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Research on the Development and Application of Antimicrobial Food Coatings to Preserve the Quality and Extend the Shelf Life of Meat and Poultry

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Abstract: Preservation techniques to prolong the freshness and usability of food items are currently a primary focus of innovation within the food industry. To this end, refrigeration has long been used in meat products; however, it does not prevent weight loss or eliminate the risk of product contamination with pathogenic microorganisms. In order to address the issue of spoilage, businesses are increasingly utilizing edible Film-Forming Substances (FFS) in conjunction with refrigeration for meat preservation. This method has proven effective in extending the shelf life of meat products considerably. This research investigates the combined effect of cryogenic storage temperatures and varying concentrations of lactic acid within food coatings on the proliferation of mesophilic aerobic, facultative anaerobic, and psychrotrophic bacteria. The study aims to shed light on a novel aspect of food preservation by exploring the synergistic relationship between these factors. It has been shown that lactic acid, due to its low dissociation constant and high penetrating ability, significantly reduces the contamination of poultry meat with mesophilic aerobic, facultative anaerobic, and psychrotrophic microorganisms when used in food coatings. Significant inhibition of the development of psychrotrophic microorganisms is observed at an acid concentration of 0.5%, while for QMAFAnM a similar effect occurs at a concentration of lactic acid in the film-forming composition (FPS) of 1.5%. It was also shown that when 2% lactic acid is introduced into a solution of film-forming compositions based on monoglycerides, a significant decrease in pH is observed from the initial 7.85-2.67, and for compositions based on lactic acid there is an average decrease in pH value from 4.6-3.1. This research holds practical value as it aims to establish a robust technique for minimizing microbial contamination in meat products. This, in turn, would substantially extend their shelf life and bolster consumer food safety. The findings derived from this study can be directly applied within the food and poultry processing sectors, leading to enhanced quality and safety standards for poultry products.

Keywords: Film-Forming Composition, Poultry Meat, Barrier Properties, Moisture Loss, Hydrolytic and Oxidative Processes, Cold Storage

Introduction

Contemporary consumers are increasingly seeking premium food items that boast extended freshness while remaining free from artificial preservatives. Traditional technologies of physical or chemical processing during the production and storage of poultry meat, as well as examination of its safety, developed in the mid-twentieth century, are noticeably outdated and require further improvement to the level of modern achievements of industrial science. The use of Edible Films and Coatings (EFCs) enhanced with natural antimicrobial substances presents a promising strategy for preserving both raw and processed meats. These films act as a protective barrier, inhibiting the growth of harmful pathogens and slowing down the decomposition process. Contemporary film-

forming formulations enable the preservation of the quality of chilled meat products during extended storage periods, exceeding six months, while minimizing energy consumption. The efficacy of different antimicrobial coatings for food preservation is influenced by several factors. These include:

- The initial microbiological quality of the meat product
- The specific ingredients used in the coating formulation
- The properties of the packaging material acting as a barrier
- The level of existing microbial contamination on the product
- The storage environment and conditions

When included in edible film-forming formulations, natural antimicrobial agents add functionality to edible coatings, resulting in Antimicrobial Edible Films and Coatings (AEFCs). The increased interest in developing and using AEFCs to preserve the quality of meat and poultry over a longer shelf life is based on consumer demand for natural and safe products.

AEFCs based on proteins, lipids, and polysaccharides, with organic acids and bacteriocins included, can be produced (Cutter, 2006; Debeaufort and Voilley, 2009). Incorporation of lipids into EFCs for meat and poultry processing can improve hydrophobicity, cohesivity and flexibility, creating superior moisture barriers and resulting in retention of freshness, colour, flavour, tenderness and microbiological stability.

Polysaccharide-based films and coatings contribute to the preservation of meat products by mitigating moisture loss and inhibiting the process of oxidative deterioration (Gennadios *et al*., 1997; Cutter, 2006). The most frequently described AEFCs in the literature are those based on chitosan polysaccharides, which are used for packaging hamburgers, pork and sausages (Vargas *et al*., 2011; Siripatrawan and Noipha, 2012). Chitosan, a versatile polymer, demonstrates efficacy as both a protective coating material and an antimicrobial agent when applied to beef fillet and chicken breast (Petrou *et al*., 2012; Higueras *et al*., 2013; Cagri *et al*., 2004), sliced turkey (Jiang *et al*., 2011; Guo *et al*., 2014), herring (Jeon *et al*., 2002), sea bass fillets (Günlü and Koyun, 2013), and cod. The application of a chitosan polysaccharide coating effectively impedes the passage of oxygen and consequently restricts the proliferation of bacteria that require oxygen for survival. The effectiveness of chitosan as an antimicrobial agent is influenced by several factors, including its specific chemical structure, molecular weight, and surrounding environmental circumstances (Siripatrawan and Noipha, 2012). Chitosan, in conjunction with lauryl arginate and nisin, has demonstrated effectiveness as a film or coating for reducing the presence of *Listeria monocytogenes* bacteria on prepared turkey (Gómez-Estaca *et al*., 2010) and fish (Günlü and Koyun, 2013).

For many years, researchers have been diligently seeking alternatives to synthetic chemical preservatives in order to minimize microbial contamination of food products, particularly by harmful pathogens. Bacteriocins are antimicrobial proteins generated by bacteria. These molecules exhibit a positive charge (cationic) and possess either hydrophobic or amphiphilic properties, meaning they can interact with both water and lipids. They are synthesized by ribosomes within the bacterial cell (Choi *et al*., 2023). Bacteriocins are a diverse group of polypeptide molecules classified according to their mechanisms of action and structural characteristics. One of these classes is lantibiotics, which include unusual acids such as dehydrobutyric acid and L-cysteine, as well as thioester amini acids (lanthionine and β-methyllanthionine), formed as a result of post-translational modifications of precursors synthesized on the ribosome. Lactic acid bacteria produce a class of antimicrobial peptides called lantibiotics, which hold significant promise for food safety applications. Notably, these lantibiotics possess "Generally Recognized As Safe" (GRAS) status, signifying their established safety for direct use in the food industry. Genes encoding the production of bacteriocins can have both chromosomal and plasmid localization. Sometimes, they can be found in mobile genetic elements such as transposon-like elements or DNA phage. Lactic acid bacteria actively produce bacteriocins and are also used as protective cultures (Fischer and Titgemeyer, 2023; Webb *et al*., 2022). The primary mechanism by which lactic acid bacteria exhibit antimicrobial properties involves three key factors:

1. Acidification: They lower the pH of their environment through the production of lactic acid
2. Nutrient depletion: They compete with other microorganisms for essential nutrients, limiting their growth
3. Inhibitory compound production: They synthesize metabolites that directly inhibit the growth of competing microbes

Biopreservation involves utilizing microorganisms or substances produced by them that possess antimicrobial properties, as a means to prolong the freshness and safety of food items. Lactic Acid Bacteria (LAB) produce bacteriocins, which are proteins deemed safe for consumption. These proteins are broken down by enzymes in the digestive system into their constituent amino acids, providing nutritional benefits to the host organism. Lactic acid bacteria are essential microorganisms involved in a wide variety of food fermentation processes. Fermentation processes significantly extend the longevity of food products when

compared to their unprocessed counterparts. Their inhibitory effect on unwanted bacteria is particularly significant for lactate production, competition for nutrients, hydrogen peroxide formation, and, for some strains, bacteriocin production. The utilization of a multifaceted approach to food preservation, incorporating physical, chemical, and biological methods, is crucial to the "barrier concept". This concept emphasizes the creation of multiple layers of protection against spoilage agents. Bacteriocins and bacteriocin-producing cultures can serve as two barriers in canning (Baindara and Mandal, 2022; Leichtweis *et al*., 2021).

To date, the most studied lantibiotic secreted by *Lactococcus lactis* is nisin (Soltani *et al*., 2021).

Initial research on the effectiveness of nisin against Listeria bacteria revealed that a concentration of 104 IU/kg significantly reduced Listeria contamination in meat. After 7 days of refrigeration at 5°C, samples treated with this nisin concentration exhibited a substantial decrease in Listeria levels, ranging from 200-250 CFU/g, compared to the initial contamination level. Despite its antimicrobial properties, nisin proved ineffective in inhibiting the growth of *Listeria monocytogenes* and *Staphylococcus aureus* when these bacteria were introduced into meat specimens and subsequently incubated at ambient temperature. Chung *et al*. (1989); Chomanov *et al*. (2023). The findings strongly suggest that nisin exhibits bacteriostatic properties, meaning it inhibits bacterial growth rather than killing them. Therefore, for optimal effectiveness, nisin application should be coupled with cold storage methods.

Organic acids are essential for ensuring the microbial safety of meat and meat products. Their effectiveness is often amplified when used alongside other antimicrobial substances.

This research paper investigates the optimal concentration of lactic acid within a food Film-Forming Composition (FFC) used in poultry meat processing. This composition was widely used for processing cattle meat at meat industry enterprises in Russia and Kazakhstan.

This research investigates the impact of edible coatings composed of monoglycerides and whey protein, enhanced with organic acids and the bacteriocin nisin, on the microbial spoilage of poultry carcasses during refrigeration.

Materials and Methods

The object of the study was the carcasses of 18 broiler chickens, a food Film-Forming Composition (FFS) based on distilled Mono Glycerides Distilled (MGD) and Acetylated Monoglycerides Distilled (AMGD) with the introduction of lactic acid of various concentrations into their composition.

Poultry carcasses produced by the Petelinskaya Poultry Farm JSC GOST 31962-2013 were purchased at the Auchan store. The carcasses were stored at a temperature of 0±2 C and a relative humidity of 85-90%, no more than 1 day before the start of the experiments.

The collection of samples for microbiological, physicochemical, histological, and sensory analyses adhered to the standards outlined in GOST 31467-2012 "Meat, offal and semi-finished products from poultry meat. Methods of sampling and their preparation for testing." The microbiological study adhered to strict aseptic techniques throughout the sampling and preparation phases. This involved the utilization of sterilized equipment, tools, and materials to prevent any contamination from external sources.

At the first stage of work, to substantiate the technological storage modes, the cryoscopic and maximum supercooling temperatures of poultry meat were determined. The study investigated the effects of different cooling techniques, specifically those involving gradual reductions in ambient temperature within a controlled environment (TSV-02 dry-air thermostat), on the preservation and storage quality of food items.

The cryoscopic and supercooling temperatures of poultry meat were determined using thermographic analysis, taking into account the stabilization of temperature on the freezing curve or the sharp change characteristic of the transition of water into ice. Air, poultry meat, and poultry product temperatures were precisely assessed using a multichannel MIT-8.10M temperature metering device (Fig. 1).

The temperature of the cooling medium and products was controlled using modern precision instrumentation, which captures and records data and then transfers it to a computer for display in the form of graphs. The objects of the study were samples of poultry meat and poultry products purchased in a retail chain: (1) Chilled chicken breast fillet, (2) Smoked-boiled chicken breast fillet, (3) Raw smoked chicken breast fillet, (4) Chilled broiler leg, (5) Chilled broiler breast fillet.

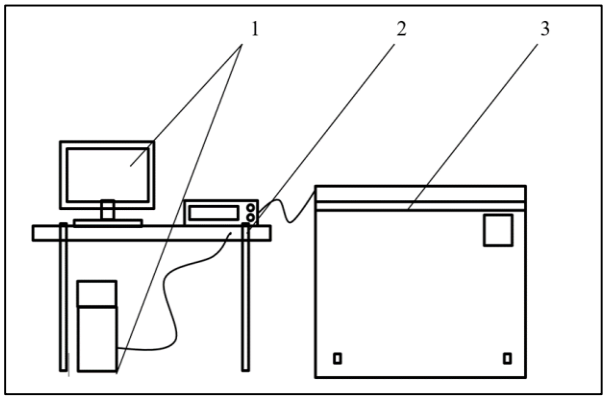


Fig. 1: Scheme of the experimental stand: (1) Personal computer, (2) Multichannel precision temperature meter MIT 8, (3) Dry air thermostat TSV-02

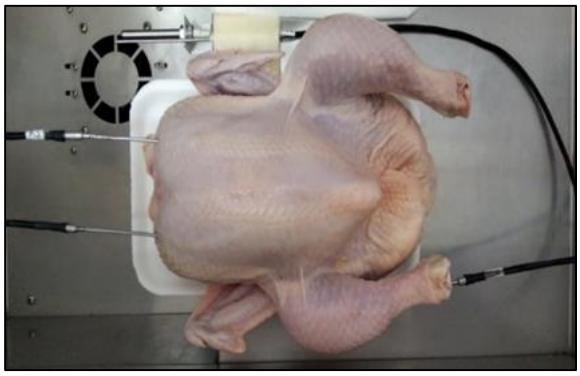
The study examined different cooling methods to determine the optimal temperature of the cooling medium required for maintaining a stable supercooled state in poultry at sub-freezing temperatures. Various initial thermal states of the poultry were considered. The studies were carried out according to a pre-developed algorithm, which provided for a slow stepwise decrease in air temperature until the maximum supercooling temperature of the product was reached (Zhlobo *et al.*, 2023).

Photos of the products used in the experiments and the placement of instrument sensors are shown in Fig. (2).

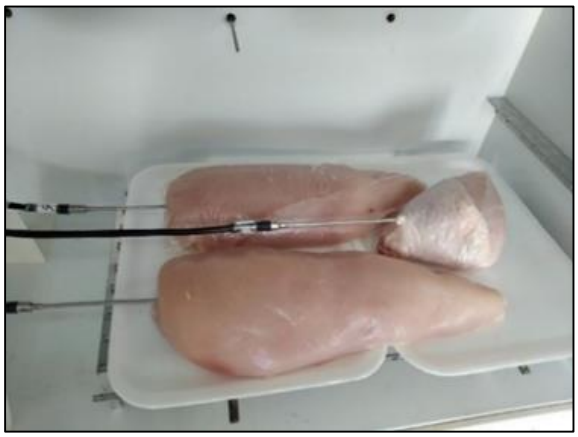
At the second stage, the influence of preservatives in the composition of various FFFC on changes in the active acidity of the medium (pH) and oxidation-reduction potential (Eh) was determined.

The composition of FFFC included distilled monoglycerides (TS 9145-357-00334623-2003) and distilled acetylated monoglycerides (TS 7511903-626-93), produced by NNOFP (Nizhny Novgorod Oil and Fat Plant) Russia, and lactic acid GOST 490-2006 produced by JSC SKIMK, Ryazan, Russia.

The food coating was prepared with the inclusion of lactic acid in a 3% FFFC solution with concentrations of 0.5; 1.0; 1.5; and 2.0%.



(a)



(b)

Fig. 2: Products used in the experiments and placement of instrument sensors

A lactic acid concentration of 0.5% was taken according to the recommendation of Mild *et al.* (2011), and 2% was taken as the maximum permissible concentration, based on the presentation of poultry carcasses. When the concentration of lactic acid in the FFFC solution increases above 2%, a change in the color of the bird's skin occurs (the appearance of white spots).

FFFC solutions were applied to the surface of poultry carcasses by spraying using a hand-held sprayer (Gigant 500 mL IAG-013). The solution temperature was 50±2°C. During the experiments, for each concentration of lactic acid, 5 (five) half carcasses of broiler chickens were used. Control (with FFFC coating without lactic acid) and test samples of poultry carcasses were stored at a temperature of 0±2 C and a relative humidity of 85-90% for 5 days.

For each of the indicated FFFC concentrations, the average values of Colonies of Mesophilic Aerobic and Facultative Anaerobic Microorganisms (CMAFanM) and psychrotrophic microorganisms were calculated after processing poultry carcasses and during their storage.

When determining the effect of preservatives in various FFFC on changes in the active acidity of the medium (pH) and oxidation-reduction potential (Eh), poultry carcasses were treated with the following compounds (WWN-Whey With Nisin, WWG-Whey With Glycerin, LA-Lactic Acid, CA-Citric Acid):

1. Food Film-Forming Composition (FFFC) based on monoglycerides, glycerin and lactic acid (FFFC-10 3% + LA 2%)
2. FFFC based on whey, glycerin and lactic and citric acids (WWG 5% + glyc. 10% + LA 2% + CA 0.2%)
3. FFFC based on whey, glycerin, lactic and citric acids and nisin (WWN 5% + glyc. 10% + LA 2% + CA 0.2% + nisin)

The recipe and microbiological and organoleptic characteristics of industrially produced FFFC based on monoglycerides are given in Tables (1-2).

Table 1: Recipe for FFFC coating based on monoglycerides, glycerin, and lactic acid-in terms of dry matter

Name of raw materials	Consumption kg. per 100 kg food coating
Food film-forming composition FFFC-10	3.0*
Distilled monoglycerides	0.84
Auxiliary emulsifier according to enterprise standard Nizhny novgorod oil and fat plant 020500-59-86	0.48
Potassium sorbic acid or sorbic acid	0.06
Distilled acetylated monoglycerides	1.32
Distilled glycerin	0.3
Lactic acid	2.0
Drinking water	95.0

Table 2: Organoleptic and microbiological parameters of food film-forming coating based on monoglycerides

Indicator name	Characteristics of indicators for coating preparation
Consistency	Homogeneous emulsion
Color	White to cream
Smell	No smell
Dry matter content in food coating, %	3.0
Total number of mesophilic aerobic and facultative anaerobic microorganisms in 1 g of food casing at the exit from the nozzles (before application to poultry carcasses), no more than	$1 \cdot 10^2$

At the third stage, the sanitary and bacteriological condition of meat samples was studied for the presence of psychotropic microorganisms and QMAFAnM.

The number of psychrotrophic microorganisms was determined according to GOST ISO 17410-2013 " Microbiology of food products and animal feed. Horizontal method for counting psychrotrophic communities "

Microbial analyses were conducted on poultry carcasses at three distinct stages: Prior to the application of film-forming compounds, immediately following treatment, and again after 3 and 5 days of storage. The samples were inoculated with a lawn in Petri dishes in PCA medium, after which they were placed in a thermostat at a temperature of 6.5°C and kept for 10 days. At the end of the thermostatting period, the colonies were counted.

The QMAFAnM in poultry meat, by-products, and semi-finished poultry products adheres to the standards outlined in GOST R 50396.1-2010. This Russian standard provides a specific methodology for determining the quantity of these microorganisms in poultry-based food items.

A representative sample of the product was collected and subsequently subjected to a serial dilution process, wherein each dilution was ten times less concentrated than the preceding one. The study aimed to quantify the population of mesophilic aerobic and facultative anaerobic microorganisms. This was achieved by preparing dilutions of the sample and selecting those that resulted in a countable number of colonies (no more than 300) when cultured on Petri dishes. Inoculations were carried out using the deep agar method.

One-milliliter aliquots of successive dilutions were inoculated into Petri dishes. Within 15 minutes following inoculation, 18 milliliters (±2 mL) of agar culture medium, melted and cooled to a temperature of 45 degrees Celsius (±1 degree), was dispensed into each inoculated cup. The inoculum was then evenly distributed throughout the agar and allowed to solidify completely.

Following solidification of the growth medium, the dishes containing the crops were incubated in a controlled-temperature environment maintained at 30 degrees celsius (± 1 degree) for a duration of 72 h (± 3 h).

Results

Food products are systems where some of the substances are in a dissociated state, for example, organic acids and the other part is represented by large molecular associations, such as proteins. In addition, water in cells is present not only in a free state as a solvent but also in a bound form. The concentration of solutes varies in cells and intercellular spaces. In the intercellular spaces, which are the thinnest capillaries, the liquid is under significant surface tension, which changes the conditions for ice formation (the temperature at which ice begins to form will be much lower).

The cryoscopic temperature is an important parameter that must be considered when storing refrigerated products, concentrating juices by freezing, aging wines and juices, and when calculating cold and freezing time. For most foods, the cryoscopic temperature (tKP) is around-1°C. However, some products with a high sugar content, such as boiled and smoked sausages, as well as hard and processed cheeses, have a lower cryoscopic temperature (Table 3) (Dibirasulaev *et al*., 2021).

Table 3: Cryoscopic temperatures of food products

Food product	Cryoscopic temperature, °C
Beef	–1.3–0.6
Veal	–0.9–0.8
Bird	–2.0
Freshwater fish	–0.5
Boiled sausages	–3.3–1.2
Smoked sausages	–7.8–4.0
Canned meat	–2.5–1.6
Hard cheeses	–9.8–5.3
Processed cheeses	–11.5–3.8
Apples	–2.1–1.4
Pears	–2.8–1.8
Grape	–3.5–1.4
Potato	–4.7–0.94
Carrot	–3.3–1.0
Cabbage	–1.4–0.4
Onion	–3.0–0.9
Tomatoes	–0.9–0.5
Green peas	–1.2–1.0

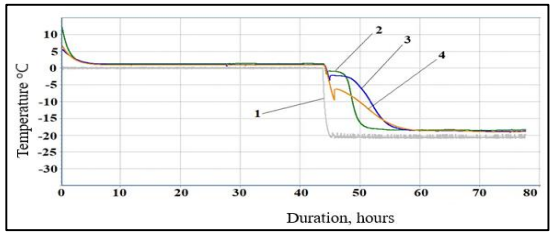


Fig. 3: Change in the maximum supercooling temperature of poultry and poultry products in a single-stage mode: (1) Air; (2) Chilled chicken breast fillet packed in cling film (p/p); (3) Smoked and boiled chicken breast fillet packed in cling film; (4) Raw smoked chicken breast fillets, packed in cling film

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Examination of data regarding the minimum achievable temperature and freezing point depression during a single-stage cooling process (Fig. 3) reveals a consistent pattern across all chicken fillet samples. In every instance, the lowest attainable temperature before overcooling occurs is observed to be lower than the calculated freezing point depression, irrespective of the initial thermal condition of the sample. However, the phase transition of water to ice in all samples occurs in a narrow time interval, 2.13 h. The duration of the phase transition between samples of different thermal states differs by less than 1.23 h.

When using a two-stage mode (Fig. 4), a significant difference is observed in the time of appearance of characteristic phase transition peaks depending on the thermal state of the meat. For chilled chicken fillets, the phase transition begins 4.18 hours after the start of the experiment, for smoked-boiled fillets after 24.32 hours, and for raw smoked fillets after 27.15 hours. It should be noted that two-stage cooling makes it possible to more clearly separate phase transitions in time.

A similar picture is observed with a stepwise decrease in air temperature in steps of 2.0°C for poultry and poultry products of various thermal states, for a 10% aqueous solution of tylose (an analog of poultry meat in terms of thermophysical properties) and distilled water (Figs. 5-7)

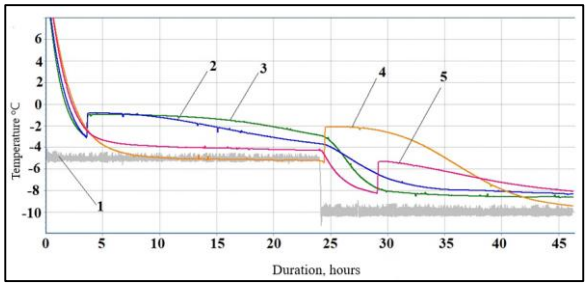

Fig. 4: Determination of the maximum hypothermia temperature for poultry and poultry products in a two-stage mode: (1) Air; (2) Chilled broiler breast fillet packed in cling film; (3) Chicken breast fillet packed in cling film; (4) Smoked and boiled chicken breast fillet packed in cling film; 5-raw smoked chicken breast fillet packed in cling film

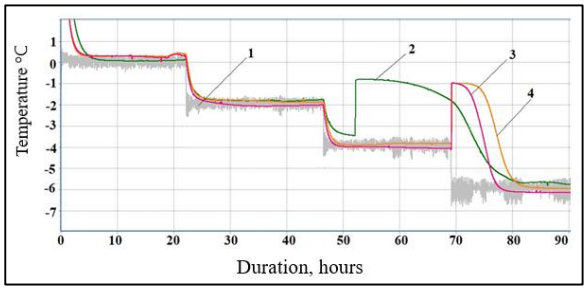

Fig. 5: Determination of the maximum temperature for hypothermia of poultry and poultry products in a stepwise mode with a step of 2°C: (1) Air; (2) Chilled broiler leg packed in cling film; (3) Chilled broiler breast fillet packed in cling film; (4) Chilled broiler leg packed in cling film

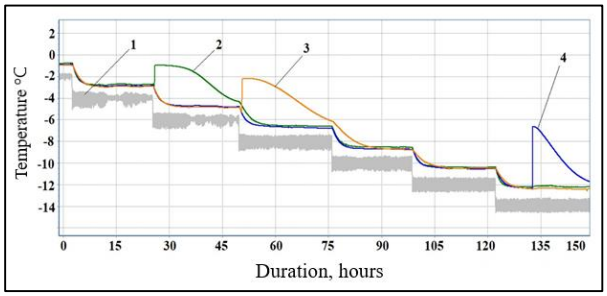

Fig. 6: Determination of the maximum temperature for hypothermia of poultry and poultry products in a stepwise mode with a step of 2°C: (1) Air; (2) Chilled broiler breast fillet packed in cling film; (3) Smoked and boiled chicken breast fillet packed in cling film; (4) Raw smoked chicken breast fillet packed in cling film

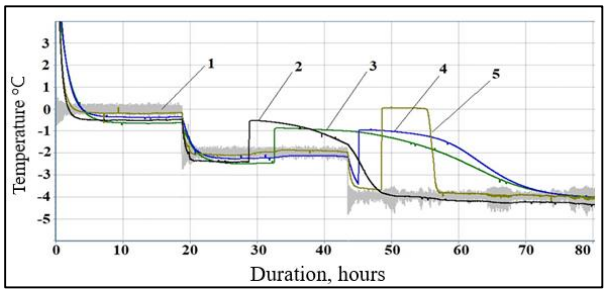

Fig. 7: Determination of the maximum supercooling temperature of tylose, poultry and distilled water in a stepwise mode with a step of 2°C: (1) Air; (2) Aqueous solution of tylose 10% (analogous to poultry meat in terms of thermophysical properties); (3) Chilled broiler breast fillet packed in cling film; (4) Chilled chicken breast fillet, packed in cling film; 5-distilled water

The inclusion of lactic acid in food coatings during the processing of poultry carcasses also effectively reduces the number of mesophilic aerobic and facultative anaerobic microorganisms during storage. Analysis of the data (Tables 4-5) to determine the effect of various concentrations of lactic acid on microbiological changes shows that significant inhibition of the development of psychrotrophic microorganisms is observed at an acid concentration of 0.5%, while for QMAFAnM a similar effect occurs at a lactic acid concentration of FFFC composition 1.5%.

Before treatment, the initial count of psychrotrophic microorganisms in poultry carcasses was approximately 2.3×10^2 Colony-Forming Units per gram (CFU/g). After treatment and a 12-hour incubation period, in samples treated with food film-forming compositions containing various concentrations of lactic acid (from 0.5-2.0%), there is a decrease in the level of contamination by one order of magnitude, while in control samples there is no treated with food coating, the level of contamination remains virtually unchanged. The same pattern is observed in changes in psychrotrophic microorganisms after three and five days of storage.

Table 4: Change in the number of psychrotrophic microorganisms during treatment with FFFC and subsequent storage of control and test samples (half carcasses of poultry), CFU/g

Time	CFU/g					
	Control 1*	Concentration of lactic acid in FFFC solution for processing prototypes, %				
		0,5	1,0	1,5	Control 2*	2,0
Initial	$2.3\pm0.27\cdot10^2$	$2.3\pm0.27\cdot10^2$	$2.3\pm0.27\cdot10^2$	$2.3\pm0.27\cdot10^2$	$2.3\pm0.27\cdot10^2$	$2.3\pm0.27\cdot10^2$
After processing	$2.0\pm0.32\cdot10^2$	$1.8\pm0.22\cdot10^1$	$1.5\pm0.12\cdot10^1$	$1.1\pm0.13\cdot10^1$	$1.2\pm0.13\cdot10^1$	$1.0\pm0.11\cdot10^1$
3 Days later	$3.0\pm0.35\cdot10^3$	$2.8\pm0.20\cdot10^2$	$2.5\pm0.18\cdot10^2$	$1.8\pm0.12\cdot10^1$	$2.2\pm0.21\cdot10^2$	$1.3\pm0.14\cdot10^1$
5 Days later	$4.9\pm0.47\cdot10^4$	$4.3\pm0.49\cdot10^4$	$4.0\pm0.33\cdot10^4$	$3.2\pm0.18\cdot10^3$	$3.5\pm0.39\cdot10^3$	$2.7\pm0.14\cdot10^2$

Control 1*-samples without application of FFFC
Control 2*-samples treated with a 2% solution of lactic acid in water

Table 5: Change in QMAFAnM during processing of FFFC and subsequent storage of control and test samples (poultry half carcasses)

Time	QMAFAnM					
	Control 1*	Concentration of lactic acid in FFFC solution for processing prototypes, %				
		0.5	1.0	1.5	Control 2*	2.0
Initial	$3.6\pm0.41\cdot10^3$	$3.6\pm0.41\cdot10^3$	$3.6\pm0.41\cdot10^3$	$3.6\pm0.41\cdot10^3$	$3.6\pm0.41\cdot10^3$	$3.6\pm0.41\cdot10^3$
After processing	$3.5\pm0.28\cdot10^3$	$3.1\pm0.23\cdot10^3$	$3.3\pm0.42\cdot10^3$	$2.7\pm0.18\cdot10^2$	$2.6\pm0.18\cdot10^2$	$2.3\pm0.21\cdot10^2$
3 Days later	$4.4\pm0.56\cdot10^4$	$4.0\pm0.29\cdot10^4$	$4.2\pm0.47\cdot10^4$	$3.6\pm0.27\cdot10^3$	$3.3\pm0.26\cdot10^3$	$3.0\pm0.27\cdot10^3$
5 Days later	$5.8\pm0.49\cdot10^5$	$5.3\pm0.49\cdot10^5$	$5.5\pm0.35\cdot10^5$	$4.8\pm0.32\cdot10^4$	$4.6\pm0.45\cdot10^4$	$8.6\pm0.48\cdot10^3$

Control 1*-Samples without application of FFFC
Control 2*-Amples treated with a 2% solution of lactic acid in water

Table 6: Influence of preservatives in the composition of FFFC on changes in pH and Eh values

No.	Name of composition	pH		Eh, mV	
		Before adding preservatives	After adding preservatives	Before adding preservatives	After adding preservatives
1.	Control (water)	7.43±0.28	-	0.53±0.06	-
2.	FFFC-10 3% + lactic acid 2%	7.85±0.23	2.67±0.13	1.05±0.13	158±5.0
3.	Whey 5% + glycerin 10% + lactic acid 2% + citric acid 0.2%	4.75±0.15	3.17±0.27	0.32±0.05	129±4.0
4.	Whey 5% + glyc. 10% + lactic acid 2% + citric acid 0.2% + nisin	4.45±0.25	3.05±0.09	0.33±0.03	140±5.0

The safety and stability of most canned foods is based on the use of several preservation methods in combination. The foundational principles behind conventional preservation techniques have been elucidated. Furthermore, research has clearly defined the extent to which these methods can effectively control microbial populations, including their ability to survive, perish, or proliferate. The preservation of food products, as well as their quality, depends on the targeted and conscious use of combined preservative factors, i.e., from the so-called barrier technology.

In this regard, it is of interest to determine changes in pH and Eh values for various FFFC with the introduction of preservatives into their composition. Table 6 shows data on the effect of including preservatives in solutions of food film-forming coatings based on monoglycerides and whey on changes in the active density of the medium (pH) and oxidation-reduction potential (Eh).

The research results show (Table 6) that when 2% lactic acid is introduced into a solution of Film-Forming FFFC based on monoglycerides, a significant decrease in pH is observed from the initial 7.85-2.67, and for FFFC based on lactic acid there is an average decrease in the pH value from 4.6-3.1, which is apparently due to the low value of the active acidity of the whey medium before the introduction of lactic acid. The extent to which environmental pH and oxidation-reduction potential are altered is influenced by both the nature of the acid involved and the specific composition of the film-forming material.

To illustrate the degree of change in the marketable appearance of control and experimental broiler chicken carcasses stored refrigerated, Fig. (8) shows a photograph of the carcasses.

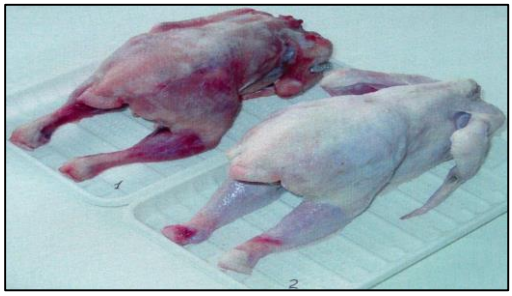

Fig. 8: Appearance of unpackaged poultry carcasses after 5 days of storage: (1) Control sample; (2) Coated FFFC based on monoglycerides

The photograph shows a clear difference in the appearance of the unpackaged control carcass and the food-coated poultry carcass.

The analysis of experimental data in Table (7) reveals a consistent pattern across various product types and thermal states (chilled, smoked-cooked, raw smoked). The average cryoscopic temperature (-2.01°C) is demonstrably higher than the average limiting supercooling temperature (-4.77°C), irrespective of these variations. This indicates the possibility of setting the lower limit of the temperature range for storing poultry meat and poultry products significantly below the cryoscopic temperature.

Recommended storage temperatures for chilled, smoked-boiled, and raw-smoked chicken fillets and breast and leg fillets (various anatomical parts) of chilled broilers, packaged in cling film are given in Table (8).
Based on the analyzed data, the optimal storage temperatures for various poultry products are as follows: Chilled fillets and broiler breast fillets at approximately -2.20°C, smoked-boiled products at -4.26°C, raw smoked products at-8.08°C, and broiler legs at -2.34°C.

Table 7: Experimental values of cryoscopic ($T_{cr.}$, °C) and limiting (T_{lim}, °C) temperatures of supercooling of chilled, cooked-smoked and raw smoked poultry and poultry products

No.	Product name	$T_{cr.}$, °C	T_{lim}, °C
	Chilled chicken breast fillet packed in cling film (c/f)	–1.13	–3.67
1	Chicken breast fillet, smoked and boiled, packed in cling film	–2.33	–3.71
	Raw sm oked chicken breast fillet packed in cling film	–6.34	–9.55
	Chilled broiler breast fillet packed in cling film	–0.83	–3.12
2	Chilled chicken breast fillet packed in cling film	–0.97	–3.04
	Chicken breast fillet, smoked and boiled, packed in cling film	–2.13	–5.43
	Raw smoked chicken breast fillet packed in cling film	–5.31	–8.25
	Chilled broiler leg packed in cling film	–0.82	–3.47
3	Chilled broiler breast fillet packed in cling film	–0.99	–4.14
	Chilled broiler leg packed in cling film	–1.01	–3.90
	Chilled broiler breast fillet packed in cling film	–0.95	–3.15
4	Chicken breast fillet, smoked and boiled, packed in cling film	–2.20	–5.31
	Raw smoked chicken breast fillet packed in cling film	–6.65	–12.36
	Aqueous solution of tylose 10% (analogous to poultry meat in terms of thermophysical properties)	–0.53	–2.41
5	Chilled broiler breast fillet packed in cling film	–0.88	–2.46
	Chilled chicken breast fillet packed in cling film	–0.96	–3.43
	Distilled water	–0.03	–3.69
	X ± S	–2.01±2.06	–4.77±2.70

Table 8: Recommended storage temperatures for chilled, smoked-boiled and raw smoked chicken fillets and chilled broiler breast and leg fillets, packed in cling film

No.	Product name	$T_{cr.}$, °C	T_{lim}, °C	T_{rs},°C
		–1.13	–3.67	–2.40
1	Chilled chicken breast fillet packed in cling film	–0.97	–3.04	–2.01
		–0.96	–3.43	–2.20
	X ± S	–1.02±0.10	–3.38±0.32	–2.20±0.20
		–2.33	–3.71	–3.02
2	Chicken breast fillet, smoked and boiled, packed in cling film	–2.13	–5.43	–3.78
		–2.20	–5.31	–5.98
	X ± S	–2.22±0.10	–4.82±0.96	–4.26±1.54
		–6.34	–9.55	–7.95
3	Raw smoked chicken breast fillet packed in cling film	–5.31	–8.25	–6.78
		–6.65	–12.36	–9.51
	X ± S	–6.10±0.70	-10.05±2.10	–8.08±1.37
		–0.83	–3.12	–1.98
4	Chilled broiler breast fillet packed in cling film	–0.99	–4.14	–2.57
		–0.95	–3.15	–2.05
	X ± S	–0.92±0.08	–3.47±0.58	–2.20±0.32
		–0.82	–3.47	–2.15
5	Chilled broiler leg packed in cling film	–1.01	–3.90	–2.46
		–0.97	–3.85	–2.41
	X ± S	–0.93±0.10	–3.74±0.24	–2.34±0.17

Discussion

A comparative analysis of chilled products shows that there is no significant difference in the recommended storage temperature between different types of products (chicken, broiler) and between individual anatomical parts (fillet, broiler leg).

Poultry meat and products made from it are a favorable breeding ground for the proliferation of many microorganisms.

The ability of psychrotrophic microorganisms to proliferate at low, positive temperatures presents a significant challenge to maintaining the quality and safety of refrigerated food products. From a scientific standpoint, it would be beneficial to investigate the combined effects of low-temperature storage (refrigeration) and the incorporation of lactic acid at various concentrations within food coatings on the inhibition and proliferation of cold-tolerant microorganisms in poultry meat throughout its shelf life (Cutter, 2006; Jiang *et al*., 2011).

Lactic acid has a lower dissociation constant than other acids; therefore, at the same concentration, it is more active and has a greater ability to penetrate the cells and tissues of the body, as a result of which it significantly affects the pH of the microbial cell and the speed of the enzymatic reaction, inhibiting them (Siripatrawan and Noipha, 2012; Janes *et al*., 2002; Jiang *et al*., 2011).

Analysis of the data reveals that when lactic acid is present at a 2% concentration, its inhibitory effect on both psychrotrophic and QMAFAnM microorganisms is significantly enhanced when incorporated into a Food Film-Forming Composition (FFFC) compared to when it is dissolved in water. This suggests a synergistic interaction between the FFFC components and lactic acid, resulting in a tenfold increase in microbial inhibition efficacy within the FFFC.

The study observed an inverse relationship between lactic acid concentration in a coating formulation and the presence of psychrotrophic microorganisms. Specifically, as the concentration of lactic acid increased, the level of contamination by these microorganisms decreased. The greatest reduction was observed in samples containing 2.0% lactic acid. The antimicrobial properties of lactic acid are likely due to its capacity to lower the pH on the surface of a product. This acidic environment hinders microbial proliferation by disrupting bacterial cell membranes, ultimately resulting in cell death and inhibited growth. (Günlü and Koyun, 2013; Bondi *et al*., 2017).

Incorporating lactic acid into edible coatings applied to poultry carcasses demonstrably decreased the populations of psychrotrophic, mesophilic aerobic, and facultative anaerobic bacteria throughout the storage period. The study findings indicate that incorporating lactic acid into food coatings can enhance the microbiological safety and prolong the shelf life of poultry and poultry-derived products.

Conclusion

This study investigated the freezing point depression and maximum temperature attained by different types of poultry meat and poultry products, examining how these properties are influenced by various cooling techniques. It is shown that when determining the values of cryoscopic and limiting supercooling temperatures, it is advisable to use a stepwise cooling mode. The effect of food coatings based on monoglycerides containing various concentrations of bakeriocin (nisin) and lactic acid on the microbiological contamination of poultry carcasses during refrigerated storage was studied. Based on studies of microbiological indicators, it has been established that the optimal concentration, which provides a preservative effect and does not affect the organoleptic characteristics of poultry carcasses, is a 2% concentration of lactic acid in the composition of FFFC. The inclusion of lactic acid in food coatings for poultry carcasses effectively reduces the number of psychrotrophic and MAFAnM during the storage of chilled poultry carcasses. Studies have demonstrated that incorporating lactic acid into food coatings can enhance the microbiological safety of poultry and poultry products, while also prolonging their shelf life.

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Author's Contributions

Lazat Umiraliyeva, Magomed Dibirasulaev and Akniet Ibraikhan: Wrote the manuscript and studied the relevant literature.

Dibirasulav Dibirasulaev: Developed the idea, looked for suitable literature, and compiled the first version.

Lidia Stoyanova, Mikhail Iskakov and Ivan Filatov: Edited and reviewed the article.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

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