Original Article

Shelf-life Extension of Nile Tilapia Fillets Using Qodume Shirazi Nanocomposite Coating Enriched With Turmeric Essential Oil

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ABSTRACT

Background: The growing demand for sustainable food preservation methods has led to the exploration of natural edible coatings aimed at extending the shelf life of perishable products.

Objectives: Our study was carried out to develop an active coating incorporating antimicrobial agent to further enhance food safety and longevity.

Methods: To investigate the effectiveness of an edible coating derived from Qodume Shirazi gum (*Alyssum homolocarpum*) infused with various concentrations of turmeric essential oil (TEO)—specifically 0%, 1%, 1.5%, and 2% (w/v)—on the shelf life of Nile tilapia fillets under refrigerated conditions (4±1 °C), chemical and microbial assessments were conducted on days 0, 7, 14, 21, and 28. Sensory evaluation was performed using the 5-point hedonic method.

Results: The coatings at 1.5% and 2% significantly reduced microbial growth compared to the control samples, keeping total viable count (TVC) and total psychrotrophic count (TPC) within acceptable limits throughout the study period. Additionally, the treated fillets showed a slower increase in pH, total volatile nitrogen (TVN), peroxide value (PV), and thiobarbituric acid reactive substances (TBARS) values than the untreated fillets. Sensory analysis confirmed these findings, with the 1.5% TEO coating receiving the highest scores for taste, appearance, and overall acceptability up to day 14. Notably, the shelf life of the coated tilapia was extended by approximately five days compared to the controls.

Conclusion: These results highlight the potential of natural edible coatings in food preservation, especially for aquatic products that spoil quickly. Incorporating TEO not only boosts antimicrobial activity but also adds value through its health benefits.

Keywords: *Alyssum homolocarpum*, Coating, Nile tilapia, Fillet, Tumeric

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Introduction

Nile tilapia (*Oreochromis niloticus*) is recognized as one of the most popular and important fish species (Shahrier et al., 2023). However, it has a short shelf life due to microbial spoilage, oxidative rancidity, and enzymatic degradation (Duarte et al., 2020; Barkhori et al., 2017). Recently, edible coatings have emerged as a promising technology to enhance the durability and shelf life of food products (Lotfi, 2025; Jebelli, 2018). These coatings are thin layers of natural or synthetic materials applied to food items to improve their quality and longevity. Edible coatings serve as protective barriers against microbial invasion and help retain moisture in seafood products. Additionally, they can mitigate the fishy aroma associated with lipid oxidation (Shahidi & Hossain, 2022). Recent studies have examined the use of natural compounds and edible coatings to extend the shelf life of fish fillets (Saei et al., 2021), particularly Nile tilapia. Turmeric extract, whether used alone or in combination with other plant extracts, has demonstrated effectiveness in slowing microbial growth, delaying chemical changes, and preserving the sensory attributes of tilapia fillets during refrigerated storage (Hakeem et al., 2023).

Chitosan-based coatings (Behmanesh et al., 2023), especially when paired with plant extracts, like Froriepia subpinnata, have shown improvements in chemical and microbial indices, extending shelf life by up to 14 days (Farhadi et al., 2022). Additionally, incorporating carvacrol into chitosan coatings has effectively reduced microbial populations and preserved quality (Chaparro-Hernandez et al., 2015). The combination of edible coatings containing turmeric extract with vacuum packaging has also produced synergistic effects in prolonging the shelf life of fish and poultry products (Dalvandi et al., 2020).

Edible coatings can be derived from various plants; however, many remain underutilized due to limited availability. Alyssum, a genus of 100-170 flowering plants in the Brassicaceae family, is well-known for its mucilage-rich seeds. This mucilage, commonly used in traditional medicine, especially in Iran, has found a new application. The seed mucilage of Qodume Shirazi (*Alyssum homolocarpum*) has significant potential for use in biodegradable films due to its excellent thickening and gelling properties. It has a low molecular weight (3.66×10^5 Da), a flexible chain, and a medium intrinsic viscosity (18.34 dL/g) at 25 °C. Primarily composed of carbohydrates (85.33%), it also contains a small quantity of uronic acid (5.63%).

The major sugar components of Qodume Shirazi seed mucilage are galactose (82.97%), glucose (5.7%), rhamnose (5.04%), xylose (2.72%), mannose (3.04%), and arabinose (0.53%), which indicates that this plant is a galactan-type polysaccharide. The carboxyl and hydroxyl groups in Qodume Shirazi seed mucilage allow it to behave like a conventional polyelectrolyte, enhancing its potential. This mucilage can thicken, replace fat, and stabilize various products (Heydari et al., 2020).

Curcumin, the active compound in turmeric, is well-known for its antioxidant and antimicrobial properties, which aid in maintaining fish quality (Nath et al., 2021). Turmeric (*Curcuma longa*) exhibits excellent antibacterial, antifungal, immunostimulatory, and anti-insecticidal activities. Declining product quality remains a significant challenge for global aquaculture development. Handling, distribution, and storage of fresh fish are particularly complex due to their highly perishable nature. Cold storage is the most effective method for controlling fish spoilage, especially in developing countries where power shortages limit cold chain operations. Given the high production and demand for innovative preservation methods, Nile tilapia serves as an ideal model fish for researching these issues and their potential solutions.

The present study aimed to investigate the effect of using edible coatings made from *A. homolocarpum*, incorporated with varying levels of turmeric essential oil (TEO), on extending the shelf life of Nile tilapia fillets under refrigerated conditions (4±1 °C).

Materials and Methods

Live Nile tilapia (*O. niloticus*) with an average weight of 550±35 g were sourced from a fish farm in Semnan, Iran. The fish were preserved in flake ice and transported to the Food Hygiene and Quality Control Laboratory at the Faculty of Veterinary Medicine, Semnan University. Upon arrival, the fish were decapitated, eviscerated, rinsed, and filleted into two sections using sterilized sharp knives. The fillets were then cut into small portions measuring approximately 6×7×4 cm, with an average weight of 50±7 g for each piece.

Turmeric essential oil extraction

Turmeric essential oil (TEO) was extracted via steam distillation using a Clevenger apparatus. Five hundred grams of dried and powdered turmeric (*Curcuma longa*) were added into a round-bottom flask, which was then filled with distilled water up to two-thirds of its capacity. The essential oil extraction was performed at boiling temperature for four hours.

Assessment of antioxidant efficacy

The antioxidant efficacy was evaluated using the free radical scavenging capacity of 2,2-diphenyl-1-picrylhydrazyl (DPPH) described by Esmaeilzadeh Kenari et al. (2014). To conduct the test, 0.3 mL of the essential oil was mixed with 3.7 mL of DPPH methanol solution (6×10^{-5} mol/L) and stirred vigorously. After allowing the mixture to sit for 30 minutes in a dark environment at room temperature (25 ˚C), the absorbance was measured at 517 nm.

The Equation 1 was used to determine the radical scavenging activity (Rezaei Savadkouhi et al. 2020):

$$1.\ Scavenging\ capability\ \% = \frac{A_0 - A_1}{A_0} \times 100$$

Where, A0 represents the absorbance of the control and A1 denotes the absorbance of the antioxidant sample.

Preparation of coatings

One gram of gum powder obtained from Qodume Shirazi seeds was added to 50 mL of distilled water and stirred for 10 minutes. To ensure complete dissolution, the solution was stirred for an additional 10 minutes at 90 ˚C. After reducing the temperature of the solution to 40 ˚C, glycerol (6% w/w) was added and mixed under continuous stirring (300 rpm) for 3 minutes. The solution was then placed in an ultrasonic bath for 5 minutes, after which 4 g of polysorbate 80 was added. TEO was incorporated at varying concentrations (0%, 1%, 1.5%, and 2%). The total volume was adjusted to 100 mL with distilled water and subjected to ultrasound for another 5 minutes. To reduce the size of the coating to the nanoscale, an ultrathorax at 1.5 kW and 10 ˚C was applied for 10 minutes (Sayyari et al. 2021).

Coating the fish fillets

The boneless and skinless fillets of fresh Nile tilapia (*O. niloticus*) were randomly divided into five groups (Table 1). Four of these groups (treatments) were submerged in the prepared Qodume Shirazi coating with different concentrations of TEO (0%, 1%, 1.5%, and 2%) for 2 minutes, and then placed on a sterile steel sieve to drain for an additional 2 minutes. The fifth group (control) was immersed in sterile distilled water and handled in the same manner as the coated samples. All samples were aseptically packaged in polyethylene bags and stored at 4±1 ˚C for further analyses.

Chemical analysis

Determination of pH

Each fish sample's pH was determined using the method outlined by Javan et al. (2024). Briefly, a blender was used to mix 10 g of each sample with 10 mg w/v of distilled water at room temperature. A Sartorius laboratory pH meter (Sartorius, USA) was then used to record the pH of the resulting suspension. The standard buffer solutions were used to calibrate the pH meter in a three-point calibration mode.

Total volatile basic nitrogen assay

The total volatile basic nitrogen (TVB-N) content in fish fillets was quantified utilizing a Kjeldahl-type apparatus, integrating methodologies outlined by Goulas & Kontominas (2005) and Urmila et al. (2015), with minor adjustments. Ten grams of homogenized fish fillet were combined with 100 mL of distilled water and centrifuged at 3,000 rpm for 10 minutes. The supernatant was subjected to filtration through Whatman No. 1 filter paper. Five milliliters of filtrate were alkalinized by the addition of 5 mL of magnesium oxide solution (10 g/L). Steam distillation was conducted utilizing a Kjeldahl distillation apparatus for 5 minutes. The distillate was gathered in a receiving flask containing 10 mL of 20 g/L boric acid and several drops of 0.1% methyl red and bromocresol green indicators. The distillate solution was titrated with 0.1 mol/L HCl, and the TVB-N content was determined using the Equation 2:

$$2.\ TVB-N(mgN/100g) = \frac{V\times C\times 14}{W} \times 100$$

W: the sample weight (g), V: the volume of titrant (mL), C: the normality of the acid (mol/L). Results were quantified as milligrams of nitrogen per 100 grams of fish fillet.

Peroxide value

The PV was assessed following the methodology of Hashemi et al. (2022), with some alterations. After lipid extraction through the Bligh and Dyer method (1959), 1 g of the extracted lipid and 30 mL of a 3:2 acetic acid: to chloroform solution were added in a 250 mL Erlenmeyer flask, and the lipids were dissolved by gentle agitation. Then, 30 mL of distilled water and 0.5 mL of saturated potassium iodide solution (1% w/v) were incorporated into the mixture and maintained in darkness for 1 minute. The liberated iodine was titrated using 0.01 N sodium thiosulfate. The PV value was computed using the

Table 1. Different coatings used for nile tilapia fillets

Groups	Coating
Control	-
Ah	Alyssum homolocarpufm coating alone
Ah + Eo 1	Alyssum homolocarpufm coating containing 1% Essential oil
Ah + Eo 1.5	Alyssum homolocarpufm coating containing 1.5% Essential oil
Ah + Eo 2	Alyssum homolocarpufm coating containing 2% Essential oil

Equation 3, and the results were presented as milliequivalents of peroxide oxygen per kilogram of lipid.

$$3.\ PV = \frac{V \times N}{W} \times 1000$$

Where, W: the sample weight (g), V: volume of sodium thiosulfate (mL), and N: the normality of the sodium thiosulfate.

Thiobarbituric acid reactive substances assay

Thiobarbituric acid-reactive substances (TBARS), generated as secondary products of lipid peroxidation, were quantified in accordance with Hashemi et al. (2022). Initially, 5 g of each fillet sample was homogenized with 15 mL of deionized water. Thereafter, the homogenate (2 mL) was combined with 2 mL of a 0.67% thiobarbituric acid (TBA) solution formulated in distilled water. The mixture was placed in a glass test tube, sealed, and heated in a water bath at 90 °C for 1 hour to promote the reaction between malondialdehyde (MDA) and TBA. Subsequent to cooling to ambient temperature, the tubes underwent centrifugation at 2000×g for 15 minutes, and the absorbance values of both the blank (AB) and the samples (AS) were quantified at 532 nm utilizing a UV-Vis pectrophotometer (Cecil, Cambridge, England). A calibration curve was established with 1,1,3,3-tetramethoxypropane (TMP) as the MDA standard. A series of standard solutions with established concentrations of MDA equivalents (range: 0.5 to 10 µM) were treated identically to the samples. The TBARS value was quantified as mg of MDA per kilogram of fish fillet, derived from the calibration curve. All measurements were conducted in triplicate to guarantee repeatability. Control samples without fish tissue were included in each batch to account for any reagent-specific absorbance.

Microbial analyses

Microbial evaluation was conducted by blending 25 g of each fish sample with 225 mL of 0.1% peptone water for 3 minutes using a laboratory blender (Model: Waring CB15, Torrington, Connecticut, USA). Subsequent serial dilutions were prepared and aliquots were inoculated onto plate count agar (PCA) for total viable count (TVC) and total psychrotrophic count (TPC), employing the pour-plate technique. Plates were incubated at 37 °C for a for TVC and 4 °C for TPC. The data were presented as log10 colony-forming units per gram (log CFU/g) of the fish meat samples.

Sensory evaluation method

Sensory evaluation of the fried fish fillet samples was conducted using a nine-point hedonic scale according to the method described by Vital et al. (2018), with minor modifications. The panel comprised 30 consumers, including 15 men and 15 women. Participants evaluated the samples for color, appearance, odor, taste, and overall acceptability on a scale ranging from 1 (dislike extremely) to 9 (like extremely).

Statistical analysis

Data analysis was conducted using a two-way analysis of variance to ensure normality and homogeneity. Duncan's test was applied at a 5% significance level to compare average values. The analysis and graph generation were performed using SPSS 20.0, Sigma Plot 14, and GraphPad Prism 9.

Results

Free radical scavenging test by DPPH method

The free radical scavenging ability test evaluated the antioxidant properties of TEO. The statistical measurements obtained during optical density (OD) assessment indicated that the DPPH concentration was 0.9288 µg/mL, and the IC_{50} was 493.187 µg/mL.

pH

The pH changes in the treated and control samples of fish fillets are shown in Figure 1A. At the conclusion of the test, the control group exhibited the highest pH value, while the Qodume Shirazi coating containing 2% TEO had the lowest value. The control's pH level was greater than that of the treatments, with higher concentrations of essential oil corresponding to lower pH levels. However, the differences between the various treatments were not significant (P>0.05).

Total volatile nitrogen

The total volatile nitrogen (TVN) levels of the various samples during the storage period in the refrigerator are illustrated in Figure 1B. The ANOVA and Tukey's supplementary tests indicated a significant difference between the control and the treatment groups (P<0.05). Additionally, there was no significant difference between the groups containing 1.5% and 2% essential oil (P>0.05). The control group showed a steady increase in TVN levels throughout the storage period, reaching the highest values among all groups. The Ah treatment displayed a similar increase in TVN levels, but at a slower rate compared to the control. Treatments with Ah plus essential oil (Ah+Eo1, Ah+Eo1.5, and Ah+Eo2) exhibited a consistent trend of gradual increases in TVN levels over time, with these groups maintaining lower TVN levels than the control and Ah groups. The addition of essential oil in these treatments appears to reduce TVN levels compared to the control and Ah groups, suggesting a potential inhibitory effect of the essential oil on nitrogen volatility. Higher concentrations of essential

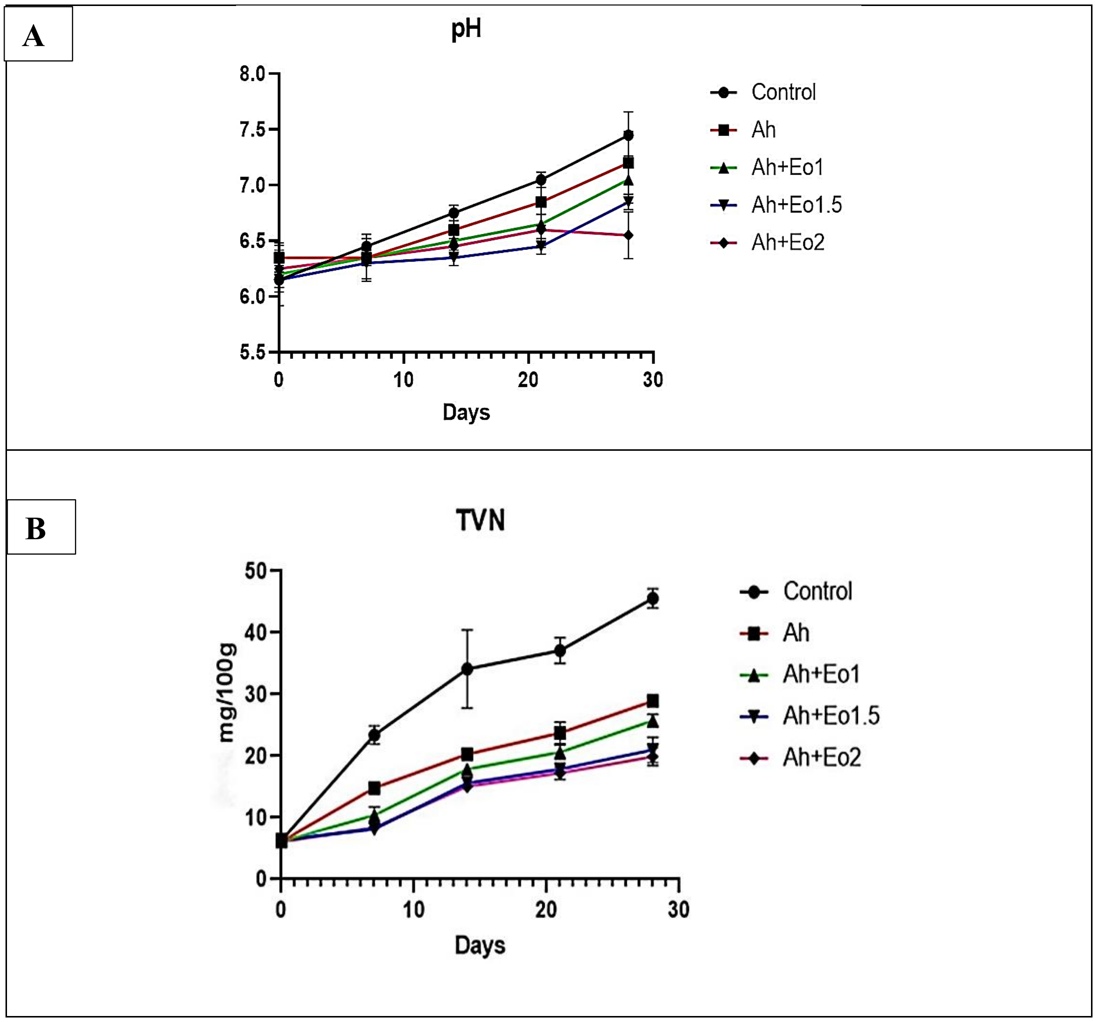

Figure 1. Changes in (A) pH and (B) total volatile basic nitrogen (TVB-N) (mg/100 g) of Nile Tilapia fillets coated with different coatings during cold storage at 4 ˚C

Note: The error bars represent Mean±SD of triplicates.

oil correspond to slightly lower TVN levels, indicating a dose-dependent effect. Overall, treatments combining Ah with TEO effectively control TVN levels over time, suggesting better preservation and reduced spoilage.

Peroxide values

Changes in the peroxide index of the fish fillet samples during the storage period in the refrigerator are depicted in Figure 2A. The control group demonstrated no significant difference (P>0.05) compared to the group coated with Qodume Shirazi. The levels of peroxidation in the essential oil groups were significantly lower than those in the control group (P<0.05). Furthermore, treatment groups with higher concentrations of essential oil exhibited increased resistance to oxidation, showing a notable reduction in peroxide values compared to the control and Ah groups. Specifically, the peroxide level in the group containing 1.5% essential oil was significantly lower than that of the 1% group (P<0.05), although there was no significant difference between the groups with 1.5% and 2% essential oil.

Thiobarbituric acid-reactive substances

Results related to the thiobarbituric acid-reactive substances (TBARS) index, which serves as an indicator of lipid oxidation, are shown in Figure 2B. The highest level of MDA was detected in the control group. ANOVA and Tukey's supplementary test revealed that the MDA levels in the control group were significantly higher than those in all treatment groups. Increasing the concen-

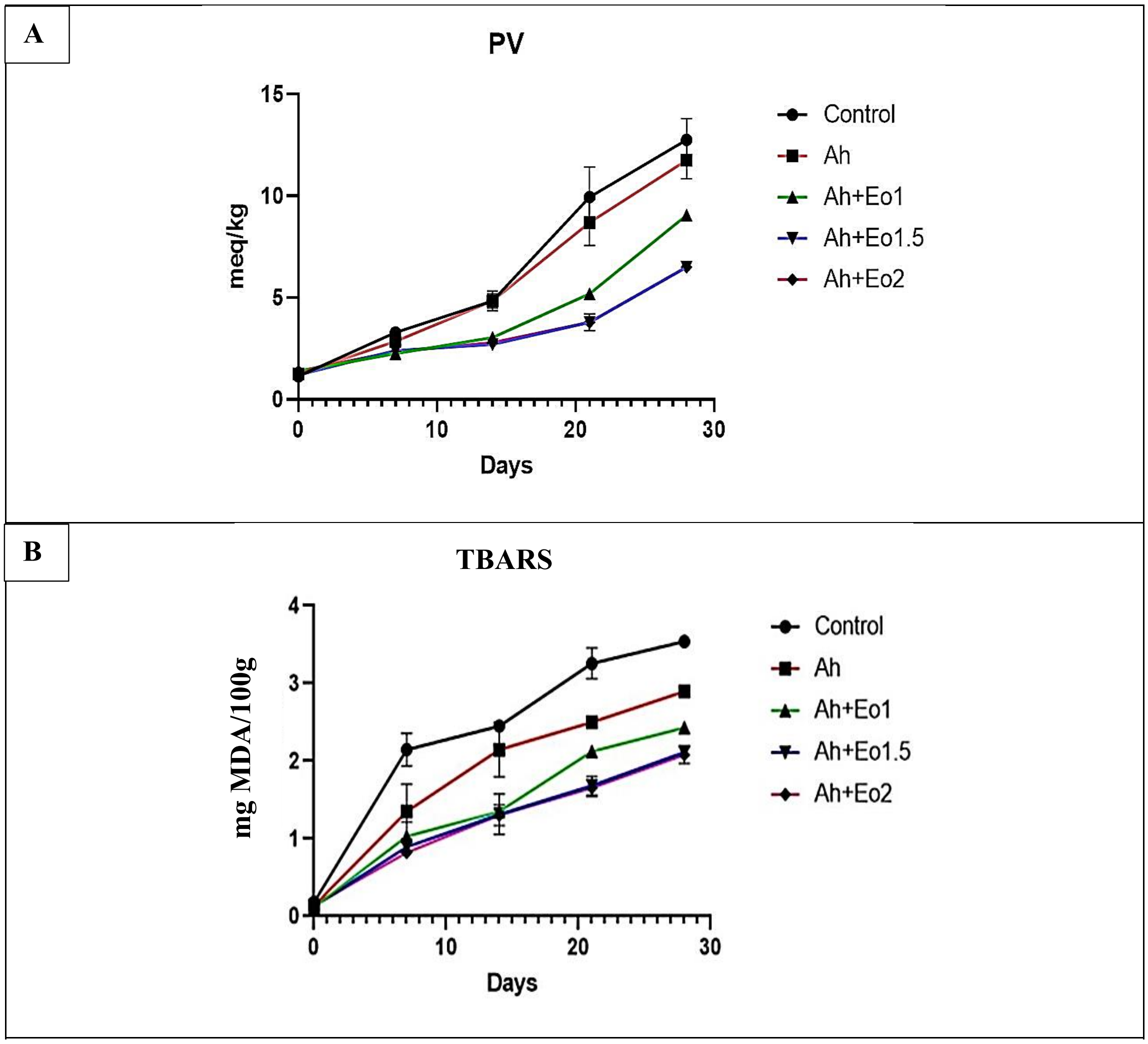

Figure 2. Changes in (A) PV and (B) TBARS (mg MDA/100g) of Nile tilapia fillets coated with different coatings during cold storage at 4 ˚C

Note: The error bars represent Means±SD of triplicates.

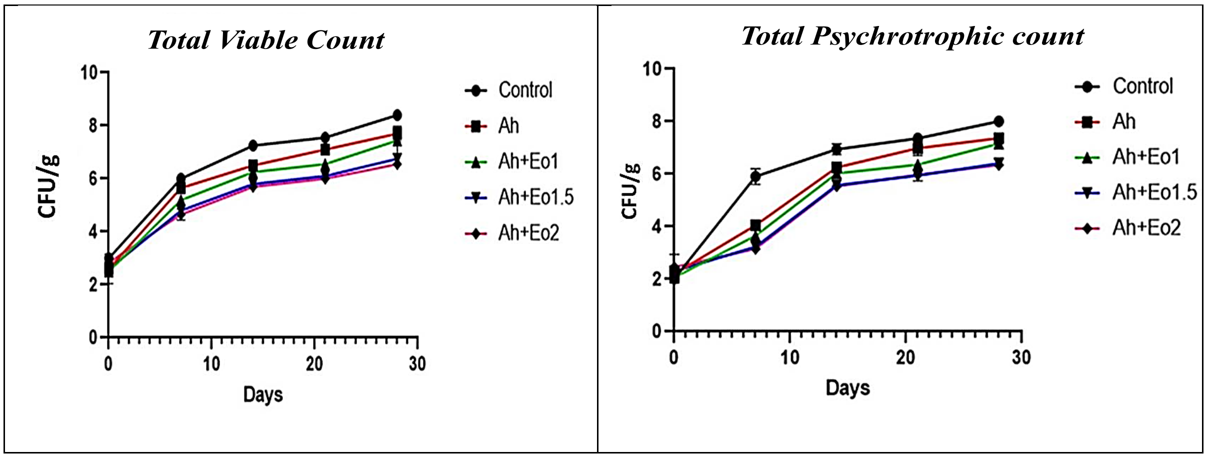

Figure 3. A) TVC and B) TPC in Nile tilapia fillets coated with different coatings during cold storage at 4˚C

Note: The error bars represent Mean±SD of triplicates.

tration of essential oil led to a decrease in MDA levels among the treatment groups (P<0.05). Nonetheless, no significant difference was observed between the groups treated with 1.5% and 2% essential oil (P>0.05).

Total viable counts (TVC)

The incorporation of TEO resulted in a gradual reduction of TVC compared to the control, with higher concentrations of the essential oil demonstrating slightly better control over bacterial growth. Changes in the TVC throughout the test period are shown in Figure 3A. The total bacteria count in the control was significantly higher than that in all treatments. As the concentration of essential oil in the coatings increased, the total bacterial count in the treatment groups significantly decreased (P<0.05). However, no significant difference was observed between the treatments containing 1.5% and 2% essential oil (P>0.05). This indicates a promising antibacterial effect of the essential oil on fish fillets.

Total psychrotrophic count

The results related to total psychrotrophic count (TPC) are presented in Figure 3B. ANOVA indicated that the area under the control curve was significantly greater than that of all treatment groups. Furthermore, as the concentration of essential oil increased, the number of psychrotrophic bacteria in the treatment groups significantly decreased (P<0.05). However, no significant difference was observed between the groups treated with Qodume Shirazi and those treated with 1.5% and 2% TEO (P>0.05).

Sensory evaluation by hedonic method

In all sensory parameters up to day 14, treatments with coating and essential oil showed significantly better results than the control. Among the essential oil treatments, increasing the essential oil concentration to 1.5% improved sensory properties, and further increases led to negative results in these parameters. In addition, the results on day 21 indicated that none of the treatments or controls were approved by the panelists.

Discussion

The results indicate that incorporating TEO into A. *homolocarpum* seed gum (AHSG) coatings effectively slowed the deterioration of tilapia fillets during refrigerated storage. The coated fillets exhibited a smaller increase in pH than the untreated control, suggesting that the coatings delayed the biochemical and microbial changes associated with spoilage. The increase in fish pH during storage is generally attributed to the accumulation of alkaline compounds generated by microbial metabolism and the degradation of nitrogenous substrates. Therefore, the lower pH values recorded in the coated samples indicate that TEO-containing coatings retarded these processes. Similar preservative effects have recently been reported for active edible coatings applied to refrigerated fish Kurek et al. (2024; Venkatachalam et al., 2025).

The lower total volatile basic nitrogen (TVB-N) values recorded in fillets treated with 1.5% and 2% TEO provide further evidence of delayed spoilage. TVB-N represents the accumulation of volatile nitrogenous compounds produced primarily through the microbial and enzymatic degradation of proteins and other nitrogen-containing

Table 2. Results of sensory evaluation

Variables	Group	Day			
		0	7	14	21
Color	Control	8.66^{a}	5.831^{c}	3.401^{c}	2.703^{b}
	Ah	8.261^{a}	6.107^{c}	4.162^{b}	2.162^{b}
	Ah + Eo1	8.304^{a}	6.503^{b}	3.663^{c}	2.861^{a}
	Ah + Eo1.5	8.132^{a}	7.135^{a}	4.901^{a}	2.164^{b}
	Ah + Eo2	8.023^{a}	6.841^{ab}	4.296^{b}	2.098^{b}
Appearance	Control	8.801^{a}	6.010^{d}	4.105^{c}	1.732^{c}
	Ah	8.764^{a}	7.502^{b}	4.132^{c}	1.864^{c}
	Ah + Eo1	8.965^{a}	7.304^{c}	4.701^{b}	2.502^{ab}
	Ah + Eo1.5	8.36^{a}	7.961^{a}	5.1^{a}	2.701^{a}
	Ah + Eo2	8.123^{a}	7.486^{bc}	4.960^{ab}	2.453^{b}
Taste	Control	8.532^{a}	6.200^{c}	3.762^{d}	1^{c}
	Ah	8.733^{a}	6.901^{b}	4.301^{c}	2.062^{b}
	Ah + Eo1	8.831^{a}	6.862^{b}	4.935^{a}	2.403^{b}
	Ah + Eo1.5	8.13^{a}	7.931^{a}	5.001^{a}	2.73^{a}
	Ah + Eo2	8.231^{a}	6.786^{b}	4.86^{b}	2.189^{b}
Consistency	Control	7.9^{a}	6.131^{c}	3.561^{d}	1.301^{c}
	Ah	7.301^{a}	6.232^{c}	4.03^{c}	2.703^{b}
	Ah + Eo1	7.632^{a}	7.111^{b}	5.531^{ab}	3.766^{a}
	Ah + Eo1.5	7.401^{a}	7.567^{a}	5.9^{a}	3.365^{a}
	Ah + Eo2	7.539	6.865^{b}	5.108^{b}	3.021^{ab}
Smell	Control	6.6^{b}	5.5^{d}	2.836^{d}	1.162^{b}
	Ah	8.4^{a}	6.231^{bc}	4.564^{c}	1.33^{a}
	Ah + Eo1	8.333^{a}	6.131^{bc}	4.662^{c}	1.301^{a}
	Ah + Eo1.5	8.831^{a}	6.831^{a}	5.1^{a}	1.432^{a}
	Ah + Eo2	8.762^{a}	6.437^{b}	4.87^{b}	1.23^{ab}

Note: Sensory evaluation of Nile tilapia fillets with different coatings during refrigerated storage at 4˚C. Within each sensory attribute and storage day, values with different superscript lowercase letters (a, b, c, and d) differ significantly ($P<0.05$), whereas values sharing at least one superscript letter do not differ significantly ($P>0.05$).

substances. Throughout storage, the treated fillets maintained lower TVB-N values than the control, indicating that the coatings inhibited the formation of these spoilage products. This finding is consistent with the systematic review by Ubaidillah et al. (2026), which reported that edible coatings containing essential oils can reduce TVB-N formation and extend the refrigerated shelf life of fish. Similarly, Faisal et al. (2025) found that a turmeric-based edible coating delayed microbial growth and TVB-N formation in mackerel. Although turmeric extract and TEO differ in chemical composition, these findings support the potential application of turmeric-derived bioactive compounds in fish preservation.

The coatings also exerted a marked inhibitory effect on lipid oxidation. Both peroxide values (PV) and thiobarbituric acid-reactive substances (TBARS) levels remained lower in the TEO-treated fillets than in the control, indicating that the treatment delayed both the primary and secondary stages of lipid oxidation. This effect is particularly important in fish products because their high polyunsaturated fatty acid content makes them highly susceptible to oxidative deterioration during storage. The observed reduction in lipid oxidation may be attributed to the combined effects of the AHSG matrix and the antioxidant properties of TEO. The coating may serve as a physical barrier to oxygen transfer, while the volatile constituents of TEO may inhibit oxidative reactions. The dual barrier and antioxidant functions of essential-oil-containing edible coatings have also been emphasized by Antonino et al. (2024) and Venkatachalam et al. (2025).

When interpreting the antioxidant activity of TEO, its chemical composition must be carefully considered. Turmeric essential oil differs from turmeric extract and oleoresin and consists primarily of volatile terpenoid compounds, particularly turmerone-type sesquiterpenes. In contrast, curcumin is a nonvolatile curcuminoid and should not be identified as a major constituent of TEO unless its presence has been analytically confirmed. Therefore, the antioxidant activity observed in the present study is more appropriately attributed to the volatile constituents of TEO than directly to curcumin. This distinction is important because the composition and biological activity of TEO may vary according to cultivar, geographical origin, extraction method, and processing conditions.

The microbiological findings further support the effectiveness of the coatings. Treatments containing 1.5% and 2% TEO significantly reduced total viable counts (TVC) and total psychrotrophic counts (TPC) compared with the untreated control. The microbial population in the control reached approximately 7 log CFU/g earlier than that in the coated samples, indicating more rapid microbial proliferation in the absence of an active coating. These results are consistent with the findings summarized by Ubaidillah et al. (2026), who reported substantial reductions in microbial growth in fish treated with essential-oil-based edible coatings. Similarly, Kurek et al. (2024) identified microbial inhibition as one of the principal mechanisms through which edible coatings extend the refrigerated shelf life of fish. The antimicrobial activity of TEO is likely associated with interactions between its volatile constituents and bacterial cell membranes. Essential-oil compounds can disrupt membrane permeability and cellular integrity, ultimately inhibiting microbial growth. This mechanism is particularly relevant to refrigerated fish because psychrotrophic bacteria, including Pseudomonas spp., can proliferate at low temperatures and contribute substantially to spoilage. Stabnikova et al. (2026) also highlighted the antimicrobial and antioxidant properties of spices and essential oils and their potential applications in food preservation.

Conclusion

The present study demonstrated that AHSG coatings incorporating TEO effectively delayed the quality deterioration of refrigerated tilapia fillets. TEO-containing coatings inhibited microbial growth and lipid oxidation, reduced the formation of spoilage indicators, and maintained sensory acceptability for longer than the untreated control. Among the tested formulations, the coating containing 1.5% TEO provided the optimal balance between preservation efficacy and sensory acceptability. Therefore, AHSG–TEO edible coatings, particularly the 1.5% formulation, represent a promising natural and biodegradable strategy for extending the refrigerated shelf life of tilapia fillets. Further research should investigate TEO release kinetics, coating stability and safety, and formulation performance under industrial processing and storage conditions.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Supervision and project administration: Sara Mehdizadeh Mood: Data curation and formal analysis: Azadeh Salimi; Investigation and writing the original draft: Ghazaleh Rahimi; Conceptualization, validation review and editing: Sara Mehdizadeh Mood and Ashkan Jebeli Javan.

Conflict of interest

The authors declared no conflict of interest.

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