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RESEARCH ARTICLE
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The Effect of Functional Ingredients of Fruit and Vegetable Raw Materials in the Composition of a Bio-Corrected Coating on the Quality of Meat Products

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ABSTRACT

The article provides information on developing a biodegradable coating for storing whole meat products. The coating composition is based on the polysaccharide (sodium alginate), incorporating red currant powder and ginger root extract. The film coatings had a thickness of 96.2µm, a tensile strength of 22.1MPa, break elongation of 19.2%, and biodegradability in the analog of human gastric juice ranged from 15 to 35min. Multisensory studies on the VOC meter device showed that the odor intensity of a sample of whole-muscle meat product stored in the coating was 0.98% higher than the control one. In the sensor reading, the profiles of the product's "visual prints" differed, indicating a higher content of free amino acids in the gas phase of the test sample. Storing boiled and smoked ham in biofilm resulted in a 13% decrease in amino-ammonia nitrogen (AAN) content, which had a positive effect on quality. The coatings' antioxidant properties are attributed to the presence of phenolic compounds (gingerol and shogaol) with hydroxyl groups that inhibit secondary oxidative changes in the product's lipid fraction. Putting delicatessen items in a biodegradable film and storing them slows the growth of mesophilic aerobic and facultative anaerobic microorganisms, as well as Staphylococcus aureus.

Keywords: Environmentally friendly technologies, Meat products, Fruit and vegetable raw materials, Bio-corrected film, Ecology, Shelf-life prolongation, Safety and quality, Antioxidant stability

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INTRODUCTION

The global food industry faces significant challenges in reducing food spoilage and waste, particularly unpackaged products. Losses of unpackaged food products associated with spoilage can reach up to 50%, while properly selected packaging reduces product losses by up to 3% (Tolikova et al., 2021). While effective at protecting food, traditional packaging materials like plastics and polyethylene have significant drawbacks. These synthetic materials can migrate dangerous low-molecular-weight compounds from the polymer film into the product. Polymer packaging materials degrade very slowly in the natural environment, leading to negative environmental impacts (Pisoschi et al., 2018; Kudryashov et al., 2019; Tikhonov & Nogina, 2019; Vereshchagin et al., 2020; Bagirov, 2021; Giro et al., 2021; Patrusheva et al., 2021; Vereshchagin et al., 2021). In light of these challenges, developing alternative packaging solutions that are both safe for consumers and environmentally friendly has become increasingly critical (Petkoska et al., 2021). In this context, the creation of packaging materials based on natural substances, which contain bactericidal and antioxidant components and are biodegradable in natural conditions under the influence of natural factors, holds great promise. This dual functionality positions biodegradable films as a sustainable alternative to synthetic polymers, addressing both food waste and environmental pollution (Wandosell et al., 2021).

Polysaccharides, a class of natural polymers, have emerged as key candidates in developing these biodegradable packaging materials (Lomartire et al., 2022). Their ability to form flexible and strong films and their inherent biodegradability make them an ideal base for eco-friendly coatings. Recent advancements have focused on enhancing the functional properties of these polysaccharide-based films by incorporating bioactive ingredients derived from raw fruit and vegetable materials. These bioactive components, such as phenolic compounds,

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flavonoids, and essential oils, contribute additional antioxidants and antimicrobial properties to the films, thereby extending the shelf life of the packaged products and maintaining their quality (Perera et al., 2021). The use of biodegradable films and protective coatings should become an alternative to synthetic polymer materials, which will contribute to solving the problem of waste disposal, which today threatens to become a global environmental disaster (Kubra & Rao, 2012; Noori et al., 2018). Films and coatings based on natural polysaccharides are a solution to the environmental problem of reducing the amount of polymer waste in the ecosystem (Valishev & Murashev, 2020; Hamann et al., 2021; Utama-Ang et al., 2021).

This study explores the formulation and application of a biodegradable coating for whole meat products, using sodium alginate as the polysaccharide base. The coating is enriched with red currant powder and ginger root extract, both known for their potent antioxidant and antimicrobial properties. The resulting bio-corrected film is evaluated for its mechanical properties, biodegradability, and its effect on the quality and safety of stored meat products. The findings underscore the potential of such biodegradable coatings in extending shelf life and ensuring product safety and reducing environmental impact, thereby contributing to more sustainable food packaging solutions.

MATERIALS & METHODS

The study's objects were boiled and smoked pork ham in a biodegradable coating. We stored the control sample of ham without a film coating. We kept the control and experimental samples of ham in a refrigerator (at 4°C) for 30 days to evaluate the impact of the biodegradable coating on their nutritional and biological value.

We prepared the film coating using sodium alginate (food grade), red currant powder, ginger root extract, and water. We applied a solution of the aforementioned ingredients to the product's surface and sprayed it with sodium chloride. Researchers have studied sensory, physical-chemical, and microbiological parameters and natural losses during storage (Myasishcheva et al., 2016; Myasishcheva et al., 2017; Shkolnikova et al., 2018). We used standard methods to determine moisture, fat, protein, ash, and carbohydrate mass fraction. The peroxide and acid numbers were determined following GOST 8285-91. The amino-ammonia nitrogen (AAN) content was assessed based on the capture of deep protein decomposition products in an aqueous meat filtrate, as per GOST R 55479-2013. The concentration of hydrogen ions (pH) was measured using the control method described in MI 103.5-105-2011 ("Meat and meat products") and GOST R 51478 ("Meat and meat products"). The acid number (AN), an indicator of the degree of hydrolytic lipid spoilage, was determined using a phenolphthalein indicator. This involved neutralizing free fatty acids with a potassium hydroxide solution. The spectrophotometric method was used to determine the primary products of lipid peroxidation, expressed as the peroxide number index (PN). The microbiological status of the product samples was established by bacteriological studies following the criteria of the Customs Union 034 - 2013 Technical Regulations. We evaluated organoleptic parameters using the VOCmeter device. The Argus program evaluated the visual odor prints (MOS 1-4) detected by the "electronic nose" device. The Argus program presents the results as profile diagrams for specific sensors: aldehydes (M1), ketones (M4), Free amino acids (M3), and low molecular weight nitrogen-containing compounds (M2).

We used standard software applications for statistical data processing, specifically StatPlus 2009 Professional 5.8.4 for Windows (StatSoftInc., USA), to statistically process the results obtained. We also used the student's t-test to evaluate the reliability of differences between samples in the experimental and control experiments.

RESULTS & DISCUSSION

The film coating was prepared using sodium alginate (M/S Shandong Jiejing Group Corporation), red currant powder, ginger root extract, water, and calcium chloride (a food additive under the E509 index), which we used as a crosslinking agent (Myasishcheva et al., 2017; Ivane et al., 2022; Zhang et al., 2022). In recent years, work has intensified on developing resource-saving technologies for the complex processing of red currant berries, a valuable source of biologically active ingredients represented by ascorbic acid, flavonoids, pectin, and organic acids in terms of citric acid. When red currant is used in food production, the sugar-acid index (SAI) determines berries' taste and technological significance. The content of pectin and dietary fiber determines the prebiotic properties of this culture's berries. Berry pulp has much value as a secondary raw material that can make the film coating healthier and better tasting (Myasishcheva et al., 2016; Myasishcheva et al., 2017; Shkolnikova et al., 2018).

Analysis of the chemical composition of red currant berry pulp revealed a significant enrichment in key bioactive compounds compared to the raw material. The pulp contains up to 59% of flavonoids, organic acids up to 37%, carbohydrates up to 31%, an increase in SAI of 12%, pectin of up to 10%, and vitamin C of up to 5% compared with the raw material (Table 1). These properties underscore the significant health benefits of red currant berry pulp, making it an excellent secondary resource for enhancing the structural integrity, biological value, and color of edible film coatings.

Table 1: The chemical composition of pomace from red currant berries

Indicator	Units	Values
Organic acids	%	1.1-1.5
Carbohydrates	%	4.5-5.4
SAI		0.2-0.3
Vitamin C	mg/100g	51.2-53.5
P-active substances		
Anthocyans	mg/100g	82.3-85.5
Leukoanthocyanins	mg/100g	219.1- 223.4
Catechins	mg/100g	273.5– 274.4
Total	mg/100g	574.9– 583.3
Pectin	%	7.9 – 8.3
Dietary fiber	%	7.15 – 7.35

Researchers developed a technological solution to produce powder from the pulp of red currant berries to achieve waste-free processing of vegetable raw materials and determine their feasibility for the formulation of film coatings. Technological solutions were based on drying the pulp at a temperature of 50°C to constant value by weight and subsequent grinding to uniformity and sieving. We poured the resulting powder with water at a temperature of 50°C until it swelled with a hydromodule of 1:10, and then utilized it as a plasticizer and dye for the film coating (Myasishcheva et al., 2016; Myasishcheva et al., 2017; Shkolnikova et al., 2018).

The interaction of alginate with calcium ions significantly increases the mechanical and barrier properties of the film coating (Hamann et al., 2021). As a natural polysaccharide, sodium alginate is composed of residues of L-guluronic and D-mannuronic acids. It is a useful film-forming polymer; it easily dissolves in water and retains moisture, forming gels. It is biodegradable, non-toxic, and low-cost.

We added a plasticizer, red currant powder, to the film-forming solution to increase their functionality, water resistance, flexibility, mechanical strength, and reduced brittleness. This plasticizer's high pectin content enhances its barrier properties. We introduced ginger extract into the biofilm to increase its antioxidant activity and bactericidal properties. Kubra & Rao (2012); Shaukat et al. (2023), and Sayadi et al. (2021) say that the rhizomes of this plant have 6.9–11.1% solids, 0.80–1.45% sugars (mainly sucrose), 1.5–2.1% ascorbic acid, and 0.38–0.58% carotenoids, all of which can be thought of as natural antioxidants.

Many studies have revealed a complex of compounds belonging to the group of terpene series hydrocarbons in ginger rhizomes. According to Noori et al. (2018), zingiberene (24.96% of all identified compounds in essential oil), b-sesqui phellandrene (12.74%), sesqui sabine hydrate (6.19%), camphene (5.90%), zingiberenol (4.26%), (E)-citral (3.93%), sabinene (3.75%), (E)-farnesene (3.73%), and italicene (3.21%) are predominant.

Phenolic diterpenes and sesqui terpenes, particularly zingiberenol, α-zingiberene, and β-sesquiphellandrene, are responsible for the potent antimicrobial properties observed in ginger extract (Valishev & Murashev, 2020; Hamann et al., 2021; Utama-Ang et al., 2021). The addition of antioxidants to edible coatings of meat products prevents lipid oxidation, discoloration, and decomposition processes (Noori et al., 2018; Sayadi et al., 2021; Shaukat et al., 2023).

We obtained the extract by hydro distilling the essential oil from ginger rhizomes on a Clevenger apparatus, following the OFS.1.4.1.0021.15. We placed a sample of 30g of crushed dried ginger in a round-bottomed flask with a volume of 2000cm^3 and filled it with 1000cm^3 of distilled water. We boiled this composition at atmospheric pressure for 180min. We dried the resulting oil over a small amount of anhydrous sodium sulfate to remove moisture.

We hydrated sodium alginate powder (concentration 1.8%) and red currant powder (4%) at 50°C and stirred them with an agitator (speed 120rpm) to obtain the gel. The resulting gel was cooled to a temperature of 0±2°C, allowed to swell (duration 3 hours), and cooled to 2°C. We added 6% of a 10% ginger extract to the gel to enhance its bactericidal and antioxidant properties. We immersed the ham in a film-forming solution and allowed the excess solution to drain (5-7min) (Kudryashov et al., 2019; Giro et al., 2021). We applied calcium chloride to the alginate gel, forming a film coating on the product by diffusion. The film formation occurs due to a biochemical reaction between sodium alginate and calcium chloride.

We sent the product to the drying chamber for 90min at a temperature of 11–12°C, a relative humidity of 75%, and an air velocity of 0.05–0.1m/s to accelerate and qualitatively form the coating layer. A homogeneous plastic film with a homogeneous structure was formed on the product's surface, with a strength similar to household packaging polyethylene films (Giro et al., 2021). The method of obtaining a film coating is characterized by ease of production and low cost (Kudryashov et al., 2019; Giro et al., 2021). We stored boiled and smoked pork ham with edible film coatings in cardboard boxes. The films' water absorption capacity correlates with temperature and time, affecting digestibility and assimilation by the body. Fig. 1 displays water absorption indicators. The structural and mechanical parameters of film coatings (Table 2) comply with the requirements of GOSTR57432-2017.

Table 2: Structural and mechanical properties of film coatings

Indicator	Units	Characteristic
Coating thickness	μm	96.2
Tensile strength	MPa (kgf/cm2)	21.2
Tensile strength	MPa	6.586
Elongation at break (L)	%	19.1%
Decomposition time in the "artificial stomach"	min	15-35
Rate of the film coating decomposition in the ground	Days	7

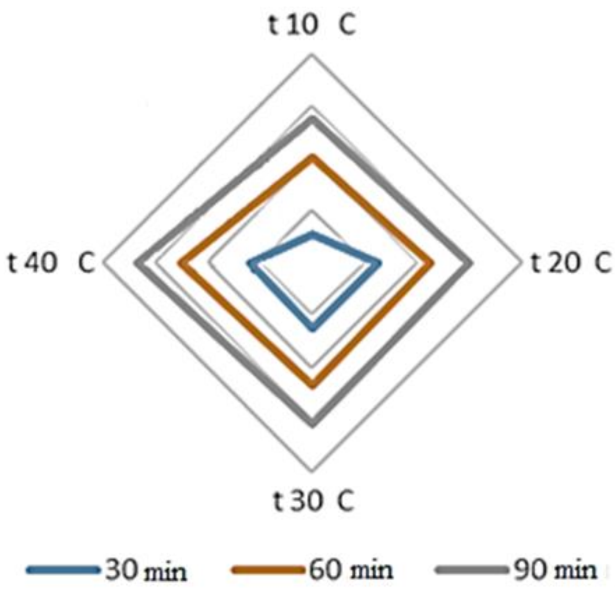

Fig. 1: Water absorption capacity of films at different temperatures.

The formulation of the RF patent for invention No. 2743754 (Giro et al., 2021), guides the production of the biodegradable film (Fig. 2 sample A). The composition also included antimicrobial and antioxidant components—red currant powder and ginger extract—in the manufacture of sample B (Fig. 2). Both samples were characterized by uniform thickness and excellent elasticity. Sample A was transparent, odorless, and tasteless; sample B was pink with a slight smell of ginger. We used sample B (Fig. 2) to evaluate the impact of the film coating on the accumulation of AAN. Storage of test samples in biofilm decreased the AAN content in delicatessen products during storage for 30 days (Table 3). Storing boiled and smoked ham in a biodegradable coating led to a 13% reduction in AAN, positively affecting product quality. The tight fit of the film coating to the product ensured a decrease in O_2 access and a delay in the growth of aerobic bacteria, achieving this effect. Preserving delicatessen products in a bio-corrected coating positively affected sensory characteristics; the samples remained juicy and fragrant throughout the regulated shelf life. The brighter color of the prototypes is due to a decrease in contact with the product with oxygen, which prevents hemoglobin oxidation, as well as the inclusion of red currant in the film formulation (Fig. 3).

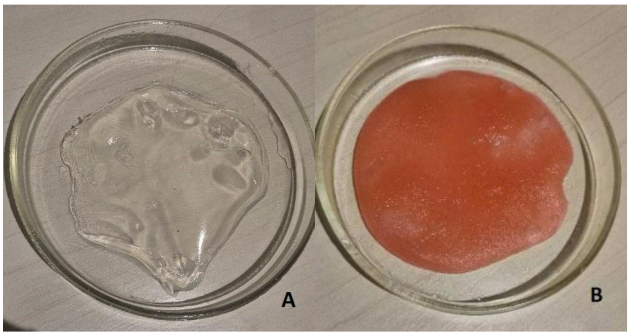

Fig. 2: Biodegradable coatings. Sample A is a film coating without red currant powder and ginger extract, Sample B is a film coating with the inclusion of red currant powder and ginger extract.

Table 3: The effect of the film coating on the content of aminoamiacic nitrogen in delicatessen products

Samples of delicatessen products	AAN amino ammonia nitrogen mg/100g
Delicatessen products in a film coating (experiment)	40.3±0.4
Delicatessen products without film coating (control)	46.4±0.5

Organoleptic analysis revealed a more intense aroma of product A (Fig. 3A); its odor sensor was 0.98% higher compared to sample B (Fig. 3B). These "visual prints" of samples A and B showed different readings on the M3 sensor because sample A had more aldehydes, ketones, volatile fatty acids, protein breakdown products, and amine nitrogen in its gas phase (Fig. 3). The biodegradation tests on the film were done in a universal soil that was enriched (t 21±2°C, 70% humidity) (TU 08.92.10-001-05048508-2017). After two days, soil bacteria began to cause the first signs of destruction; on the fourth day, the area started to shrink, and on the seventh day, the coatings completely decomposed in the soil. In humans, the film breaks down in the digestive tract through oxidation and hydrolysis reactions involving endo- and exoenzymes. The degradation time of the biofilm in the human gastrointestinal tract ranged from 15 to 35 minutes (Borodulin et al., 2020; Fedorenko et al., 2020; Popov et al., 2020; Prosin et al., 2021; Bakin et al., 2024).

We studied the dynamics of oxidative (Fig. 4 and Fig. 5) and microbiological parameters to assess the effect of biofilm on the storage capacity of boiled and smoked ham and determined natural losses within 30 days (Table 4, 5). Due to its tight fit to the surface and prevention of moisture exchange, the film coating reduced products' natural weight loss, minimizing shrinkage (Table 4).

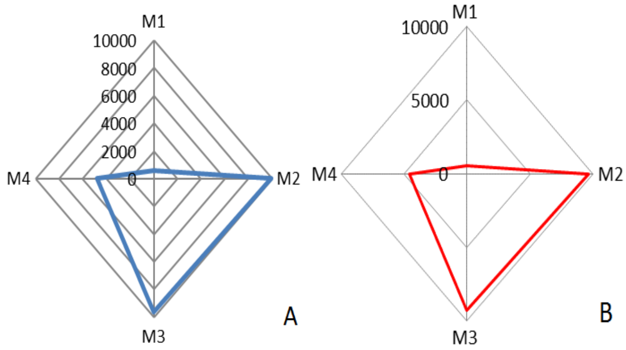

Fig. 3: Profile diagrams of the "visual imprint" of the odor of the samples studied.

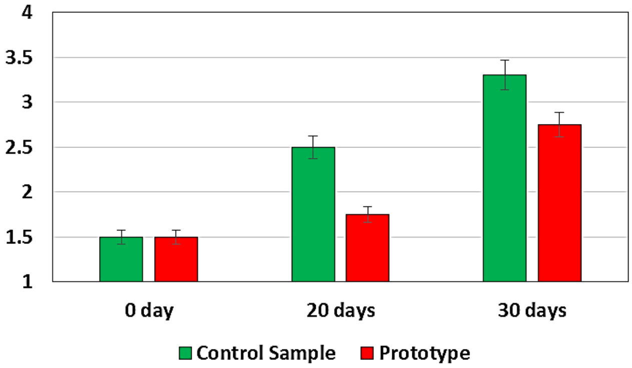

Fig. 4: Dynamics of the acid number of control and experimental samples of boiled and smoked ham.

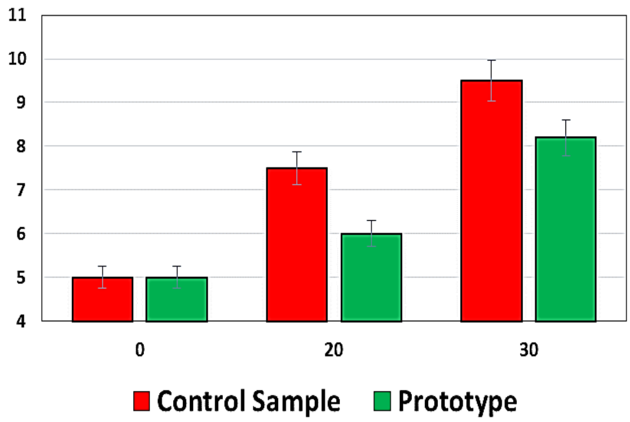

Fig. 5: Dynamics of the peroxide number of control and experimental samples of boiled and smoked ham.

Table 4: Natural weight loss (%) during the storage of boiled and smoked ham of the control and experimental sample

Name of the storage facility (shelf life)	Control, % Without coating	Biofilm experiment, %
Boiled and smoked ham 20 days	4.5	4.1
Boiled and smoked ham for 30 days	8.7	8.2

Table 5: Microbiological contamination of smoked – boiled ham in biofilm

Shelf life	Smoked – boiled ham (control)	Smoked – boiled ham (coated)
Resistance to microorganisms (QMA&OAMO CFU/g)		
0 days	$2.0*10^2$	$1*10^2$
20 days	$4.25*10^2$	$3.5*10^2$
30 days	$1.0*10^3$	$9.0*10^2$
Resistance to microorganisms of *Staphylococcus Aureus*, B 1g/cm^3		
0 days	Not found	Not found
20 days	Not found	Not found
30 days	Not found	Not found

The study found a significant increase in the microbiological parameters of QMA&OAMO CFU/g (1.0*103) during the 30-day storage of product control samples at a temperature of 4°C. We noted inhibition of the number of microorganisms QMA&OAMO CFU/g ($9.0*10^2$) while storing experimental samples. We did not detect Staphylococcus aureus in samples throughout the entire shelf life (Table 5). Biofilm's high antimicrobial properties are due to the presence of phenolic diterpenes and sesquiterpenes in its composition, particularly zingiberenol, α-zingiberene, and β-sesqui phellandrene in ginger extract (Kumar et al., 2023).

The acid number (AN) of boiled and smoked ham stored in biofilm for 20 and 30 days was 27.6 and 13.3% lower than the control by 27.6 and 13.3%, respectively. The product's peroxide number (PN) in the biofilm stored for 20 and 30 days was significantly lower (20.3 and 14.1%, respectively) than in the control samples (Nešić et al., 2019).

The reduction of oxidative spoilage is due to a decrease in oxygen access to the product. Ginger contains phenolic compounds such as gingerol and shogaol, which have antioxidant properties because they have benzene rings containing hydroxyl groups (Perera et al., 2021).

Ginger extract works as an antioxidant by reacting with phenolic compounds and adding hydrogen atoms from the hydroxyl group to the radical. This creates an antioxidant radical derivative that is stable enough to protect its steric structure.

Conclusion

We obtained samples of film coatings based on sodium alginate, dry red currant powder, and ginger extract. The lipid oxidative process rate has slowed because red currant and ginger extract were added to the biofilm compound. A comparison of the sensory analysis data showed that the odor intensity of the ham samples stored in the coating for 30 days at a temperature of 4°C was 0.98% higher than the control. The profiles of the product's "visual prints" differed in the sensor reading, which indicated a higher content of free amino acids in the gas phase of the test sample. Researchers discovered that storing delicatessen products in a biodegradable film delays the growth of the microorganism *Staphylococcus aureus*. The coatings' high bactericidal properties are due to their inclusion in the composition of ginger extract containing a complex of compounds belonging to the group of terpene series hydrocarbons, such as zingiberene (24.96%), b-sesqui phellandrene (12.74%), sesquisabine hydrate (6.19%), camphene (5.90%), zingiberenol (4.26%), (E)-citral (3.93%), sabinene (3.75%), (E)-farnesene (3.73%), and italicene (3.21%). The coatings' antioxidant properties are due to a decrease in oxygen access to the product, as well as the presence of phenolic compounds (gingerol and shogaol) containing hydroxyl groups that inhibit secondary oxidative changes in the product's lipid fraction. The AAN content of boiled and smoked ham in biofilm decreased by 13% during storage, which positively affected quality. Because they come from nature, edible alginate gel-based film coatings are safe for people to use. They protect products from oxidative damage, stop them from shrinking, ensure the quality stays the same during storage, are better for the environment, and have extra preventative properties and a prebiotic orientation. The developed biodegradable coating is not difficult and not expensive to produce. It serves as a carrier of natural dyes, flavors, and antimicrobial and antioxidant agents. Introducing an innovative method of storing food products in a bio-corrected film for production will allow Russian enterprises to compete with foreign manufacturers and export their products.

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