Wiley
Advances in Agriculture
Volume 2025, Article ID 8896948, 11 pages
https://doi.org/10.1155/aia/8896948

WILEY

Research Article

Use of Mastic Gum and *Pistacia atlantica* Gum in Maintaining the Quality of Shrimp During Storage

Mahnia Sharifi,[1] Amir Hossein Elhami Rad ,[1] Akram Sharifi ,[2] and Ahmad Pedram Nia[1]

[1]*Department of Food Science and Technology, Sabzevar Branch, Islamic Azad University, Sabzevar, Iran*
[2]*Department of Food Science and Technology, Qa. C., Islamic Azad University, Qazvin, Iran*

Correspondence should be addressed to Akram Sharifi; asharifi@iau.ac.ir

Received 24 January 2025; Revised 10 September 2025; Accepted 16 October 2025

Academic Editor: Deepika Kohli

Copyright © 2025 Mahnia Sharifi et al. Advances in Agriculture published by John Wiley & Sons Ltd. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

Shrimp (*Litopenaeus vannamei*) is very sensitive to oxidation damage during the storage process. Meanwhile, the use of edible coating illustrates promising findings in increasing the shelf life, while also preserving meat quality. In the current study, the *Pistacia atlantica* gum (PAG) was extracted, microcoated, and finely combined with mastic gum for coating shrimp during the storage process. Fresh shrimp were randomly divided into six groups: (1) control shrimps were not coated with any coating solution, (2) shrimps were coated with the coating mastic gum (100%), (3) shrimps were coated with the coating mastic gum (30%) containing PAG (70%), (4) shrimps were coated with mastic gum (45%) containing PAG (55%), (5) shrimps were coated with mastic gum (15%) containing PAG (45%), and (6) commercial sample (shrimps were coated with a synthetic cellophane polymer). The highest inhibition of free radicals, amounts of phenolic compounds, and microcoating efficiency were obtained with spray-drying microencapsulation. With the increase in the concentration of mastic gum of nanoemulsions, the brightness intensity decreased significantly ($p < 0.05$), and the intensity of redness, yellowness index (YI), and turbidity of coatings increased significantly ($p < 0.05$). By increasing the level of PAG in nanoemulsions, the particle size decreased significantly ($p < 0.05$). The film coating improved the pH, color, and texture properties ($p < 0.05$). The packaging film exhibited some antioxidant activity, which was significantly improved ($p < 0.05$) by the addition of the PAG extract with significant inhibition diameters against DPPH free radical. The results outlined from this study show that PAG has potential bactericidal effects against *S. aureus* and *E. coli* (30% mastic gum and 70% PAG showed the best results). Therefore, this kind of packaging is impressive in enhancing the shelf life of shrimp during the storage process at 4°C.

Keywords: antimicrobial activity; *Pistacia atlantica*; polyphenolic contents; shrimp packaging; storage process

1. Introduction

Today, the environmental concerns caused by the use of synthetic polymers for food packaging have turned consumers' attention to the use of biodegradable materials with environmental benefits, such as biodegradation and reduction of carbon dioxide emissions, and regeneration of raw materials that lead to global warming [1]. Meanwhile, the rapidly evolving field of food science nanoparticle research plays a crucial role in a wide range of the seafood industry. Recent developments in nanoemulsion-based technology have made it possible to synthesize novel materials to maintain the quality of seafood during storage [2, 3], such as nanoemulsion-based coatings and films, which are advanced strategies for fish preservation [4].

One of the goals of the seafood industry is to improve the preservation technologies of perishable and unstable foods to reach the final products with optimal quality. Chemical additives have been extensively used to prevent the survival and proliferation of microorganisms, but their safety and impact on human health are under discussion. Natural preservatives are alternatives for improving seafood quality and safety. The herbal and spice extracts could be successfully applied as natural antimicrobials for the elimination of foodborne microbes and pathogen growth [5]. The natural antimicrobial agents are slowly released to the food surface, and

therefore, they remain at high concentrations for extended periods [6]. Muñoz-Tebar et al. [7] showed that using the combination of plant essence, freezing, and modified atmosphere as a different protection technology indicated fewer bacterial counts because it has potential synergistic effects. Therefore, the approaches used for storage should not only prevent the biochemical activities of enzymes but also prevent oxidation.

Fish and seafood are of important part of our culture and nutrition that have been combined with spices and herbs for a long time. Shrimp (*Litopenaeus vannamei*) is a good source of omega-3 fatty acids, protein, and non-protein nitrogen compounds (amino acids), among other nutrients. However, this rich biological composition makes shrimps highly susceptible to microbiological spoilage, limiting their shelf life. During storage, the quality of seafood degrades due to a complex process, where biochemical, microbiological, or physical changes occur [8]. Traditional methods for storing shrimp, such as cold storage and freezing, cannot be an effective barrier against spoilage [9]. The obtained results by Shafieipour and Sami [10] showed that the refrigerator thawing method had a lower effect in decreasing the chemical quality of the pink shrimp than microwave and water thawing methods, and multiple freeze–thawing processes caused some deleterious effects on the quality of the frozen shrimps.

Active packaging innovations extend shelf life with bioactive compound integration [11]. Edible films are a thin layer of material coated or wrapped around a food product to act as a barrier to the surrounding environment [12]. This kind of continuous matrix was prepared from natural polymers such as carbohydrates, proteins, polysaccharides, and/or lipids, which can lead to increased shelf life and minimize the loss of water and volatile compounds [13]. The use of antioxidant compounds in edible films and coatings formulations is mainly to delay the development of off-flavors, prevent lipid oxidation, and improve color stability [14]. These coatings reduce lipid oxidation, moisture loss, and microbial growth and create a protective barrier [15]. In this regard, Afshar Mehrabi et al. [16] reported that chicken fillets coated with *Nepeta pogonosperma* extract and chitosan displayed a longer shelf life. As noted by Herbon [17], extending shelf life reduces losses arising from waste, which in turn could result in increased profits. Carrión-Granda et al. [18] demonstrated the effectiveness of chitosan-enriched coatings, offering a promising alternative to control the growth of pathogen and spoilage microorganisms on peeled shrimps during refrigeration storage.

The genus *Pistacia*, which is part of the Anacardiaceae family, is grown in different countries such as Iran [19]. Pistachio nuts contain great amounts of phenolic compounds, with appropriate antioxidant activity [20]. These characteristics make the species valuable not only for direct food use but also for pharmacological purposes in local communities [21]. Meanwhile, mastic gum is an extract from the *P. atlantica* tree with well-known anticancer and antioxidant properties due to its high content of polyphenol compounds [22].

In the current study, the *Pistacia atlantica* gum (PAG) was extracted, microcoated, and finely combined with mastic gum for coating shrimp during the storage process at 4°C.

Table 1: Treatments in the microcapsule production.

Code	Treatments
1	Maltodextrin + spray-drying
2	Sodium caseinate + spray-drying
3	Maltodextrin + freeze-drying
4	Sodium caseinate + freeze-drying

2. Materials and Methods

2.1. Preparation of Alcoholic Extract of PAG. The PAG alcoholic extract was determined by the method described by Ghalavand et al. [23]. Briefly, PAG was collected and picked by hand from the central district of the region of Sabzevar, Razavi Khorasan province, Iran. The PAG was identified by a herbarium collection manager at the University of Sabzevar (Herbarium No. HLu27061402). Hulls were separated, and fresh plant material was dried naturally in the shadow on laboratory benches at room temperature (23–24°C) for 6 days until crisp and vacuum-dried after rinsing/drying. Then, 150 g of the plant powder was suspended in 600 mL of hydroethanolic solution for 48 h at room temperature. The mixture was filtered using a fine muslin cloth, followed by filter paper. The filtrate was placed in an oven to dry at 40°C. The obtained clear residue extracts were kept at −20°C until required for utilization.

2.2. Spray-Drying Microencapsulation. This process was executed through a mini spray dryer (Büchi Labortechnik AG, Flawil, Switzerland), and the operational conditions for both total solids content were as follows: inlet air temperature 170 ± 5°C, outlet air temperature 85 ± 5°C, air flow 600 L/h, rate of feeding 5 mL/min, and atomization pressure 300 Mega psi. Maltodextrin and sodium caseinate were thoroughly studied as the encapsulating agent and verified their antioxidant activity. The resultant powders were stored to exclude light and oxygen and were conserved at −20°C until further analysis (Table 1).

2.3. Freeze-Drying Microencapsulation. For freeze-drying microencapsulation, the solutions were desiccated utilizing a freeze-drier (Operon-Korea) for a duration of 42 h (−86°C, 5 mbar). The desiccated materials were pulverized with a pestle and mortar and subjected to ultrasound (5 kHz, 10–15 min). Subsequently, they were stored in amber glass bottles with screw caps in a freezer (−50°C) until required for utilization.

2.4. Measurement of Microcoating Efficiency of PAG Extract. For the microcoating efficiency of PAG extract, the fine particle solution was prepared and centrifuged at 13,000 rpm for 30 min, and the supernatant was filtered with a PTFE syringe with a pore size of 0.22 μm. Then, 2 mL of acetonitrile was added, and the same procedure described for maltodextrin was carried out. The amounts of phenolic and anthocyanin compounds were quantified; the absorbance was measured at 454 nm with a spectrophotometer (Milton Roy Company, Warminster, USA).

Encapsulation efficiency (EE %) was calculated using this formula:

$$\mathrm{EE} = \left(P_t - P_f/P_t\right) \times 100,$$

where P_t is the total amount of drug in the dry extract and P_f is the free amount of dry extract during preparation.

2.5. Particle Size. First, a small amount of powder samples was dissolved in 2-propanol and then added to a water-filled tank. The size of particles is measured as they are drawn through the instrument's chamber, with the laser diffraction technique analyzing how the particles scatter a laser beam to determine their size distribution, based on the principle that smaller particles scatter light at larger angles.

2.6. Particle Size in Emulsions. The particle size distribution in emulsions was measured with a Particle Size Analyzer (Sympatec GmbH, Berlin, Germany). Due to the tendency of macroscopic particles to skew the distribution, the calculated z-average particle size will be used in subsequent analyses, but the particle size distribution curve was drawn according to the diameter of the emulsion particles.

$$D_Z = \frac{\sum S_i}{\sum \frac{S_i}{D_i}}.$$

In this formula, D_i is the particle diameter, and S_i is the particle scattering intensity.

2.7. Production of Antimicrobial Film. Aqueous film-forming pullulan solutions containing PAG extracts were prepared in three concentrations ($\times 1, \times 1.5, \times 2$ minimum inhibitory concentration [MIC]) by using the solution casting method. After the completion of aeration, 70 cc of each solution was slowly poured into the center of the Teflon plates. Then the plates were placed on a perfectly level surface to dry at ambient temperature, and films were formed. The time required to make the film was 36 h. Then, the films were stored in a desiccator at a temperature of 25°C and a relative humidity of 50% to adjust the humidity (to reach a constant weight). A saturated solution of magnesium nitrate was used to create a relative humidity of 50%. Edible films containing fine particles were made using the spray-drying method and maltodextrin wall material. First, 2.5 g of mastic gum and 200, 500, 700, and 1000 mg/L of powder were added to 100 mL of distilled water. The pH of the produced dispersion was adjusted to 8 with 0.1 N. NaOH, and the mixture was stirred on a magnetic stirrer for 20 min at 90°C to ensure denaturation. After that, the enclosed corm extract was added to the dispersion (0%–0.5%) and homogenizer. It was used to synthesize the composite film for 10 min at 10,000 rpm. It was then mixed by a magnetic stirrer for 15 min and then settled. Ultrasonic bath for 15 min to ensure a homogeneous distribution. Finally, glycerol (30% w/w) was added, and the dispersion was mixed for 30 min with a stirrer.

2.8. Antioxidant Activity of Films. Antioxidant activity tests were carried out using the Folin-Ciocalteu and DPPH methods. DPPH assay was done according to Sadeghi et al. [24]. PAG alcoholic extract solution (50 µL) at different concentrations was added to DPPH solution (0.004% in methanol; 5 mL). Afterward, the samples were stored in the dark and at ambient temperature for 30 min. The sample's absorbance was read at 517 nm. The radical scavenging activity was measured by the following equation:

$$\text{Radical scavenging activity} = [(\mathrm{ADPPH} - \mathrm{AS})/\mathrm{ADPPH}] \times 100,$$

where AS and ADPPH are the absorbance of samples and DPPH solution, respectively.

2.9. Antibacterial Assay. The disc diffusion method was used to determine the antibacterial activity of PAG extract. Antibacterial activity was tested against Gram-positive strains (*S. typhimurium*, *S. aureus*, and *B. cereus*) and Gram-negative strains (*P. aeruginosa*, *V. cholerae*, *and E. coli*) that were provided by the Department of Biotechnology, Iranian Research Organization for Science and Technology (IROST), Tehran, Iran. Intermediate cultures were prepared from the stock cultures according to the preparation guidelines of IROST to create fresh 18–24 h cultures before each experiment. Fresh suspensions of tested bacteria were prepared by transferring a loopful from a stock culture to brain–heart infusion (BHI) broth (Merck, Germany) and incubation at 35°C for 18–24 h. Prepared suspensions were adjusted to an absorbance of 0.10 at 600 nm using a spectrophotometer (Milton Roy Company, Warminster, USA). Bacterial enumeration and colony count were done by duplicate plating from a tenfold serial dilution on BHI agar after incubation at 35°C for 24 h. The average number of bacteria in the optical density of 0.10 was equal to 5.00×108 CFU/mL.

2.10. Coating of Shrimp and Storage. The shrimps were cleaned of any dirt and thoroughly washed, and after that, the cleaned samples were kept in ice until further use (within 5 h). After the coating solutions were prepared, the shrimps were wholly submerged in the coating material and positioned on a wire rack for 1 min to drip off any excess coating. At the same time, it was exposed to air for 5 min to dry up the coating material on the surface of the shrimp. Then, the samples were dipped in the edible coating solution for a second time for 1 min, hung for 45 s, and dried for 30 min. There were six treatments: (1) control shrimps were not coated with any coating solution, (2) shrimps were coated with the coating mastic gum (100%), (3) shrimps were coated with the coating mastic gum (30%) containing PAG (70%), (4) shrimps were coated with mastic gum (45%) containing PAG (55%), (5) shrimps were coated with mastic gum (15%) containing PAG (45%), and (6) commercial sample (shrimps were coated with a synthetic cellophane polymer). In film form, regenerated cellulose is called cellophane, a versatile, nonplastic film.

To produce these packages, 50 g of the fillet sample was transferred to each of the sterile plastic petri dishes (diameter 9 mm). The intended films were drawn on the petri dishes (except for the control sample) to create a hypothetical package and were placed inside the refrigerator (1 ± 4°C) for 12 days. Since after the use of each package containing shrimp

Table 2: Inhibition of free radicals, total phenol, and microencapsulation efficiency of different treatments of drying.

Parameters	MT + freeze-drying	SC + freeze-drying	MT + spray-drying	SC + spray-drying
Inhibition of free radicals (%)	77.55^{bc}	76.39^{cd}	79.05^{b}	84.27^{a}
Total phenol (ppm)	31.06^{b}	33.06^{b}	47.04^{a}	49.05^{a}
Microencapsulation efficiency (%)	62.24^{c}	56.13^{d}	89.24^{a}	87.11^{ab}

Note: The superscript letters (a–d) show significant differences in each row ($p<0.05$).
Abbreviations: MT, maltodextrin; SC, sodium caseinate.

fillets, the microbial conditions were destroyed during sampling and moving, five replicates were produced from each package from the very beginning, and on the 1, 3, 9, and 12 days of refrigeration, and one of them was also used once on the day of packaging production (0 days).

2.11. Tests of Coated Shrimps During the Storage Period

2.11.1. Texture Profile Analysis. A texture analyzer LFRA-4500 (Stable Micro Systems Ltd., Surrey, UK) was used to evaluate the texture profile (hardness, cohesiveness, and gumminess) of shrimp muscle samples based on the official analytical method ISO 11036 (2020). The texture profile analysis was performed at room temperature under the following conditions: constant test speed, 1.0 mm/s; deformation of the whole shrimp meat sample, 50%; hold time between cycles, 3 s; and trigger force, 0.05 N. Shrimps samples (20 g) were homogenized using 100 mL of distilled water, and the homogenate was checked for pH using a tabletop digital pH meter [25].

2.11.2. Microbial Tests. About 1 g of shrimp meat was mixed with 9 mL of 0.85% sterile saline solution. The mixture was then homogenized for 2 min at 250 g. The homogenized solution was logarithmically diluted in a sterile physiological saline solution. 1 ml of each dilution was inoculated onto plate count agar culture medium. The cultured samples were incubated at 35°C for 2 days to determine the total viable count and at 4°C for 7 days.

2.11.3. Colorimeter Test. The films' color parameters (L, luminance/brightness; a, red/green; b, yellow/blue) were assessed using an SC-80C colorimeter from Minolta CR360 Series, Minolta Camera Co. Ltd. (Osaka, Japan).

2.12. MIC. MIC was determined by the broth dilution method according to Bostanci et al. [26]. Briefly, the solutions of the hydroethanolic extract of PAG were prepared in 1.5 mL Eppi by dissolving dry plant extract (0.120 g) in DMSO to a final concentration of 100 mg/mL. 25 µL of each sample was inoculated into the first wells using Mueller–Hinton broth (Becton Dickinson, Sparks, MD, USA) in 96-well microplates. Then, 25 µL of each bacterial suspension was inoculated into wells. A growth control well and a sterility control well were also studied for each strain. The microtiter plates were incubated at 37°C for 24 h. After incubation, 40 µL of a 0.4 mg/mL solution of iodonitrotetrazolium chloride (INT) was added to each well as an indicator of microbial growth. The plates were incubated at 37°C for 30 min, and the MIC values were visually determined.

2.13. Statistical Analysis. Statistical analysis was performed using one-way analysis of variance (ANOVA) and Duncan's multiple range test with a significance level set at $p<0.05$, utilizing SPSS software (version 22.0, SPSS Inc., Chicago, IL, USA) for Windows.

3. Results and Discussion

In this study, phenolic compounds from PAG ratios were extracted and microencapsulated by freeze and spray-drying using maltodextrin as the encapsulating agent and verified their antioxidant activity. Phytochemicals, including phenolics, terpenoids, and flavonoids, have been known as chemical contents of plants that play significant biological actions as antioxidants by decreasing lipid peroxidation byproducts and increasing endogenous antioxidant enzymes (CAT, SOD, and PGE2) [27]. According to the obtained results, the type of wall material did not have a significant effect on the preservation of phenolic compounds ($p>0.05$), but the degree of preservation of phenolic compounds was influenced by the type of drying method ($p<0.05$) (Table 2). Microencapsulation by spray-drying becomes a promising alternative for protecting the bioactive compounds using a polymeric matrix [28]. Due to solvent removal, the highest inhibition of free radicals, amounts of phenolic compounds, and microcoating efficiency were obtained with spray-drying microencapsulation. Similar results were found in films based on quince seed mucilage containing thyme essential oil [29]. Spray-drying resulted in smaller and more uniform particles, which were commonly associated with improved dispersion and stability in formulations. In the current study, the microencapsulation efficiency of PAG is $89.24\% \pm 0.04\%$. Recently, Kucharska-Guzik et al. [30] reported that freeze-drying produced larger particles with a wider distribution range, which could benefit applications where a lower bulk density or free-flowing texture is desirable.

Sharayee et al. [31] investigated the effect of the microencapsulation process on the antioxidant properties of angelica essential oil and reported that the microencapsulation efficiency of this oil with a polysaccharide wall was 85%. These authors stated that food-grade polymers that are generally chosen for the microcoating of important food ingredients should protect the core material against oxidation, heat, and evaporation. Considering that maltodextrin has charged groups, it creates hydrophilic or hydrophobic parts. Maltodextrin has low emulsion stability and emulsifying capacity. Therefore, a combination of maltodextrin and other compounds could be employed for microencapsulation [32]. On the other hand, sodium caseinate has been used as a

Table 3: The amount of thickness in films containing different concentrations of mastic gum and *Pistacia atlantica* gum (PAG).

Concentrations of mastic gum (weight/weight)	Thickness (mm)
Films containing 15% mastic gum + 85% PAG	0.069[a]
Films containing 30% mastic gum + 70% PAG	0.073[b]
Films containing 45% mastic gum + 55% PAG	0.078[c]

Note: The superscript letters (a–c) show significant differences in each column ($p < 0.05$).

stabilizer for microencapsulation via spray-drying microencapsulation with good results.

The effect of different mastic gum and PAG concentrations on film thickness is shown in Table 3. With increasing mastic gum concentrations, the thickness of the films increased (0.069–0.078 mm). This can be the result of the inclusion of mastic gum, changing the structural homogeneity. Aydogdu et al. [33] reported that the thickness of the films increases after a mastic gum concentration of 1% g/g solvent, which suggests a shift in structural homogeneity after this concentration.

Hoque et al. [34] reported that the incorporation of herb extracts, including cinnamon, clove, and star anise extracts, into gelatin and partially hydrolyzed gelatin increased the tensile strength and decreased water vapor permeability of the resulting films. However, those extracts could affect the color of the resulting films to some degree. In the current research, the in vitro data suggest that the incorporation of mastic gum and PAG increases the potential synergy effects that could be successfully incorporated into biodegradable alginate edible films. Norajit et al. [35] demonstrated that the ginseng extract can be successfully incorporated into biodegradable alginate films and retain excellent antioxidant activities. It is interesting to note that ginseng exhibited increased free-radical scavenging activities following an extrusion process. The incorporation of ginseng extract into the alginate films did not cause major changes in the moisture content values. Therefore, the increase in the thickness of the film can be due to the presence of the chemical composition of the mastic gum in the film or due to the formation of holes in the film network after the evaporation of volatile compounds with low molecular weight in the drying stage of the film. Based on the results, film samples containing 45% mastic gum were considered to increase the thickness and the possibility of greater resistance and stability.

Figure 1 shows the antioxidant activity of films. The film prepared from mastic gum showed 77.4% inhibitory activity on DPPH radical. The antioxidant properties of the films increased significantly with increasing mastic gum concentration ($p < 0.05$). Similar results were found in films based on mucilage seeds containing thyme essential oil [36]. Phenolic compounds are one of the most important classes of natural antioxidants and are closely related to the antioxidant activity of plant tissues [36]. Bakhshi Khoramdareh et al. [37] showed a positive correlation between phenolic compounds of Bene gum (such as ferulic acid, gallic acid, quercetin, etc.) and antioxidant activity. This positive relation between phenolic compounds (as potent hydrogen donors) and DPPH radical scavenging activity has been reported by previous investigations [38, 39].

Table 4 shows the results of the studies conducted on the antimicrobial effects (diameter of growth inhibition zone and MIC) of the films on the desired microorganisms using the disc diffusion method. The MIC of the selected PAG was estimated using the broth dilution method as described in the methods section. The results outlined from this study show that PAG has potential bactericidal effects against *S. aureus* and *E. coli*. These tests estimate in vitro antimicrobial susceptibility [38]. In our study, discs prepared from commercial films (synthetic cellophane polymer) did not show any antimicrobial activity on the tested bacteria. Films containing 15%, 30%, and 45% by weight of mastic gum and whole mastic gum caused a significant nongrowth zone in the culture medium of *S. aureus* and *E. coli*. Bakhshi Khoramdareh et al. [37] showed that the *Pistacia atlantica* (Bene) oleoresin gum was effective against all bacteria tested (including *E. coli*, *S. typhimurium*, *P. aeruginosa*, *L. monocytogenes*, *B. cereus*, and *S. aureus*), and due to the distinctive structure and complexity of their double-layer cell membrane, Gram-negative bacteria showed higher resistance than Gram-positive bacteria. Dadalioğlu and Evrendilek [36] revealed that all essential oils exhibited a very strong antibacterial activity against the tested bacteria (*E. coli*, *S. typhimurium*, *L. monocytogenes*, and *S. aureus*). Films containing 15% w/w concentration of mastic gum and 85% PAG showed the most activity on *S. aureus* and *E. coli* bacteria by creating a non-growth halo with a diameter of 22.23 and 20.18 mm, respectively. These results are in agreement with the previous findings of Jouki et al. [29] and Burt [40], who showed that plant essential oils are more effective on Gram-positive bacteria (*S. aureus* and *L. monocytogenes*) than Gram-negative bacteria (*P. aeruginosa* and *S. typhimurium*). In conclusion, it can be seen that among Gram-positive bacteria, *Lactobacillus plantarum* was the most resistant bacterium against the films containing the antimicrobial compound of mastic gum and PAG.

Changes in the pH levels of shrimp samples stored at 4°C are shown in Figure 2. The initial pH of shrimp was 6.9, which increased significantly (7.88) with increasing storage time ($p < 0.05$). This increase in pH levels is due to the increase in volatile bases produced, such as ammonia and trimethylamine, internal and bacterial metabolites, or microbial enzymes in shrimp tissue [41]. This increase in pH level hurts the quality properties of the product, especially smell, color, and texture during the storage period, which impacts storage life and generates economic losses and food waste.

By increasing the concentration of mastic gum, the brightness of the coatings decreased ($p < 0.05$) (Figure 3). It can be seen that there was a significant difference in terms of color between the solutions containing different concentrations of coating ratios containing mastic gum and PAG, and it was also significant in the color indices (Figure 4). It is observed in higher percentages of the wall material compared to the carrier. In the examination of the color parameter of the commercial sample, there was a significant difference with the samples containing nanoemulsion ($p < 0.05$), so that the brightness in the commercial sample, considering

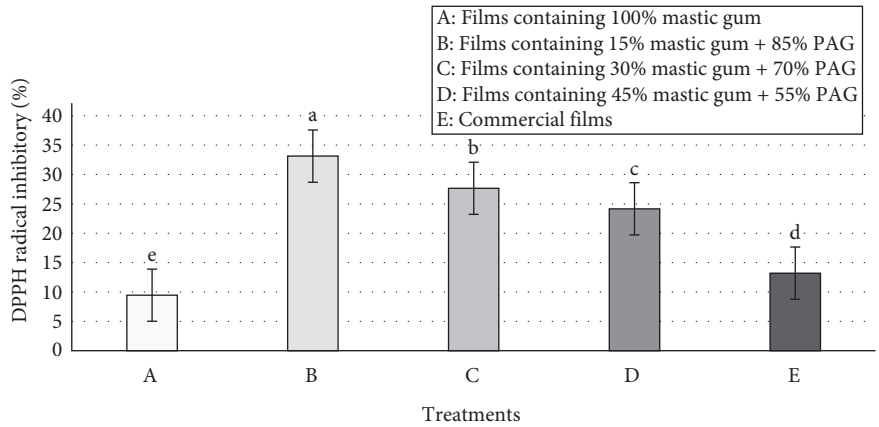


Figure 1: Antioxidant activity of films containing different concentrations of mastic gum and *Pistacia atlantica* gum (PAG). Different letters indicate significant differences ($p < 0.05$).

Table 4: Antimicrobial activity of mastic gum and *Pistacia atlantica* gum (PAG) against Gram-positive (*S. aureus*) and Gram-negative (*E. coli*) bacterial strains.

Treatments	*S. aureus*		*E. coli*	
	Zone of inhibition (mm)	MIC (mg/mL)	Zone of inhibition (mm)	MIC (mg/mL)
Films containing 100% mastic gum	10.11^{d}	11.66^{a}	4.32^{d}	10.06^{a}
Films containing 15% mastic gum + 85% PAG	$22/23^{a}$	11.33^{a}	20.18^{a}	9.66^{a}
Films containing 30% mastic gum + 70% PAG	$14/13^{c}$	10.33^{a}	11.76^{c}	9.33^{a}
Films containing 45% mastic gum + 55% PAG	21.34^{b}	8.66^{b}	18.52^{b}	7.22^{b}
Commercial films	0^{e}	0^{c}	0^{e}	0^{c}

Note: The superscript letters (a–e) show significant differences in each column ($p < 0.05$).

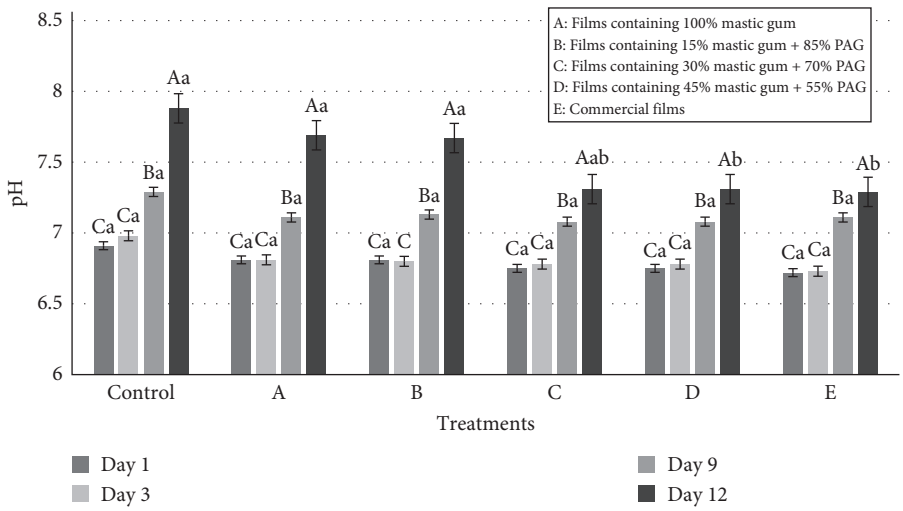


Figure 2: Changes in pH values of nanoemulsions with different concentrations of mastic gum and *Pistacia atlantica* gum (PAG). Different letters indicate significant differences ($p < 0.05$).

the synthetic polymer as a coating and reducing the color changes, is evident. On the other hand, the polymers in the mastic gum are completely dissolved in water, and due to the impact of light rays on them, reflection and scattering of light occur, which can lead to a decrease in the brightness of the emulsions at the same time as the concentration of the gum increases. Similar results were obtained by using carboxymethyl cellulose in emulsion production with Cadun et al. [42]. Also, it was shown that in the presence of PAG and high proportions of emulsion sample number 4, the color of the solution becomes greener. But the noteworthy point is that in the presence of mastic gum and the decrease in the ratio of particles to the carrier material leads to a decrease in the intensity of green. This is even though adding mastic gum to water (in the absence of PAG) does not have much effect on the intensity of redness of the solutions. It seems that the

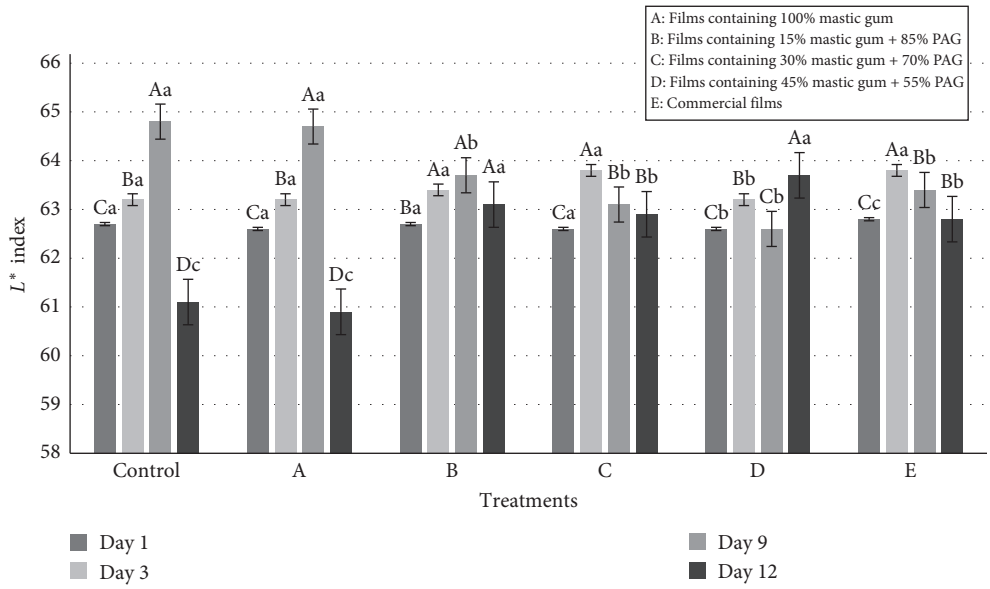


Figure 3: Changes in the L^* index of the coating nanoemulsions as a function of the nanoemulsion and the carrier material percentage. Different letters indicate significant differences ($p<0.05$).

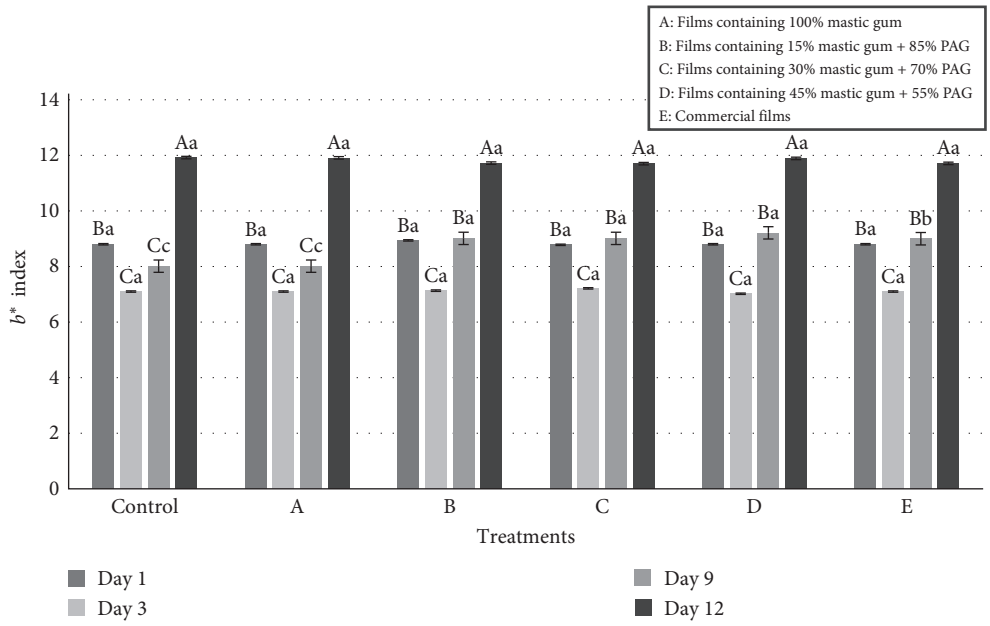


Figure 4: Changes in the b^* index of coating nanoemulsions as a function of nanoemulsion to carrier material percentage. Different letters indicate significant differences ($p<0.05$).

pH of mastic gum causes the color of the extract to change from yellow to red. Yellowness index (YI) is another indicator that was investigated for coating emulsions. YI was investigated as a function of coating type and storage time [43]. Based on the results, increasing the concentration of the emulsion in proportion to the carrier material increased the intensity of the YI. The same color change was also observed in higher emulsion concentrations, such that the highest intensity of YI was seen in the antimicrobial sample (antimicrobial mastic gum film containing microcoated pith PAG mixed with the carrier material in a ratio of 45% to 55% as a coating) (code no. 4). In the investigation of the effect of increasing time, color changes were significant in samples with different coatings, so that in a clear examination, the lowest amount of changes in the L^* index was reported in the sample containing the ratio of 30%–70% nanoemulsion and carrier material and then the sample with commercial film, which had no statistically significant difference ($p<0.05$) with each other, and the most changes in color during the storage period were observed in the uncoated sample and the control sample with mastic gum coating alone. The results show that the use of PAG in the preparation of the film had a significant effect on

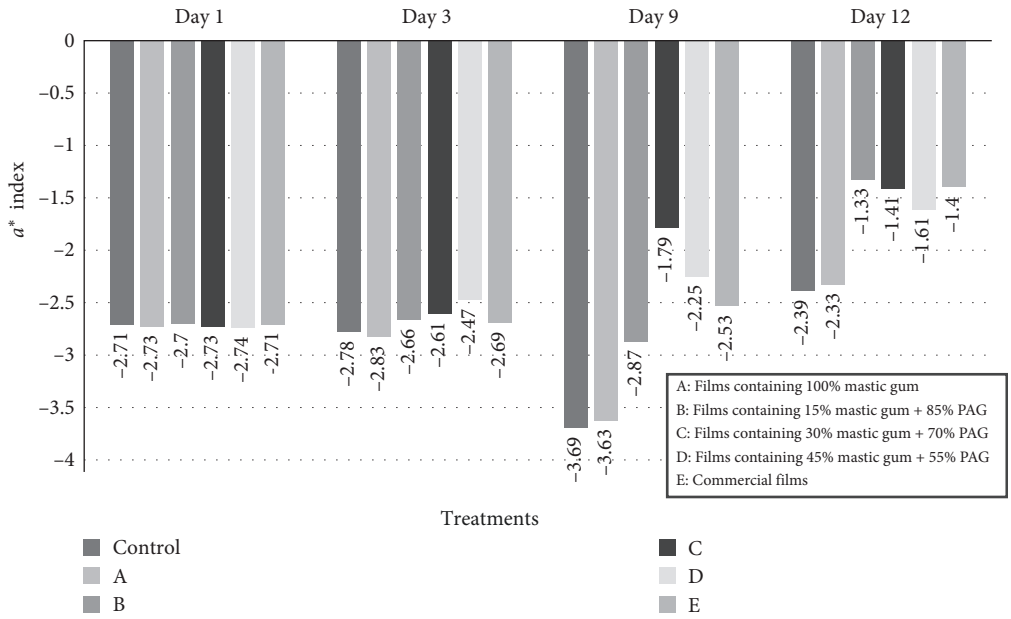


FIGURE 5: Changes in the a^* index of the coating nanoemulsions as a function of the nanoemulsion to the carrier material percentage.

maintaining the color quality of the samples and reducing the changes in this index. Greater microbial growth on the surface of shrimps decreases light intensity by forming a slimy layer, accelerates pigment oxidation—particularly in uncoated samples—and induces black spot formation in coated samples as a consequence of oxygen entrapment. Covering and preventing the contact of oxygen with the tissue will not occur, and the samples will have a brighter color. No significant difference was reported. What was determined in this study was that the color of the surface of the shrimps is slightly greenish, and there is no change in the intensity of the redness parameter with the coating and the passage of time ($p > 0.05$). It also applies to the interpretation of the a^* index (Figure 5). With the increase in time, the amount of changes in the samples, except for the uncoated sample, did not show a significant difference from each other. As the amount of extract increased, the process of color changes was observed, whereas the commercial film sample demonstrated no statistically significant difference in comparison with the experimental films [44].

By increasing the level of PAG in nanoemulsions, the particle size decreased significantly ($p < 0.05$). In line with the current results, Xiong et al. [45] found that the particle size decreased with increasing concentration of xanthan gum/lysozyme nanoparticles. Naji-Tabasi et al. [46] also indicated that by increasing the Baneh (*Pistacia atlantica*) gum concentration, the particle size significantly decreased. Aggregation and agglomeration of nanoparticles primarily depend on particle size [46]. They found that the size of the particles is effective on the ultimate oil absorption capacity and the stability of the emulsion. Khanahmadi et al. [47] observed that obtaining an optimum particle size (smaller size) in nanoemulsions depends on several parameters, including the power and duration of sonication, as well as the concentration of glycerol and surfactant. Their findings indicated that an increase in PAG particle size leads to the formation of highly unstable nanoemulsions.

The texture of the samples was evaluated to check their changes during storage at 4°C using the Instran device, and the parameters of stiffness, intertissue cohesion, elasticity, and chewability were evaluated. Table 5 shows the results of the ANOVA of tissue evaluation data. The results showed that the ratio of nanoemulsion in different treatments, as well as time, has a significant effect on the stiffness parameter ($p < 0.05$). Increasing the concentration of both compounds led to a greater hardness of the shrimp tissue. The highest hardness was observed in the samples coated with films containing 45%–55% of the compounds, as well as in the commercial film sample. Since phenolic compounds are present in the film containing different proportions of nanoemulsion, these compounds can cause interaction between protein strands through covalent and noncovalent bonds, which can increase tissue stiffness. Therefore, increasing the concentration of phenolic compounds increases the hardness of shrimp samples. On the other hand, mastic gum also contains polysaccharide compounds in these films, and these compounds can also participate in protein–polysaccharide interactions and increase the stiffness of the tissue [48]. The stiffness in uncoated treatments increased until the 3rd day and decreased from the 9th to the 12th day [49]. In the samples with films containing different ratios of carrier and nanoemulsion, this parameter showed an increase up to the seventh day. By comparing the results of hardness intensity and pH level changes of shrimp, it can be seen that the samples with a lower percentage of nanoemulsion, without coating, and containing gum alone had a higher pH; the high pH of these samples provided conditions in which they were more susceptible to microbial spoilage, and therefore, after 3 days of coating the

Table 5: Texture profile analysis of emulsion stabilized by different concentrations of mastic gum and *Pistacia atlantica* gum (PAG).

Parameters	Storage time (h)	Treatments				Commercial films
		100% mastic gum	15% mastic gum + 85% PAG	30% mastic gum + 70% PAG	45% mastic gum + 55% PAG	
Hardness (N)	1	7.98 ± 0.93^{B}	7.85 ± 0.44^{B}	8.19 ± 0.42^{A}	7.66 ± 0.22^{A}	7.31 ± 0.42^{A}
	3	8.08 ± 0.73^{B}	8 ± 0.64^{B}	9.31 ± 0.54^{A}	8.56 ± 0.92^{A}	8.01 ± 0.82^{A}
	9	8.29 ± 0.84^{B}	8.43 ± 0.65^{AB}	9.56 ± 0.57^{AB}	9.68 ± 0.42^{A}	8.56 ± 0.57^{AB}
	12	12.39 ± 0.92^{A}	12.37 ± 0.99^{A}	13.74 ± 0.91^{A}	14.05 ± 0.67^{A}	12.74 ± 0.91^{A}
Cohesiveness	1	0.33 ± 0.02^{A}	0.38 ± 0.03^{A}	0.29 ± 0.01^{A}	0.29 ± 0.05^{A}	0.22 ± 0.01^{A}
	3	0.30 ± 0.02^{A}	0.31 ± 0.03^{A}	0.29 ± 0.01^{A}	0.28 ± 0.04^{A}	0.23 ± 0.01^{A}
	9	0.29 ± 0.02^{A}	0.30 ± 0.03^{A}	0.29 ± 0.01^{A}	0.27 ± 0.04^{A}	0.24 ± 0.01^{A}
	12	0.24 ± 0.02^{A}	0.24 ± 0.03^{A}	0.26 ± 0.01^{A}	0.23 ± 0.03^{A}	0.25 ± 0.01^{A}
Springiness (mm)	1	8.31 ± 0.65^{A}	7.33 ± 0.11^{A}	7.6 ± 0.17^{A}	6.8 ± 0.20^{B}	7.36 ± 0.37^{A}
	3	8.11 ± 0.62^{A}	7.37 ± 0.21^{A}	7.49 ± 0.27^{A}	6.87 ± 0.10^{B}	7.21 ± 0.17^{A}
	9	8.07 ± 0.65^{A}	7.43 ± 0.20^{AB}	7.76 ± 0.54^{AB}	6.91 ± 0.68^{B}	7.13 ± 0.54^{AB}
	12	7.34 ± 0.17^{A}	7.10 ± 0.11^{A}	7.11 ± 0.19^{A}	6.39 ± 0.20^{B}	6.91 ± 0.19^{A}
Chewiness (mJ)	1	17.67 ± 0.29^{A}	17.18 ± 1.65^{A}	17.28 ± 0.70^{A}	17.65 ± 0.53^{A}	17.38 ± 0.70^{A}
	3	17.97 ± 0.29^{A}	17.68 ± 1.25^{A}	17.68 ± 0.10^{A}	18.65 ± 0.53^{A}	18.38 ± 0.70^{A}
	9	18.67 ± 0.39^{A}	18.68 ± 1.65^{A}	18.68 ± 0.70^{A}	19.15 ± 0.36^{A}	18.61 ± 0.40^{A}
	12	21.15 ± 1.45^{B}	21.38 ± 2.03^{B}	24.70 ± 0.58^{A}	26.17 ± 0.39^{A}	24.61 ± 0.58^{A}

Note: All data are presented in the manner of means ± SD ($n = 3$). The diverse letters for each parameter indicate a significant difference ($p < 0.05$).

Table 6: Antimicrobial activity of active films stabilized by different concentrations of mastic gum and *Pistacia atlantica* gum (PAG).

Treatments	*S. typhimurium*	*S. aureus*	*B. cereus*	*P. aeruginosa*	*V. cholerae*	*E. coli*
100% mastic gum	0	0.47	0.16	0.16	0	0
15% mastic gum + 85% PAG	0	10.16	3.12	3.17	0.68	3.54
30% mastic gum + 70% PAG	1.16	9.5	6.21	4.16	2.23	4.87
45% mastic gum + 55% PAG	4.66	11.33	13.47	7.66	8.48	13.08
Commercial films	14.87	17.44	22.11	13.17	16.55	21.54

shrimp, it seems that the protease activity of the microorganisms softens the shrimp tissue and reduces its hardness. On the other hand, overcoming the autolysis reaction on cadaver stagnation in shrimp muscles reduces the stiffness in its tissue, which is often due to the enzymatic breakdown of muscle proteins [50].

As can be seen in Table 5, the effective factor on intertissue cohesion is the increase in emulsion ratio in treatments and time, which has a significant effect ($p < 0.05$). The intertissue cohesion decreases in all treatments until the 3rd day, but after that, an increase in this parameter can be seen. After the death of aquatic animals, including shrimp, autolysis reactions make the meat softer and reduce the connections between muscle cells. Therefore, intertissue cohesion gradually decreases. But all the samples suffered tissue disintegration on the 9th day during the test, and thus, the area under the graph increased and causing this parameter to increase again. In general, with the increase of emulsion or high ratios of nanoemulsion (40%–45%), intertissue cohesion increased. Increasing the concentration in the treatment containing a ratio of 45–40 compared to the carrier material, as well as the sample containing the commercial film, could increase the elasticity of the samples, which can also be related to the decrease in bleeding due to the increase in the concentration of the film and Tween 80. The results obtained are consistent with Faraj Zadeh et al. [51].

The results obtained from microbial tests on shrimp shelf life are summarized in Table 6. As the durability results indicate, the highest microbial resistance was observed in the samples coated with antimicrobial films of mastic gum containing micro-coated PAG, mixed with the carrier material at a ratio of 45%–55%. In contrast, for the control samples (films containing only mastic gum as the coating), microbial resistance was maintained until the 12th day of storage. In this research, films containing a high proportion of nanoemulsion significantly increased the shelf life of shrimp microbes. The results obtained from the microbial test showed that there was a relatively good harmony in the shelf life of the control and coated samples with coatings without corn extract. Similar results were reported by Arashisar et al. [52].

4. Conclusion

Active films containing 45% PAG extract had a suitable antimicrobial effect on all tested microorganisms, which could

increase the shelf life of shrimp during the storage process. The results showed that packaging film has significant antioxidant properties with significant inhibition diameters against DPPH free radical, which could be because of its phenolics, terpenoids, and flavonoids. Therefore, this kind of packaging is impressive in enhancing the shelf life of shrimp during storage at 4°C. Based on the current results, the oxygen barrier coatings should therefore be used with even more pronounced ceasing if enriched with antioxidants.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

This research received no external funding.

References

[1] A. Samir, F. H. Ashour, A. A. A. Hakim, and M. Bassyouni, "Recent Advances in Biodegradable Polymers for Sustainable Applications," *npj Materials Degradation* 6, no. 1 (2022): 68.

[2] F. Islam, A. Imran, M. Afzaal, et al., "Nanotechnology for the Improvement of the Quality, Properties, and Safety of Food and Agriculture: Recent and Future Trends," *Cogent Food & Agriculture* 10, no. 1 (2024): 2024.

[3] H. Hamali, F. Masoumi, B. Baradaran, and G. Hamidian, "Plasma Rich-Platelet (PRP) Potentially Attenuates Tamoxifen Spermatogenic Dysfunction in Rat's Model: Sperm Quality, Histomorphometric, and Apoptosis Assessment," *Asia Pacific Journal of Medical Toxicology* 14 (2025): 7–12.

[4] J. Zhao, W. Lan, and J. Xie, "Recent Developments in Nanoemulsions Against Spoilage in Cold-Stored Fish: A Review," *Food Chemistry* 429 (2023): 136876.

[5] E. S. H. Atwaa, M. R. Shahein, H. A. Radwan, et al., "Antimicrobial Activity of Some Plant Extracts and Their Applications in Homemade Tomato Paste and Pasteurized Cow Milk as Natural Preservatives," *Fermentation* 8, no. 9 (2022): 428.

[6] H. Von Döhren, *Antibiotics: Actions, Origins, Resistance* (Protein Science, Washington, DC, 2004).

[7] N. Muñoz-Tebar, J. A. Pérez-Álvarez, J. Fernández-López, and M. Viuda-Martos, "Chitosan Edible Films and Coatings With Added Bioactive Compounds: Antibacterial and Antioxidant Properties and Their Application to Food Products: A Review," *Polymers* 15, no. 2 (2023): 396.

[8] S. Zivanovic, S. Chi, and A. F. Draughon, "Antimicrobial Activity of Chitosan Films Enriched With Essential Oils," *Journal of Food Science* 70, no. 1 (2005): M45–M51.

[9] M. Ramos, A. Jiménez, M. Peltzer, and M. C. Garrigós, "Characterization and Antimicrobial Activity Studies of Polypropylene Films With Carvacrol and Thymol for Active Packaging," *Journal of Food Engineering* 109, no. 3 (2012): 513–519.

[10] A. Shafieipour and M. Sami, "The Effect of Different Thawing Methods on Chemical Properties of Frozen Pink Shrimp (*Penaeus duorarum*)," *Iranian Journal of Veterinary Medicine* 9 (2015): 1–6.

[11] I. Usman, S. Sana, H. M. Jaffar, et al., "Recent Progress in Edible Films and Coatings: Toward Green and Sustainable Food Packaging Technologies," *Applied Food Research* 5, no. 2 (2025): 101070.

[12] E. Díaz-Montes and R. Castro-Muñoz, "Edible Films and Coatings as Food-Quality Preservers: An Overview," *Foods* 10, no. 2 (2021): 2021–2249.

[13] T. Bourtoom, "Edible Films and Coatings: Characteristics and Properties," *International Food Research Journal* 15 (2008): 237–248.

[14] M. Aminzare, M. Hashemi, E. Ansarian, et al., "Using Natural Antioxidants in Meat and Meat Products as Preservatives: A Review," *Advances in Animal and Veterinary Sciences* 7, no. 5 (2019): 417–426.

[15] M. A. Kurek, P. Pišonić, M. Ščetar, et al., "Edible Coatings for Fish Preservation: Literature Data on Storage Temperature, Product Requirements, Antioxidant Activity, and Coating Performance-A Review," *Antioxidants* 13 (2024): 1417.

[16] F. Afshar Mehrabi, A. Sharifi, and M. Ahvazi, "Effect of Chitosan Coating Containing Nepeta Pogonosperma Extract on Shelf Life of Chicken Fillets During Chilled Storage," *Food Science & Nutrition* 9, no. 8 (2021): 4517–4528.

[17] A. Herbon, "Shelf-Life Extension Under Implementation Costs," *Computers & Industrial Engineering* 180 (2023): 109241.

[18] X. Carrión-Granda, I. Fernández-Pan, I. Jaime, J. Rovira, and J. I. Maté, "Improvement of the Microbiological Quality of Ready-to-Eat Peeled Shrimps (*Penaeus vannamei*) by the Use of Chitosan Coatings," *International Journal of Food Microbiology* 232 (2016): 144–149.

[19] P. Ebrahimian, A. Najafi, and A. Abedinia, "Effect of Nanoencapsulated Pistachio Green Hull Extract in the Carboxymethyl Cellulose and Soy Protein Isolate Edible Coatings on Shelf-Life Quality of Fresh Pistachio," *Journal of Food Processing and Preservation* 2024, no. 1 (2024): 1–11.

[20] Q. Wu, L. Xie, and H. Xu, "Determination of Toxigenic Fungi and Aflatoxins in Nuts and Dried Fruits Using Imaging and Spectroscopic Techniques," *Food Chemistry* 252 (2018): 228–242.

[21] A. Khadivi, F. Mirheidari, A. Saeidifar, Y. Moradi, and Y. Tunç, "Morphological and Pomological Variations of *Pistacia atlantica* Desf. subsp. cabulica and subsp. mutica in Sistan-Va-Baluchestan Province, Iran," *BMC Plant Biology* 25 (2025): 248.

[22] H. S. Rahman, "Phytochemical Analysis and Antioxidant and Anticancer Activities of Mastic Gum Resin From *Pistacia atlantica* Subspecies kurdica," *Onco Targets and Therapy* 11 (2018): 4559–4572.

[23] M. Ghalavand, H. Esmaeili-Gouvarchin-Ghaleh, M. Mirzaei-Nodooshan, S. Vazifedost, and S. Mohammadi-Yeganeh, "An Evaluation of the Effects of *Pistacia atlantica* Gum Hydro-Alcoholic Extract on the Phagocytosis Ability of Macrophages and Atherosclerosis Development in Hypercholesteremic Rats," *ARYA Atherosclerosis* 18, no. 4 (2022): 1–6.

[24] E. Sadeghi, M. Akbari, M. Khanahmadi, M. Azizi-Lalabadi, and F. Karami, "Effect of *Pistacia atlantica* (Bane) Essential Oil on Oxidative Stability of Sunflower Oil," *Journal of Food Quality and Hazards Control* 10 (2023): 21–28.

[25] N. P. Nirmal and S. Benjakul, "Melanosis and Quality Changes of Pacific White Shrimp (*Litopenaeus vannamei*) Treated With Catechin During Iced Storage," *Journal of Agricultural and Food Chemistry* 57, no. 9 (2009): 3578–3586.

[26] M. T. Bostanci, A. S. Bulbul, I. S. Celik, et al., "Investigation of Antibacterial, Antifungal, Antibiofilm, Antioxidant and

Anticancer Properties of Methanol Extracts of Salvia Marashica İlçim, Celep & Doğan and Salvia Caespitosa Montbret & Aucher Ex Benth Plants With Medicinal Importance," *Chemosphere* 288 (2022): 132602.

[27] T. S. Al-Qaisi, A. A. J. Jabbar, M. M. H. M. Raouf, et al., "A Traditional Gum Exudate From, *Pistacia atlantica*, Ameliorates Etha-Nol-Mediated Gastric Ulcer in Rats: Possible Molecular Mechanisms," *Food Science & Nutrition* 13, no. 3 (2025): e70049.

[28] M. D. Otálora, A. Wilches-Torres, and J. A. Gómez Castaño, "Spray-Drying Microencapsulation of Pink Guava (Psidium guajava) Carotenoids Using Mucilage From Opuntia Ficus-Indica Cladodes and *Aloe Vera* Leaves as Encapsulating Materials," *Polymers* 14, no. 2 (2022): 310.

[29] M. Jouki, S. A. Mortazavi, F. T. Yazdi, and A. Koocheki, "Characterization of Antioxidant–Antibacterial Quince Seed Mucilage Films Containing Thyme Essential Oil," *Carbohydrate Polymers* 99 (2014): 537–546.

[30] A. Kucharska-Guzik, L. Guzik, A. Charzyńska, and A. Michalska-Ciechanowska, "Influence of Freeze Drying and Spray Drying on the Physical and Chemical Properties of Powders From *Cistus creticus* L. Extract," *Foods* 14, no. 5 (2025): 849.

[31] P. Sharayee, R. Ghavidel, and H. Badfrasa, "Effect of Micro-Coating Process Using Freeze Dryer on Physical, Chemical and Antioxidant Properties of Golper Essential Oil," *Journal of Innovation in Food Science and Technology* 10 (2018): 136.

[32] M. A. Kurek and A. Pratap-Singh, "A Plant-Based (Hemp, Pea and Rice) Protein-Maltodextrin Combinations as Wall Material for Spray-Drying Microencapsulation of Hempseed (*Cannabis sativa*) Oil," *Foods* 9, no. 11 (2020): 1707.

[33] A. Aydogdu, M. Akgun, and E. Kirtil, "Effect of Mastic Gum Integration on Improvement of Polylactic Acid Biodegradable Films," *Polymer Engineering & Science* 63, no. 5 (2023): 1539–1550.

[34] M. S. Hoque, S. Benjakul, and T. Prodpran, "Properties of Film From Cuttlefish (*Sepia pharaonis*) Skin Gelatin Incorporated With Cinnamon, Clove and Star Anise Extracts," *Food Hydrocolloids* 25, no. 5 (2011): 1085–1097.

[35] K. Norajit, K. M. Kim, and G. H. Ryu, "Comparative Studies on the Characterization and Antioxidant Properties of Biodegradable Alginate Films Containing Ginseng Extract," *Journal of Food Engineering* 98, no. 3 (2010): 377–384.

[36] I. Dadalioğlu and G. A. Evrendilek, "Chemical Compositions and Antibacterial Effects of Essential Oils of Turkish Oregano (*Origanum minutiflorum*), Bay Laurel (*Laurus nobilis*), Spanish Lavender (*Lavandula stoechas* L.), and Fennel (*Foeniculum vulgare*) on Common Foodborne Pathogens," *Journal of Agricultural and Food Chemistry* 52, no. 26 (2004): 8255–8260.

[37] N. B. Khoramdareh, H. Hamedi, and A. Sharifan, "Pistacia atlantica (Bene) Oleoresin Gum: The Antioxidant and Antimicrobial Activity, and Potential Encapsulation of Saccharomyces boulardii and Lactobacillus acidophilus in Kefir With Sodium Alginate/Bene Gum Polymer, Preprints," *Research Square* 8 (2022).

[38] A. A. Hatamnia, N. Abbaspour, and R. Darvishzadeh, "Antioxidant Activity and Phenolic Profile of Different Parts of Bene (*Pistacia atlantica* Subsp. Kurdica) Fruits," *Food Chemistry* 145 (2014): 306–311.

[39] S. M. Nachvak, S. Hosseini, A. Nili-Ahmadabadi, D. Dastan, and M. M.Rezaei, "Chemical Composition and Antioxidant Activity of *Pistacia atlantica* Subsp. Kurdica From Awraman," *Journal of Reports in Pharmaceutical Sciences* 7, no. 3 (2018): 222–230.

[40] S. Burt, "Essential Oils: Their Antibacterial Properties and Potential Applications in Foods—a Review," *International Journal of Food Microbiology* 94, no. 3 (2004): 223–253.

[41] W. Fan, J. Sun, Y. Chen, J. Qiu, Y. Zhang, and Y. Chi, "Effects of Chitosan Coating on Quality and Shelf Life of Silver Carp During Frozen Storage," *Food Chemistry* 115, no. 1 (2009): 66–70.

[42] A. Cadun, D. Kışla, and S. Çaklı, "Marination of Deep-Water Pink Shrimp With Rosemary Extract and the Determination of Its Shelf-Life," *Food Chemistry* 109, no. 1 (2008): 81–87.

[43] S. H. Peighambardoust, M. Yaghoubi, A. Hosseinpour, K. Alirezalu, M. Soltanzadeh, and M. Dadpour, "Development and Application of Dual-Sensors Label in Combination With Active Chitosan-Based Coating Incorporating Yarrow Essential Oil for Freshness Monitoring and Shelf-Life Extension of Chicken Fillet," *Foods* 11, no. 21 (2022): 3533.

[44] M. E. Sosa-Morales, R. Orzuna-Espíritu, and J. F. Vélez-Ruiz, "Mass, Thermal and Quality Aspects of Deep-Fat Frying of Pork Meat," *Journal of Food Engineering* 77, no. 3 (2006): 731–738.

[45] T. Xiong, H. Sun, Z. Niu, et al., "Carrageenan-Based Pickering Emulsion Gels Stabilized by Xanthan Gum/Lysozyme Nanoparticle: Microstructure, Rheological, and Texture Perspective," *Foods* 11 (2022): 3757.

[46] S. Naji-Tabasi, M. S. Shakeri, A. Modiri-Dovom, and S. Shahbazizadeh, "Investigating Baneh (*Pistacia atlantica*) Gum Properties and Applying Its Particles for Stabilizing Pickering Emulsions," *Food Chemistry* 11 (2024): 101111.

[47] M. Khanahmadi, F. Shahrezaei, M. Sharifi, and G. R. Bardajee, "Ultrasound-Assisted Preparation and Optimization of Natural Flavoring Nanoemulsion for Dairy Products Based on *Pistacia Khinjuk* in Lab Scale," *Chemical Methodologies* 7 (2023): 524–539.

[48] C. Mavrakis and V. Kiosseoglou, "The Structural Characteristics and Mechanical Properties of Biopolymer/Mastic Gum Microsized Particles Composites," *Food Hydrocolloids* 22, no. 5 (2008): 854–861.

[49] M. Ngadi, Y. Li, and S. Oluka, "Quality Changes in Chicken Nuggets Fried in Oils With Different Degrees of Hydrogenatation," *LWT - Food Science and Technology* 40, no. 10 (2007): 1784–1791.

[50] N. Nunak and G. Schleining, "Instrumental Textural Changes in Raw White Shrimp During Iced Storage," *Journal of Aquatic Food Product Technology* 20, no. 4 (2011): 350–360.

[51] F. F. Zade, S. A. Shahidi, and S. Hamze, "Optimization of Chitosan and/or Gelatin Edible Coatings to Improve Quality of Refrigerated Shrimp," *Journal of Food Science and Technology* 13 (2015): 79–91.

[52] S. Arashisar, O. Hisar, M. Kaya, and T. Yanik, "Effects of Modified Atmosphere and Vacuum Packaging on Microbiological and Chemical Properties of Rainbow Trout (Oncorynchus Mykiss) Fillets," *International Journal of Food Microbiology* 97, no. 2 (2004): 209–214.