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Ensuring the food and biological safety of meat and meat-containing products from microbial contamination

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SUMMARY: Ensuring the safety and quality of meat products is vital due to their susceptibility to lipid oxidation and microbiological contamination, and poses challenges for public health and industry standards. This study aimed to assess the efficacy of plant-derived natural antioxidants in prolonging the shelf-life and maintaining the quality of beef products. Emulsions derived from CO_2 extracts of calendula, ginger, St. John's wort, green tea, and red pepper were evaluated for their efficacy in inhibiting lipid oxidation and microbial proliferation through a combination of experimental and microbiological investigations. The findings indicated that green tea displayed the greatest antioxidant activity among the evaluated plant extracts. The optimum dose of the emulsion, established at 0.8–1%, significantly mitigated lipid oxidation, controlled hydrolytic and oxidative degradation, and preserved the flavor, aroma, and color of meat products. This underscores the potential of plant-based emulsions as natural alternatives for enhancing the safety and shelf-life of meat.

KEYWORDS*: Bacteria; CO_2 extracts; Disinfection of equipment surfaces; Microorganisms; Ultraviolet irradiation.*

RESUMEN: ***Garantizar la seguridad alimentaria y biológica de la carne y los productos que contienen carne frente a la contaminación microbiana.*** Garantizar la seguridad y calidad de los productos cárnicos es vital debido a su susceptibilidad a la oxidación lipídica y la contaminación microbiológica, lo que plantea retos para la salud pública y las normas de la industria. El objetivo de este estudio era evaluar la eficacia de los antioxidantes naturales de origen vegetal para prolongar la vida útil y mantener la calidad de los productos cárnicos. Se evaluó la eficacia de emulsiones derivadas de extractos de CO_2 de caléndula, jengibre, hierba de San Juan, té verde y pimiento rojo para inhibir la oxidación lipídica y la proliferación microbiana mediante una combinación de investigaciones experimentales y microbiológicas. Los resultados indicaron que el té verde mostraba la mayor actividad antioxidante entre los extractos vegetales evaluados. La dosis óptima de la emulsión, establecida entre el 0,8% y el 1%, mitigó significativamente la oxidación lipídica, controló la degradación hidrolítica y oxidativa y preservó el sabor, el aroma y el color de los productos cárnicos. Esto subraya el potencial de las emulsiones vegetales como alternativas naturales para mejorar la seguridad y la vida útil de la carne.

PALABRAS CLAVE*: Bacterias; CO_2 extractos; Desinfección de superficies de equipos; Irradiación ultravioleta; Microorganismos.*

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1. INTRODUCTION

The assurance of food and biological safety in meat and meat-containing products is of paramount importance, given their susceptibility to microbial contamination, which poses significant health risks to consumers and substantial economic losses to producers. Meat products are inherently prone to spoilage due to their rich nutrient content, making them ideal environments for the proliferation of pathogenic microorganisms such as bacteria, viruses, and fungi. The increasing incidence of foodborne illnesses underscores the urgency of developing more effective methods for detecting, controlling, and eliminating microbial contaminants (Elbehiry *et al*., 2023). Moreover, the global trade in meat products necessitates stringent safety standards to prevent the spread of diseases across borders. Consequently, the challenge of maintaining the

microbial safety of these products while preserving their nutritional quality and sensory attributes is a critical concern for the food industry, regulatory bodies, and public health organizations. This situation calls for innovative approaches and technologies to ensure the safety and integrity of meat and meat-containing products throughout their production, processing, distribution, and storage phases.

In 2024, Kazakhstan's meat market was anticipated to provide around $12.58 billion in sales, representing a significant segment of the national food industry (Statista, 2024). The market is projected to rise yearly by 8.58% from 2024 to 2029, signifying a vigorous and growing industry. Household expenditure patterns highlight the significance of meat, as meat and meat products account for 17% of overall food purchase expenditures, representing the greatest proportion among all food groups (Bureau of National statistics of Agency, 2024). Per capita consumption indicates this need, averaging 80.1 kg of meat and meat products per year. The increasing demand for high-quality, minimally processed foods with prolonged shelf-life requires the advancement of preservation technology. The integration of natural plant extracts and advanced technologies in meat preservation addresses customer demands for healthier and more sustainable food alternatives.

The process of contamination by pathogenic and opportunistic microorganisms of food products is brought on by numerous factors. Maikanov *et al.* (2022) note that the bacteria of the *Enterobactericeae* family multiply in disturbed conditions of heat treatment, or in violation of the washing regime. Exposure to other stressors on microorganisms leads them to a non-culturable state in which they do not grow and multiply. Then the identification of bacteria by traditional microbiology methods becomes difficult. Temperature, irradiation, oxidative stress, pulsating electric field, starvation, lyophilization, preservatives and disinfectants act as stress factors which induce the transformation of microbial cells into viable non-culturable cells (Al-Gashgari *et al*., 2023).

The latter factor can trigger the contaminating bacteria to enter a non-culturable state, as Manap and Serikkyzy (2023) and Kenenbay *et al.* (2023) add. Currently, viable non-culturable cells have been described in more than 60 bacterial species. Gram-positive pathogens such as *Staphylococcus*, *Streptococcus*, *Listeria*, *Enterococcus*, *Mycobacterium*, *Corynebacterium*, *Lactobacillus*, as well as spores of *Bacillus*, *Clostridium* and Gram-negative bacteria have been identified among such pathogens: *Pseudomonas*, *Burkholderia*, *Vibrio alginolyticus*, *Shigella*, *Vibrio parahaemolyticus*, *Campylobacter jejuni*, *Yersinia*, *Aeromonas*, *Salmonella spp*., *E. coli*, *Citrobacter*, *Edwardsiella*, *Brucella*, *Cronobacter*, *Legionella*.

In their research, Issimov *et al.* (2022) pay special attention to the ability of microorganisms to acquire resistance to antiseptics and disinfectants. For example, 10% of *Listeria*, 13% of *Staphylococcus spp*. and 30% of *Pseudomonas spp*. showed resistance to quaternary ammonium compounds. The resistance of microflora to antibiotics and disinfectants was studied. The ability of microorganisms to adapt to unfavorable environmental conditions and the use of disinfectants leads to the formation of resistant strains of bacteria in industrial plants.

At the same time Abylgazinova *et al.* (2023) and Begdildayeva *et al.* (2023) state that, ensuring food safety is complicated by the development of resistance of microorganisms to the antibiotics used and the ability of many pathogenic and opportunistic bacteria to form biofilms that make it difficult to destroy microbial individuals on the surfaces of food processing enterprises. In this regard, American and European scientists are also conducting research on the use of such means of antimicrobial protection of meat products such as packages with modified gas atmosphere, commercial bacteriophages, bacteriocins, radiant energy using ultraviolet (UV) irradiators, ozonation and the most effective – electrochemically activated solutions.

The reviewed works describe in detail the pathways of occurrence and spread of pathogens and opportunistic pathogens in meat and meat-containing products, but they lack research on specific methods of solving this problem. Therefore, this study aims to characterize the influence of biological products of natural origin with antioxidant activity, as well as radiant energy and ultraviolet irradiators on ensuring the food and biological safety of meat and meat-containing products.

2. MATERIALS AND METHODS

This study used a set of scientific methods to investigate the effect of natural antioxidants derived

from plant extracts on the microbial contamination of meat and meat products with a focus on food and biological safety. Theoretical methods including analysis and synthesis of scientific literature from Kazakh and European sources in biology, engineering and philosophy provided the basis for this study. Using these methods, a basis for experimentation was established to formulate the main possibilities of using natural extracts to increase the shelf-life and safety of meat products.

The experimental part of the study was conducted on the basis of the Kuban State Technological University. First, the selection and preparation of samples of meat products, divided into two groups: control and experimental. The experimental group was treated with plant extracts known for their antioxidant properties which affect the lipid fraction of meat-containing products. The extracts were obtained from calendula, ginger, St. John's wort, green tea and red pepper using CO_2 extraction techniques to obtain oil-like or paste-like substances readily soluble in alcohols and fats.

In the study, a combination of specific diagnostic and empirical methods was employed to assess the physicochemical parameters of the samples. Diagnostic methods, such as pH measurements, spectroscopic analysis for chemical composition, and microbiological cultures for pathogen detection, provided direct evaluation of the quality of the samples. Meanwhile, empirical (experimental) approaches included controlled experiments to determine the effectiveness of different food handling and storage methods as well as the impact of different conditions on food safety and quality, which allowed for deeper knowledge of food safety standards and practices.

An important aspect of the study was a comparative analysis of the research of Western European and Kazakhstan sources on the problem of food and biological safety of meat and meat products. During the analysis, parallels and differences between different approaches to ensure the safety of these products from microbial contamination were drawn using the method of analogies. The experimental study was aimed at investigating the effectiveness of complex emulsions derived from vegetable raw materials in improving the technological and physiological characteristics of the target food products by incorporating biologically active substances into their formulation.

Aqueous and CO_2 extracts of plant materials were prepared according to strict guidelines, with aqueous extracts obtained by boiling the plant materials in water and sedimentation, and CO_2 extracts obtained by supercritical fluid extraction with natural carbon dioxide without the use of inorganic salts (Yıldırım *et al*., 2024). These extracts were evaluated for their antioxidant potential and effect on the lipid fraction of meat products.

Throughout the study, conventional methods including electrochemical activation of solutions were used to determine the physicochemical parameters of the solutions and meat products. Analytical instruments and techniques such as Excellence S475 multiparameter (METTLER TOLEDO, Switzerland), portable pH meters and an amperometric digital titrator for the titration of active ingredients were used. In addition, microbiological analyses including morphological classification of microorganisms, PCR analysis of residual cell fractions and time-of-flight secondary ion mass spectrometry were performed to evaluate the antimicrobial efficacy of the solutions.

3. RESULTS

To unify the test conditions and, consequently, simplify their reproduction on other research platforms, commercial preparations approved by the Ministry of Health of the Republic of Kazakhstan, sources of probiotic microorganisms recommended as dietary supplements, were used in the experiment.

As part of the implementation of the concept of creating biological products of natural origin with antioxidant activity against oxidative processes in the lipids of meat-containing products, complex emulsions obtained by the sonochemical method, based on water and CO_2 extracts from plant raw materials, were used. A clear, slightly pearlescent emulsion was obtained with a parts ratio (%): water 86.8; calendula, ginger (0.2 mg/g), St John's wort, green tea (82.3), red pepper; SO_2 complex of plant extracts 0.2; carrageenan 1%. The study was aimed at the selection of natural antioxidant substances for the protection of the lipid composition in meat products, based on the study of their antioxidant activity and composition in a variety of herbal infusions. The conducted amperometric test revealed the maximum presence of antioxidants of both types, lyophilic

and hydrophilic, in green tea. Interestingly, it was observed that mineral substances, with table salt as one of the carriers, occupy 70.4% of the composition of powdered soluble green tea extract.

The focus of this study lies in the development of food emulsions using vegetable oils which hold significant interest. Vegetable oils derived from plants possess valuable biotechnological properties that make them appealing, particularly due to their high linoleic acid content of up to 73% and their abundance of micronutrients such as vitamins and minerals. These properties contribute to their potential benefits in preventing premature aging and promoting overall health (Mogilyov *et al.,* 2023). In this study, a composite extract obtained from medicinal plants using CO_2 extraction techniques was employed. This extract contained beneficial compounds such as resveratrol and a variety of bioflavonoids known for their health-promoting properties. The objective of the experiment was to investigate the impact of ultrasonic exposure time and frequency on the particle size parameters and consistency of the emulsion.

To evaluate the effect of ultrasonic treatment, the experimental data were analyzed and are shown in Figures 1 and 2 of the report. These figures provide insights into the relationship between ultrasonic exposure parameters and the resulting particle size distribution as well as the overall consistency of the emulsion. The findings from this experiment have the potential to inform the food industry regarding strategies for utilizing vegetable oil-based emulsions, maximizing their stability, and ensuring desirable flavor profiles. Such advancements in emulsion technology can lead to the creation of a wide array of food products with improved sensory attributes and enhanced health benefits, catering to consumer demands and preferences.

Figure 1 demonstrates how processing frequency and duration affect the particle size of emulsions. The data represent the mean of three replicates (n=3) with frequencies (x-axis) shown in kilohertz (kHz). Statistical analysis was performed using one-way ANOVA with post hoc Tukey's test. Significant differences ($p < 0.05$) are denoted by different letters above data points. The particle size diminishes as the frequency escalates from 100 to 1300 kHz, regardless of the processing length. Prolonged processing durations (7 minutes) often yield bigger particle sizes than shorter intervals (3 and 5 minutes), suggesting that protracted ultrasonic exposure may lead to the development of larger aggregates or less efficacy in particle disintegration. The ideal particle size (~96 nm) is noted at the maximum frequency (1300 kHz) and reduced periods (5 and 3 minutes). A frequency of 700 kHz with a processing duration of 5 minutes attains an equilibrium between decreased particle size and energy efficiency. Standard deviation values were assessed in Table 1.

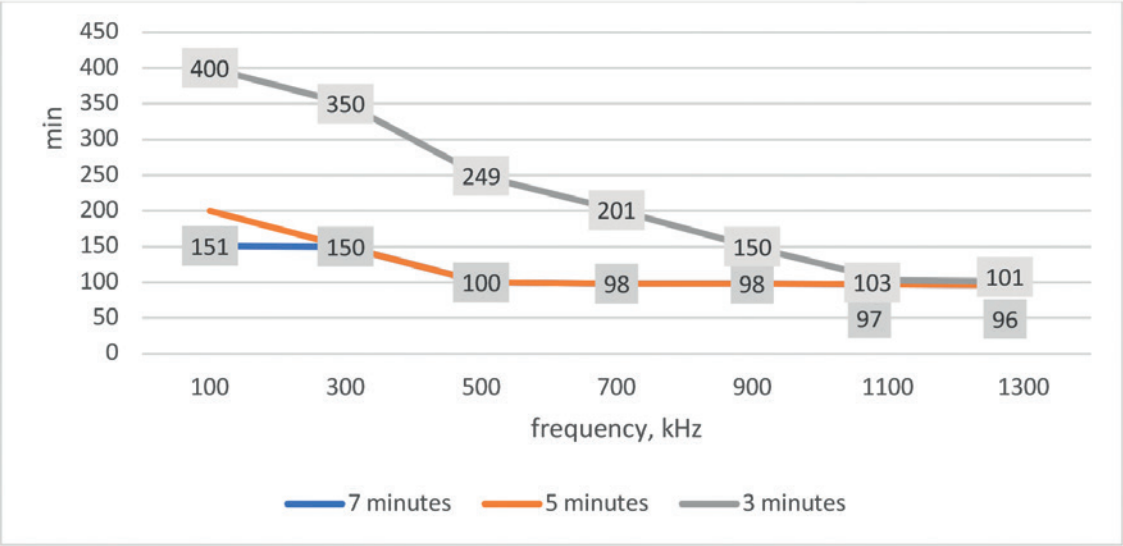

Figure 1. The relationship between emulsion particle size and variations in processing frequency (from 100 to 1300 kHz) and duration (from 2 to 7 minutes)

Table 1. Particle size distribution of emulsions processed at various ultrasonic frequencies and durations

Frequency (kHz)	Particle Size (7 min)	Particle Size (5 min)	Particle Size (3 min)
100	400 ± 15	151 ± 8	350 ± 12
300	350 ± 14	150 ± 7	249 ± 10
500	249 ± 12	100 ± 6	201 ± 8
700	201 ± 10	98 ± 5	150 ± 7
900	150 ± 9	98 ± 5	103 ± 6
1100	103 ± 7	101 ± 6	101 ± 6
1300	96 ± 6	96 ± 5	96 ± 5

Data represent the mean of three replicates (n=3) with frequencies (x-axis) shown in kilohertz (kHz). Statistical analysis was performed using one-way ANOVA with post hoc Tukey's test. Significant differences ($p < 0.05$) are denoted by different letters above data points. Figure 2 illustrates the impact of processing frequency and duration on emulsion stability, quantified in days.

The stability of the emulsion continuously improves with increased frequencies and extended processing times. After 1300 kHz and 7 minutes, stability attains its peak after 35 days. The short processing period (2 minutes) leads to markedly reduced stability across all frequencies, with the least stable emulsion seen at 100 kHz (4 days). Stability significantly enhances from 500 kHz to 700 kHz, after which it levels out over all lengths. This indicates that frequencies over 700 kHz do not significantly improve stability, and 5-minute processing intervals provide an effective balance between stability and processing duration. Standard deviation values are presented in Table 2.

According to the results of the study, the stability of the emulsion is manifested at a frequency of 700 kHz, during the optimal processing time – 5 minutes. A further increase in frequencies and reduction of particles to increase the stability of the food emulsion is not significant. In order to determine the appropriate amount of the formulated emulsion to be incorporated into food product formulations, an assessment was conducted to evaluate the extent of lipid oxidation in prototype meat samples. This

Table 2. Emulsion stability across different ultrasonic frequencies and processing durations

Frequency (kHz)	Stability (2 min)	Stability (5 min)	Stability (7 min)
100	4 ± 1.0	10 ± 1.2	16 ± 1.5
300	10 ± 1.1	16 ± 1.3	17 ± 1.4
500	15 ± 1.2	23 ± 1.5	25 ± 1.7
700	25 ± 1.4	30 ± 1.8	31 ± 1.9
900	27 ± 1.5	30 ± 1.7	31 ± 1.8
1100	30 ± 1.7	31 ± 1.8	32 ± 2.0
1300	30 ± 1.8	34 ± 2.0	35 ± 2.2

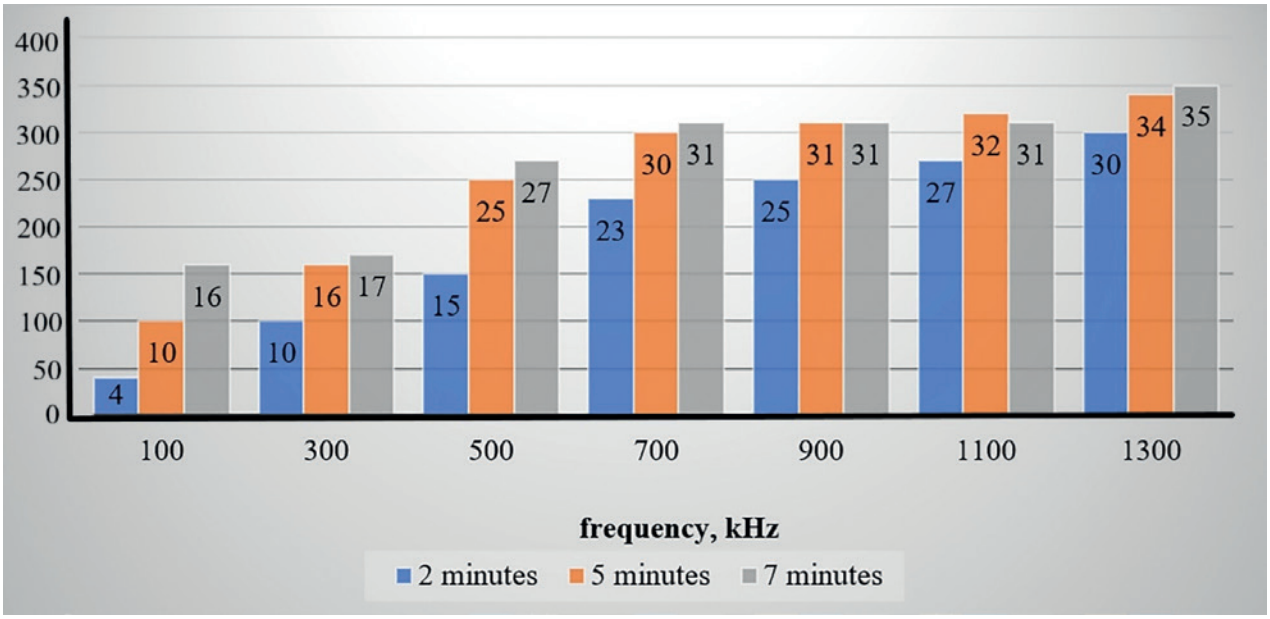

Figure 2. How emulsion stability is affected by alterations in processing frequency and duration

assessment involved monitoring changes in the levels of thiobarbituric acid reactive substances (TBARS), which are indicative of lipid oxidation.

The conducted studies have successfully determined the optimal dosage range for the emulsion, identifying it to be between 0.8 and 1% of the total formulation. This precise dosage range ensures the desired outcome in terms of oxidation control while maintaining product integrity. The formulation innovation and development of appropriate conditions for creating a complex food emulsion using aqueous and CO_2 extracts have brought about considerable advancements in the range of ingredients available for use in specialized product formulations. This expanded selection of ingredients now offers greater flexibility in designing meat products that cater to both physiological and technological requirements. The incorporation of these specialized emulsions has the potential to enhance the overall quality, shelf-life, and sensory attributes of the final meat products, satisfying the demands of consumers in terms of taste, texture, and appearance. This innovation opens up new avenues for product diversification and market competitiveness within the food industry.

The control batch was subjected to freezing at or below –18 °C for 90 days. The resistance of lipids in these frozen samples to degradation varied, as confirmed by the experimental results. Organoleptic inspection rated the quality of the control samples after a 90-day storage period as "poor". The detection threshold for lipid oxidation by-products was significantly lower, limiting the shelf-life of meat and meat-based products. Studies have shown that plant emulsion extracts inhibit hydrolytic and oxidative deterioration of lipids in meat products, which is attributed to the action of active elements (such as phenolic diterpenes, essential oils, carbonic acid, catechins and bioflavonoids) on the course of chain reactions, thereby improving the quality of meat and contributing to better preservation of taste, odor and color (Figure 3). In evaluating the effect of antioxidants from plant extracts on the sensory properties of meat and meat-filled products, attributes such as distinct flavor and aroma of meat, firm texture and moisture content were observed. No significant differences or signs of degradation were noted until 90 days had elapsed. However, after this period, the control samples acquired an odor and taste of "stale fat", indicating the oxidative degradation of lipids, and their texture became less elastic, which limited their shelf-life to 90 days. Conversely, samples treated with plant emulsion extracts maintained "satisfactory" quality for 207 days.

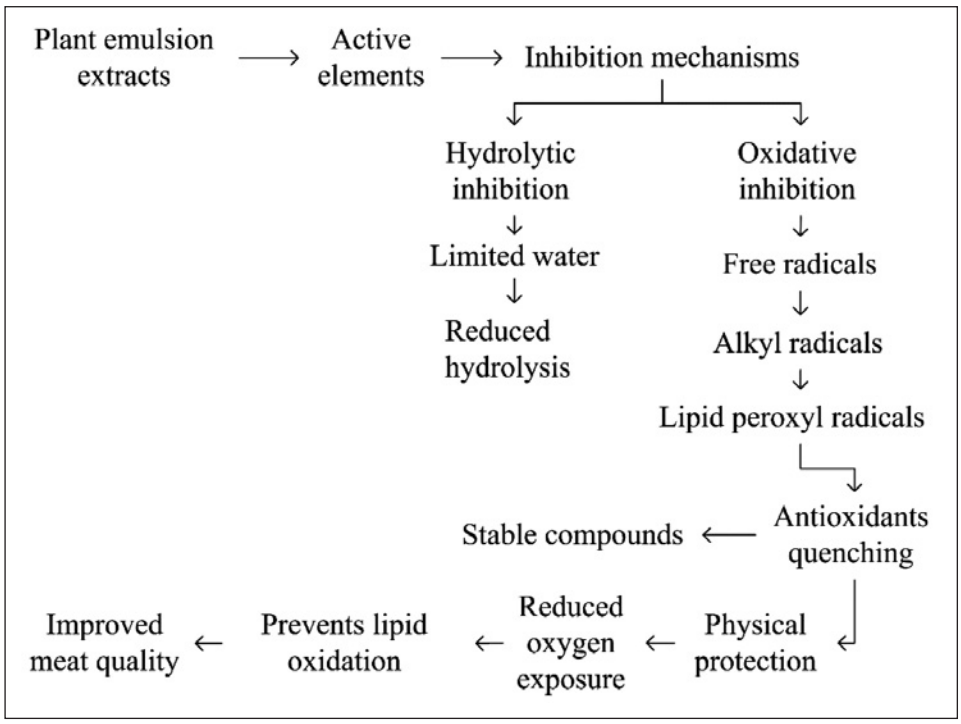

Figure 3. Mechanism of inhibition by plant emulsion extracts

The combination of cold storage with plant emulsion extracts markedly prolongs the shelf life of meat and meat products by leveraging the preservation properties of both techniques. Cold storage slows down the growth of microbes and oxidative reactions. On the other hand, plant emulsion extracts, which are high in antioxidants and antimicrobials, also stop lipid oxidation and microbe degradation. The use of these extracts in meat products can improve quality attributes such as color, aroma, and texture, resulting in a longer shelf-life compared to items kept without these enhancements. Collectively, they construct a more efficient preservation approach, sustaining the sensory and nutritional integrity of meat over prolonged periods.

The overall quality of frozen semi-finished products depends not only on biochemical transformations but also on the quality of raw materials, particularly fats. After six months of storage, meat products treated with emulsions of plant extracts showed 100% survival of infusoria, confirming their "non-toxicity". Antioxidant-enriched meat products were also characterized by increased potassium content, as well as significant amounts of manganese (152-155 μg/100 g) and iron (785-786 mg/100 g). Based on the safety and organoleptic evaluation, a confirmed shelf-life of 6 months at a temperature not exceeding –18 °C was established for these products. The implementation of modern technological solutions in meat processing enterprises plays a crucial role in extending the shelf-life of various products. The scientific findings presented in this study provide valuable insights into controlling the growth and reproduction of microorganisms in the food industry, thereby enabling the production of high-quality meat products using different approaches.

One potential strategy to enhance food and biological safety in the meat industry involves the integration of physical methods, such as radiant energy and UV irradiators, along with the application of ozonation for disinfecting drying chambers and employing radiation treatment. These methods serve as additional tools to ensure effective microbial control and enhance food safety measures for meat and meat-containing products. Furthermore, the use of UV rays for treating surfaces, equipment, and containers within industrial facilities yields positive outcomes for maintaining sanitary and hygienic conditions. Such treatment contributes to improved air quality and, subsequently, extends the shelf-life of meat products. This approach represents a valuable addition to the arsenal of techniques employed to ensure the safety and quality of meat products, providing industry professionals with diverse methods to combat microbial contamination. By adopting these advanced methods and incorporating them into food processing practices, meat industry stakeholders can uphold high standards of food safety, resulting in products with extended shelf-life and improved overall quality. This integration of modern technical solutions contributes to better preservation, hygiene, and consumer satisfaction in the meat industry.

Such processing, on a production scale, requires strict regulations for compliance with freezing technologies. The procedure is carried out by shock freezing at temperatures from +20 to 0 °C (cooling), from 0 to –5 °C (freezing) and from -5 to –18 °C (freezing). These three stages ensure a high speed of processes, which reduces the freezing time of meat and meat-containing products by more than four times. Despite the main disadvantage of the high cost of equipment, it is actively used not only in large restaurants or manufacturing enterprises, but also in small enterprises of the food industry. After freezing, the minimum dose of irradiation ensures the preservation of the technical characteristics of meat products, and the maximum dose serves to preserve the structural integrity of the assortment, functional and organoleptic properties of the product, thus providing safety for the consumer. If these storage conditions are not observed, the procedure will have to be repeated, which is why the quality and value of meat products will decrease. The area of UV radiation that accounts for maximum bactericidal sensitivity is carried out at a wavelength of 265 nm. At the same time, ultraviolet radiation is ineffective for some types of bacteria and fungi, and radiation cannot penetrate the hidden cavities of raw materials or deep into the product.

Multiple variables contribute to the ineffectiveness of UV radiation against certain bacteria and fungi, including the microorganism's resistance mechanisms, the existence of protective structures like biofilms, and the depth of microbial colonies within substrates. For example, spore-forming fungi and some bacterial species have developed DNA repair mechanisms that enable them to endure UV damage, whereas biofilms can protect microorgan-

isms from direct exposure. Moreover, UV radiation possesses restricted penetrating powers, rendering it useless in accessing concealed cavities or deeper strata of raw materials. Although augmenting the intensity or dosage of UV irradiation can improve its effectiveness, this strategy requires meticulous oversight to prevent potential harm to the product or the environment, since elevated levels may result in adverse alterations in food quality or safety (Table 3).

During the course of the study, it was observed that when microorganisms are exposed to UV irradiation, the thymine molecules in their deoxyribonucleic acid form dimers, leading to a hindered growth and reproduction rate. To assess the efficacy of inactivating plant raw materials, a combination of ultra-high frequency fields and UV radiation was employed. In this approach, a meat sample contaminated with *Salmonella spp*. test culture was initially treated with 400 W microwaves for 40 seconds, followed by UV irradiation at a dosage of 50 kJ/m^2 for 15 minutes. The experimental outcome demonstrated a significant reduction in bacterial counts when microwave and UV radiation were utilized in conjunction, resulting in an 8-log decrease in the number of bacteria. In comparison, UV radiation alone resulted in a 5-log reduction. These findings indicate that the combined effect of both types of radiation substantially enhances the effectiveness of disinfection, offering a promising method for microbial inactivation within the food industry.

By leveraging the synergistic impact of microwave and UV radiation, the food industry can potentially enhance its disinfection protocols and minimize microbial contamination risks. This innovative approach presents an opportunity to improve food safety measures and reduce the presence of harmful microorganisms in food products, thereby ensuring consumer protection and preserving the quality and integrity of the food supply. Continued exploration and implementation of such combined radiation methods may contribute to advancements in the field of food safety and aid in the production of safer and healthier food products. The introduction of high-tech methods to ensure the food and biological safety of meat products will allow the Republic of Kazakhstan to supply high-quality chilled raw materials with a prolonged shelf-life to the foreign market.

Table 3. Methods for enhancing the shelf-life and quality of meat and meat-containing products

Method	Advantages	Disadvantages
Radiation Treatment	Prolongs shelf-life Effective against microbial growth Widely approved and used	High cost of equipment Potential consumer resistance Limited penetration ability
Bacteriophage Treatment	Targets specific pathogens Innovative packaging solutions Maintains microbiological integrity	Limited effectiveness for some strains Expensive to implement
Use of Bacteriocins	Heat resistant Natural preservative Effective against specific bacteria	Mechanism not fully understood Variability in bacterial resistance
Lactic Acid Bacteria	Enhances organoleptic properties Shortens ripening time	Limited effectiveness for lactic acid-producing microorganisms
Modified Atmosphere Packaging (MAP)	Prevents spoilage Dynamically adjusts internal environment Compatible with various products	Expensive equipment Higher product cost
Active Packaging	Provides long-term protection Enhances food safety	Limited scalability High implementation cost
Edible Coatings	Biodegradable Antimicrobial properties Environmentally-friendly	Limited to specific applications Requires further optimization for widespread use
High-Pressure Processing	Reduces cooking time Extends shelf-life Suitable for heat-sensitive products	High cost of equipment Possible impact on sensory attributes

4. DISCUSSION

The results obtained indicate a sufficiently high level of effectiveness of the measures taken to ensure the food and biological safety of meat and meat-containing products from microbial contamination. Nevertheless, for the information to be objective and relevant, it should be compared to similar works by other authors.

For example, Chalmers *et al.* (2020), Mohan *et al.* (2022) and El-Sayed *et al.* (2021) point out that Europe alone puts more than 200,000 tonnes of irradiated products on the market each year. More than 50 countries provide treatment for agricultural and food products, 7 countries have approved it for meat products, 13 for fish and seafood, and radiation treatment of spices is practiced worldwide. The degree of radiation exposure is based on the physical and biological parameters of the effect on a living cell and depends on the selected dose and type of radiation. Low doses inhibit the growth of microorganisms, prolonging the shelf-life of products. This indicates the prevalence of this method, although in the above study it can be seen that the most effective is the use of combined action.

In 2023, bacteriophage treatment was used in France to decontaminate microorganisms before packaging products with phage-containing food ingredients, as noted by Xie *et al.* (2024) and Neffe-Skocińska *et al.* (2020) Innovative packaging solutions have been developed that utilize cellulose membranes impregnated with a bacteriophage suspension and phages encapsulated in alginate beads. This approach, along with the use of films impregnated with liposomal phage capsules, is aimed at preserving the original microbiological integrity of food products, which may become useful for the use of such a technique in the Republic of Kazakhstan.

In addition to traditional preservatives for extending the shelf-life of food, Muzolf-Panek *et al.* (2020), Osaili *et al.* (2021) and Firmanda *et al.* (2023) note the popularity of the use of bacteriocins and the bacteria that produce them. Their heat resistance makes them interesting for use as food preservatives, which is particularly relevant for countries with a developed food industry. In Middle Eastern countries, the annual incidence of food poisoning-related illnesses is very high. At the same time, the use of bacteriocins as food preservatives has not been sufficiently studied, although the experience of German colleagues shows the effectiveness of such a method. The sensitivity or resistance of bacteria to the action of bacteriocins is determined by the presence of special receptor structures on the cell surface, which regulate the selective activity of bacteriocins against bacteria of different species. In the above study, positive rates of CO_2 extract utilization were demonstrated, which is also related to the receptor reflexivity of bacteria.

The mechanism of the action of bacteriocins is heterogeneous and not fully understood, D'Amore *et al.* (2020), Zdolec and Kiš (2021) and Osemwowa *et al.* (2021). For example, the mechanism of the damaging action of nisin is not related to the presence of receptors. Nisin interacts with the inner membrane, forming ion channels through which hydrophilic components with molecular masses up to 0.5 kDa are transported. Lactococci, lactostreptins and diplococci do not contain lanthionine, interact with a specific receptor and form pores. "Nisin", as an antibiotic substance produced by certain strains of Lactococcus lactis, is related to bacteriocins (Sabitov *et al.,* 2021). As a preservative, nisin is used in the food industry. In the industry, the drug nisin is referred to as "nisaplin". These clarifications are very important for selecting the right strategy to ensure the food and biological safety of meat and meat-containing products from microbial contamination for Kazakhstan producers.

The use of lactic acid bacteria as a source of bacteriocins has practical potential. Bouriga *et al.* (2023), Leroy *et al.* (2023) and Tayeb *et al.* (2023) claim that, among other things, they make it possible to influence the course of the technological process by shortening the ripening time and improving the organoleptic properties of the finished product. Microcins, polypeptide antibacterial substances of low molecular weight, which pharmacologists consider to be very promising inhibitors of microorganisms onto which indicator strains settle, are considered related and even similar to bacteriocins as anticontaminants. The diffusion method is considered by scientists to be a very effective screening method. It can be used to study the quantification of the action of bacteriocins on indicator strains. The speed of this process is influenced by the size of the bacteriocin molecule and, consequently, the ability of bacteriocins to pass through a membrane of

a certain size (cellophane). This method is reasonable to use when testing certain strains. In addition, this method is not always effective for testing lactic acid microorganisms that produce lactic acid during growth, which also has a bactericidal effect.

In turn, Kumar *et al.* (2021), Courrol and Vallim (2021) and Mohammed *et al.* (2020) argue that the use of packaging technology prevents the spoilage process of meat products. For products that are highly resistant to gas penetration, modified atmosphere packaging is used. In addition, for products that are subject to "breathing" during their entire shelf-life, controlled atmosphere packaging is used. This method involves dynamically adjusting the internal gas environment inside the package, which changes throughout the shelf-life due to the respiratory activity of the stored products, biochemical transformations and the gradual migration of gases through the packaging material. Thanks to special film materials, certain components, including preservatives and antiseptics, are introduced into the material of "active" packaging. These preparations are universal; they can be applied to polymer packaging to ensure the long-term protection of meat products, and are used for surface treatment. This information is very important because the above study only looked at internal exposure formulations, while films have positive potential.

Nevertheless, studies by Zhang *et al.* (2023) and Elmassry *et al.* (2022) criticize this technique. According to their statements, the disadvantage of packaging technology is more expensive processing equipment, due to which, the cost of the product increases significantly. The technology of processing products under high pressure is known, the advantages of which are the reduction in cooking time, the possibility of use with products which are sensitive to heat, and the extension of shelf-life. The disadvantage is the high cost of equipment and the deterioration of organoleptic indicators. This indicates the correctness of considering internal methods of influence to ensure the safety of meat in the Republic of Kazakhstan.

Researches Michalczyk *et al.* (2021), Segueni *et al.* (2023) and Adetuyi *et al.* (2024) show successful practices in the use of edible coatings. An Indian university has developed antimicrobial, biodegradable films for food packaging that provide protection against *E. coli*, *Salmonella*, *Listeria monocytogenes*. The film is produced by mixing soybean and cereal grains with glycerol and 4% nisin powder, so that it contains not only nisin but also various enzymes. This is a very important study not only from the biological point of view, but also from the ecological point of view, which may have prospects for use in the Republic of Kazakhstan.

Thus, the reviewed research confirmed the information provided in the above study and advanced the ideas of ensuring the food and biological safety of meat and meat-containing products from microbial contamination to a new level.

5. CONCLUSIONS

The results showed that the use of natural extracts increased the shelf-life and safety of meat products. The complex emulsions obtained from vegetable raw materials showed antioxidant activity and improved the quality of meat products. These emulsions remained stable at 700 kHz with optimum processing time of 5 minutes. The incorporation of plant emulsion extracts into meat products reduced the oxidation rate, resulting in an increased shelf-life of up to 207 days compared to the control group, whose shelf-life was limited to 90 days. The treated samples also demonstrated sensory properties such as distinct flavor, aroma, firm texture and moisture content.

The study recommended the use of complex emulsions in meat product formulations and established a confirmed shelf-life of 6 months at a temperature not exceeding -18 °C. In addition, the combination of microwave and ultraviolet radiation showed promising results in the disinfection of meat products. In conclusion, this study showed that the use of natural extracts and complex emulsions derived from vegetable raw materials can increase the shelf-life, safety and quality of meat products. The experimental findings demonstrated a substantial decrease in the number of bacteria when microwave and UV radiation were employed in conjunction, resulting in an 8-log reduction in bacterial counts. In comparison, the application of UV radiation alone led to a 5-log reduction. Consequently, the combined utilization of these two radiation methods significantly enhances the disinfection efficacy, making it a promising approach for microbial inactivation within the food industry.

Future studies are suggested to investigate the application of high-tech techniques such as ozonation in the food industry to ensure food and biological safety. In addition, the study recommends that attention should be paid to freezing techniques, storage conditions and microbial inactivation to improve the quality and value of meat products.

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DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

AUTHORSHIP CONTRIBUTION STATEMENT

Sh Abzhanova, S Sabraly, Ye Yerzhigitov, A Katasheva, B Rskeldiyev contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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