in Table 1. The chemical composition and organoleptic

characteristics of sausages processed with starter lactic acid bacterial cultures were investigated with the aim of increasing their shelf life in vacuum packaging in a refrigerated chamber at a temperature of  $4 \pm 1$  °C.

**Table 1**

Scheme of the research to determine the influence of starter cultures of lactic acid microorganisms on the chemical composition and organoleptic characteristics of "Juicy" sausages during storage in vacuum packaging in a refrigerated state (n = 20)

Variant	Experimental conditions
Control	"Juicy" sausages of the first grade in vacuum packaging
Experimental 1	"Juicy" sausages of the first grade treated with starter culture SafePro BLC-48 ( <i>Lactobacillus curvatus</i> ) at a rate of $5 \times 10^6$ CFU/cm <sup>2</sup> of surface
Experimental 2	"Juicy" sausages of the first grade treated with a mixture of starter cultures SafePro BLC-48 ( <i>Lactobacillus curvatus</i> ) + Bactoform Rubis ( <i>Lactococcus lactis</i> subsp. <i>lactis</i> ) at a rate of $5 \times 10^6$ CFU/cm <sup>2</sup> of surface

For the research, lactic acid microorganisms SafePro BLC-48 (*Lactobacillus curvatus*) + Bactoform Rubis (*Lactococcus lactis* subsp. *lactis*) produced by Chr. Hansen (Chr. Hansen Ukraine LLC, Kyiv) were used, meeting food safety requirements. Sausages were made using polyamide casings from Evro-Bar (ATRIM PAK Company, Kharkiv, Ukraine), as well as vacuum packaging from Amilen PA/PE (Kozak+ LLC, Vinnytsia, Ukraine).

All variants of sausages were stored in refrigerator conditions until signs of spoilage appeared. The examination of results was conducted on the 1st, 18th, 21st, 30th, and 36th day of sausage storage in the refrigerator. Five samples of sausages were taken for each examination.

The analysis of the chemical composition of sausages was carried out at the Zakarpattia Regional State Laboratory of the State Food Safety Service in Uzhhorod and Expert Center "Biolights" LLC in Ternopil.

Organoleptic examinations of sausages were conducted based on external appearance and consistency of the filling upon slicing, condition of the casing and vacuum packaging, as well as smell and taste. The moisture, ash, protein, and fat content in the sausages were determined. The moisture content in the sausages was determined by successive weighing and drying of samples in a drying cabinet. The nitrogen content in the sausages was determined by the Kjeldahl method, with mineralization of samples using a DK 6 wet mineralizer (Velp Scientifica, Italy), and ammonia was driven off using a semi-automatic steam distillation apparatus according to Kjeldahl UDK 129 (Velp Scientifica, Italy). The protein content in the sausages was determined by the calculation method. The ash content in the sausages was determined by combustion of samples in a Nabertherm L15 muffle furnace (Germany). The fat content in the sausages was determined by the Soxhlet method using an automatic extraction device SER 148 (Velp Scientifica, Italy). The pH of the sausages was determined using an Ezodo PP-203 pH meter (Gondo Electronic, Taiwan).

The statistical analysis of the obtained results was performed using the ANOVA program, with the data in the tables presented as  $\bar{x} \pm SD$  (mean  $\pm$  standard deviation). The difference between groups was considered significant using Tukey's test at  $P < 0.05$  (taking into account the Bonferroni correction).

## Results

Storage of "Juicy" sausages in the vacuum packaging of the control variant on the first and 18th day showed that they met the requirements for a quality product in terms of appearance, consistency of the filling on the cut, as well as aroma and taste. The casing of the sausages in the control variant was strong, elastic, tightly adhering to the filling, slightly moist. On the cut, the sausages had a homogeneous structure, dense, and uniform pink color of the filling. The taste and aroma of the sausages were pleasant, characteristic of this product with a moderate saltiness. On the 21st day of storage in the refrigerator, signs of spoilage appeared in the sausages, including sliminess, the appearance of juice and its cloudiness, as well as delamination of the vacuum packaging. After opening the vacuum packaging, a sour smell was detected, indicating spoilage and unsuitability for consumption and further storage.

Treatment of "Juicy" sausages before vacuum packaging with the starter culture SafePro BLC-48 (*Lactobacillus curvatus*) or a mixture of

starter cultures SafePro BLC-48 (*Lactobacillus curvatus*) + Bactoferm Rubis (*Lactococcus lactis* subsp. *lactis*) during storage in the refrigerator on the first, 18th, and 30th day ensured the appearance, consistency, color of the filling on the cut, aroma, and taste of the sausages characteristic of a high-quality product.

After opening the vacuum packaging, it was found that the casing of the sausages was strong, elastic, tightly adhering to the filling, easily removable without sticking to the filling. The filling on the cut had a homogeneous structure and a uniform pink color. The taste and aroma of the sausages for both treatment options were pleasant, characteristic of this product with a moderate saltiness.

On the 36th day of storage, in both treatment variants with starter cultures of lactic acid bacteria, the appearance of cloudy juice, delamination of the vacuum packaging, slight sliminess were observed, and after its opening, a sour smell was detected, indicating spoilage of the product and its unsuitability for further storage. It is worth noting that in terms of storage duration and organoleptic characteristics, "Juicy" sausages treated with the starter culture SafePro BLC-48 did not differ from sausages treated with a mixture of starter cultures SafePro BLC-48 + Bactoferm Rubis.

The moisture, fat, protein, and ash content in the sausages of the control and both treatment variants with starter cultures of lactic acid bacteria on the first day of storage in vacuum packaging in a chilled state met the technical specifications and did not differ from each other.

Storage of sausages in vacuum packaging until the 18th day did not change the chemical composition of the sausages for either the control and the two treatment variants with starter cultures of lactic acid bacteria (Table 3). On the 21st day of storage, sausages from the control variant with signs of spoilage were not subjected to chemical analysis and were not used in further studies.

**Table 2**

Chemical composition of "Juicy" sausages treated with lactic acid bacteria starters on the first day of storage in vacuum packaging (% ,  $x \pm SD$ ,  $n = 5$ )

Parameter	Control variant	SafePro BLC-48	SafePro BLC-48 + Bactoferm Rubis
Moisture	60.21 ± 1.24	59.93 ± 1.02	59.25 ± 1.14
Protein	11.21 ± 0.56	11.89 ± 0.45	11.77 ± 0.96
Fat	24.51 ± 1.34	23.29 ± 1.78	24.01 ± 1.32
Ash	2.61 ± 0.19	2.65 ± 0.21	2.59 ± 0.13

Note: no significant differences between experimental variants were found based on Tukey's test.

Sausages treated with lactic acid bacteria starters remained without signs of spoilage until the 30th day. Meanwhile, the moisture, fat, protein, and ash content in the sausage samples for both treatment variants with lactic acid bacteria starters were at the same level (Table 4). On the 36th day of storage in vacuum packaging, sausages treated with lactic acid bacteria starters showed signs of spoilage and were not used for chemical analysis.

**Table 3**

Chemical composition of "Juicy" sausages treated with lactic acid bacteria starters on the 18th day of storage in vacuum packaging (% ,  $x \pm SD$ ,  $n = 5$ )

Parameter	Control variant	SafePro BLC-48	SafePro BLC-48 + Bactoferm Rubis
Moisture	60.11 ± 1.18	59.78 ± 0.62	60.15 ± 1.10
Protein	11.16 ± 0.23	11.49 ± 0.25	11.47 ± 0.29
Fat	24.32 ± 0.94	24.02 ± 0.48	24.15 ± 1.18
Ash	2.62 ± 0.11	2.60 ± 0.12	2.48 ± 0.32

Note: see Table 2.

**Table 4**

Chemical composition of "Juicy" sausages treated with lactic acid bacteria starters during storage in vacuum packaging (% ,  $x \pm SD$ ,  $n = 5$ )

Parameter	SafePro BLC-48	SafePro BLC-48 + Bactoferm Rubis
Moisture	61.01 ± 1.12	60.18 ± 1.22
Protein	11.39 ± 0.62	11.25 ± 0.59
Fat	23.41 ± 1.44	23.65 ± 1.21
Ash	2.62 ± 0.18	2.53 ± 0.23

Note: see Table 2.

**Table 5**

pH value of "Juicy" sausages treated with lactic acid bacteria starters on the 30th day of storage in vacuum packaging (unit,  $x \pm SD$ ,  $n = 5$ )

Day of research	Control variant	SafePro BLC-48	SafePro BLC-48 + Bactoferm Rubis
1	6.71 ± 0.12 <sup>a</sup>	6.68 ± 0.14 <sup>a</sup>	6.59 ± 0.17 <sup>a</sup>
18	6.63 ± 0.13 <sup>a</sup>	6.15 ± 0.14 <sup>b</sup>	6.02 ± 0.11 <sup>b</sup>
30	–	6.05 ± 0.10 <sup>b</sup>	5.91 ± 0.07 <sup>b</sup>

Note: control sausages spoiled by day 21 and were not subjected to analysis; different letters of superscripts <sup>a</sup>, <sup>b</sup> indicate values that significantly differed within the same row and column of the table ( $P < 0.05$ ) based on Tukey test with Bonferroni correction.

On the 18th day of storage, the pH value of sausages treated with SafePro BLC-48 starter culture or the combination of SafePro BLC-48 + Bactoferm Rubis starter cultures was lower than in the control variant by 0.48 units and 0.61 units, respectively. However, no significant difference in pH value was observed between sausages treated with both variants of lactic acid bacteria starters. Subsequently, sausages from the control variant were not subjected to further analysis. Storage of sausages treated with SafePro BLC-48 starter culture and the combination of SafePro BLC-48 + Bactoferm Rubis starter cultures led to a further decrease in pH value by 0.63 units and 0.68 units, respectively, compared to the initial values on the first day of storage.

## Discussion

Lactic acid bacteria are considered the primary component of the microbial population found in various types of cooked sausage products in vacuum packaging. It has been shown that *Lactobacillus sakei* and *Lactobacillus curvatus* are the main bacterial species characteristic of these products. *L. sakei* constitutes the predominant part of the microbial population which causes the spoilage of meat products, including sausages. The proliferation of lactic acid bacteria on the surface of sausages creates undesirable sensory properties, such as a sour aroma and taste. Additionally, a specific spoilage phenomenon has been identified, characterized by long, stringy polysaccharide threads between sausages or sausage pieces. Cooking sausages destroys lactic acid bacteria on their surface; however, during cooling and packaging, their recontamination occurs (Korkeala & Björkroth, 1997). Undesirable growth of field strains of lactic acid bacteria in meat products is one of the main reasons for their spoilage during storage in vacuum packaging. Presumably, this was one of the reasons for the spoilage of sausages in the control group observed on the 21st day of storage in a chilled state. Increased numbers of field strains of lactic acid bacteria cause specific spoilage of meat products, manifested by the appearance of a sour odor, a decrease in pH, and the formation of slime, which shortens their shelf life (Martins et al., 2020; Min et al., 2023).

During sausage spoilage, ammonia, sulfur compounds, ketones, aldehydes, complex esters, organic acids, and biogenic amines are often detected, which are the main molecules produced by spoilage microorganisms (Pellegrini et al., 2023). Enterobacteria, mold, and field strains of lactic acid bacteria produce ammonia and acetic acid, both of which indicate sausage spoilage. Lactic acid bacteria can produce ammonia compounds only when the sugar content in the meat mixture is low. The presence of acetic acid, which imparts a sour odor to sausages, is caused by enterobacteria, mold, and heterofermentative bacteria. In fermented sausages, enterococci, Enterobacteriaceae, and some lactic acid bacteria are typically the main producers of biogenic amines, such as tyramine, histamine, cadaverine, and putrescine, which also determine the sensory characteristics of these products, especially towards the end of their shelf life (Iacumin et al., 2016). During the storage of sausages treated with starter cultures of lactic acid bacteria, even with the appearance of cloudy juice on the 36th day, we did not detect the smell of ammonia, which is due to the predominant number of starter lactic acid cultures in the product.

It is known that the sensory attributes of meat and meat processed products, including sausages, are important criteria for consumer choice. However, they do not always reflect the degree of microbial contamination of the finished product at the beginning and during storage (Vovko-trub et al., 2023). This also applies to cooked sausage products, which are treated with starter cultures of lactic acid bacteria before vacuum packa-

ging. It should be noted that in the case of treating sausages with starter cultures of lactic acid microorganisms, the total number of mesophilic aerobic and facultative anaerobic microorganisms increases due to beneficial bacteria, which ensure product preservation and guarantee its safety for consumers. This explains the increased shelf life of sausages in our experiment for both treatment options. Moreover, the sensory attributes of sausages during the 30-day storage in vacuum packaging corresponded to a high-quality and safe product, as confirmed by their chemical composition. The results of our analysis of the chemical composition of sausages treated with starter cultures of lactic acid bacteria are consistent with data obtained by Parrini et al. (2019), which indicate that storage of sausages for up to 30 days in vacuum packaging does not affect the moisture, protein, fat, and ash content. Significant changes in the chemical composition of sausages may occur between the 30th and 60th day of storage in a chilled state (Parrini et al., 2019), and with the use of the bacteriocin nisin and a composition of natural plant antioxidants (Alirezalu et al., 2019), these changes may occur after 45 days of storage. Similar changes were observed by us for sausages treated with starter cultures SafePro BLC-48 or a mixture of starter cultures SafePro BLC-48 + Bactoferm Rubis on the 36th day of storage.

As an important parameter, pH value can significantly affect the color, water-holding capacity, protein properties, taste, and shelf life of meat products (Choi & Chin, 2020; Feng, 2022). Our research results are consistent with the data obtained during the analysis of cooked sausages stored in vacuum packaging with initial pH values ranging from 5.83 to 5.96 (Stangierski et al., 2020). In another study, the pH range of sausages varied from 6.19 to 5.39 and decreased from the 7th to the 60th day of storage (Parrini et al., 2019). The decrease in pH value during the storage of sausage products in vacuum packaging may be associated with the intrinsic properties of meat or fermentation microorganisms, and specifically with the growth of starter cultures of lactic acid bacteria. The difference in the pH value of sausages recorded between treatment options may be associated with the presence of field strains of *Lactobacillus* in the control group sausages (Badia et al., 2020).

Lactic acid bacteria, which form the basis of starter cultures, including *Lactobacillus sakei*, *Pediococcus acidilactici*, *Lactobacillus curvatus*, are used to extend the shelf life of raw and cooked meat products (Sharma et al., 2022). The antimicrobial activity of lactic acid bacteria is explained by the complex action of their metabolites. In addition to organic acids, hydrogen peroxide, diacetyl, and CO<sub>2</sub>, they also produce a large group of proteinaceous substances with significant antimicrobial or bacteriostatic activity, known as bacteriocins (Rzepkowska et al., 2017; Łaskiewicz et al., 2021), which in our experiment allowed us to increase the shelf life of sausages by 12 days. This partly explains the insufficient effectiveness of treating turkey or pork meat sausage products solely with lactic acid at concentrations of 1% and 2%, and 0.57 and 1.13%, respectively, for storage in modified atmosphere packaging in a chilled state. Such treatment of sausage products to suppress spoilage processes did not increase their shelf life beyond 22 days (Luong et al., 2020). A similar outcome was observed for the use of sodium lactate as a preservative, which did not extend the shelf life of cooked sausages in vacuum packaging even at maximum concentration (de Lima et al., 2022).

The use of vacuum packaging creates anaerobic conditions that affect the microbial composition during the storage of sausages (Spada et al., 2024), leading to the destruction of a significant number of aerobes in such conditions. However, considering that one of the main microorganisms causing spoilage in cooked meat products, including sausages, are members of the Enterobacteriaceae family, which are facultative anaerobes recognized as responsible for foodborne illnesses and resistant to antibiotics in anaerobic conditions, they may continue to proliferate and remain active. In such cases, the use of special strains of lactic acid bacteria starter cultures, such as SafePro BLC-48, which are also facultative anaerobes, may be effective by creating competition and unfavorable conditions for spoilage microorganisms (Li et al., 2021). Moreover, the use of specific strains of lactic acid bacteria starter cultures is considered a strategy for biocontrol of pathogens and spoilage microorganisms in meat products from ground meat and an alternative to chemical preservatives (Abouloifa et al., 2023). Another advantage of lactic acid bacteria starter cultures is their ability to improve the physicochemical and organoleptic characteristics of meat pro-

ducts during storage (Abouloifa et al., 2022), which is consistent with the results of our research.

Simultaneously, vacuum packaging, which removes air without replacing it with other gases, prevents water loss and contamination of the product by unwanted microbiota (Tømsgren et al., 2018), which aligns with the stable chemical composition indicators, especially the moisture content in sausages during 30 days of storage for both treatment options with lactic acid bacteria starter cultures. The use of a mixture of starter cultures SafePro BLC-48 + Bactoferm Rubis for treating sausages before vacuum packaging proved to be insufficiently effective and did not improve the shelf life of sausages, as aerobic conditions are required for the growth of the Bactoferm Rubis strain.

## Conclusions

Storage of "Juicy" sausages in vacuum packaging without treatment with lactic acid bacteria cultures ensures the stability of their chemical composition for up to 18 days of storage in a chilled state, but by the 21st day, signs of spoilage occur: the appearance of cloudy juice, sliminess, a sour odor, and delamination of the vacuum packaging.

Treating "Juicy" sausages with the SafePro BLC-48 starter culture (*Lactobacillus curvatus*) or a mixture of SafePro BLC-48 (*Lactobacillus curvatus*) + Bactoferm Rubis (*Lactococcus lactis* subsp. *lactis*) before vacuum packaging up to 30 days of storage in a chilled state does not affect the chemical composition of sausages in terms of moisture, protein, fat, and ash content. It also ensures organoleptic indicators in terms of taste, smell, and appearance characteristic of a product of proper quality. Spoilage of sausages for both treatment options with starter cultures occurs on the 36th day of storage in refrigerator conditions and is characterized by the appearance of cloudy juice, a sour odor, and delamination of the vacuum packaging.

The pH value of sausages for both treatment options with lactic acid bacteria cultures decreases throughout the storage period, reaching values of 6.05 and 5.91 on the 30th day of storage.

Treating "Juicy" sausages with both a single culture and a mixture of lactic acid bacteria starter cultures increases their shelf life in a chilled state by 12 days. The research results can be used to justify the use of microbial biopreservatives for storing sausages and other cooked meat products in vacuum packaging. The effectiveness of using a mixture of lactic acid bacteria cultures for treating sausages requires further investigation due to the presence of aerobic microorganisms causing their spoilage and the use of other types of packaging.

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