



## Impact of *Aloe vera* gel and patchouli essential oil-based edible coatings on the shelf life and quality of trout fillets

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### ABSTRACT

In this study, the effectiveness of edible coatings containing *Aloe vera* gel (AVG) and patchouli oil (PY) on the quality preservation of trout (*Oncorhynchus mykiss*) fillets during cold storage ( $4\pm 1^\circ\text{C}$ , 12 days) was investigated. Experimental groups were composed of uncoated control (K0), AVG-coated (K1), AVG+PY-coated (1%; K2) and AVG+PY-coated (2%; K3) samples. Microbiological (total mesophilic bacteria, total psychrotrophic bacteria, yeast and mould), chemical (pH, TVB-N, TBARS), and sensory analyses were performed to evaluate quality changes during storage. The results demonstrated that AVG+PY coatings significantly reduced lipid oxidation, as evidenced by lower TBARS values compared to the control group. TVB-N levels also remained lower in coated samples, indicating delayed spoilage. Overall, the synergistic combination of AVG and PY proved effective in slowing microbial growth and oxidative deterioration, thereby enhancing the storage stability of trout fillets. Stability was maintained up to 12 days under refrigerated storage, ensuring acceptable quality throughout the period. These findings highlight the potential of AVG+PY coatings as a natural, eco-friendly, and functional alternative to synthetic preservatives in aquatic product preservation.

**Keywords:** *Aloe vera* gel, Patchouli oil, Trout fillet, Edible coating, Shelf life

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## Introduction

Fish and fish products constitute an essential component of the human diet owing to their richness in high-quality proteins, omega-3 fatty acids, vitamins, and minerals. Nevertheless, their high water activity, neutral pH, and nutrient-dense composition render them highly vulnerable to microbial proliferation and oxidative spoilage. This susceptibility significantly restricts the shelf life of fish fillets and often results in quality deterioration before reaching consumers. Consequently, there has been a growing interest in natural and safe preservation approaches to extend the shelf life of fish products (Mei et al., 2019; Aberoumand et al., 2024; Liu et al., 2024; Mozzon et al., 2024; Noreen et al., 2025), with edible coatings emerging as a promising strategy to enhance the storage stability of seafood by forming a protective barrier against microbial contamination and oxidative reactions (Usman et al., 2025).

*Aloe vera*, a member of the Liliaceae family and the most commercially important species of the *Aloe* genus, has attracted considerable attention in this context. Its fleshy leaves contain a viscous mucilaginous gel rich in approximately 75 nutrients and more than 200 bioactive compounds, including carbohydrates, amino acids, saponins, enzymes, vitamins, minerals, lignin, and salicylic acid (Basmatker et al., 2011; Thy et al., 2023; Sharma & Kaur, 2025). This diverse biochemical composition endows *Aloe vera* gel (AVG) with notable antioxidant, antimicrobial, and humectant properties, which have been widely exploited in medical, cosmetic, and food applications. In food preservation, *Aloe vera* gel (AVG) has been extensively investigated as an edible coating material in various products, including fruits, vegetables, poultry, and seafood, due to its ability to reduce water loss, maintain textural integrity, delay oxidative reactions, and inhibit microbial growth (Ali et al., 2021; Sarker & Grift, 2021; Al-Hijazeen & Ibrahim, 2024; Waris & Pilavtepe-Celik, 2025). Despite these multifunctional properties, most studies have focused on AVG alone, while research combining AVG with essential oils remains limited. Compared to other essential oils such as thyme, clove, and peppermint, which have been extensively studied in seafood preservation, patchouli oil remains relatively underexplored in this context. In particular, investigations involving patchouli oil in seafood preservation are lacking, highlighting a gap in the literature and the need to explore potential synergistic effects. Patchouli oil, derived from the leaves of *Pogostemon cablin*, is a natural essential oil traditionally used in medicine, cosmetics, aromatherapy, and food applications. Its chemical profile is dominated by sesquiterpenes such as patchoulol, which confer strong antimicrobial, antifungal, and antioxidant activities. These bioactive properties make patchouli oil a promising candidate for

food preservation, as it can suppress microbial growth and mitigate oxidative deterioration in perishable products (Beşirik & Göger, 2023; Mrisho et al., 2025). Unlike other essential oils widely applied in seafood preservation, patchouli oil offers a distinctive sesquiterpene-rich composition and has been scarcely investigated in food systems. Therefore, the present study introduces patchouli oil as a novel candidate in combination with *Aloe vera* gel, aiming to provide new scientific insights into their synergistic antimicrobial and antioxidant effects, while also offering a practical, environmentally friendly preservation strategy for seafood products.

Accordingly, the present study aims to evaluate the effectiveness of *Aloe vera* gel combined with patchouli oil as an edible coating for rainbow trout fillets. The research focuses on the coating's ability to inhibit microbial growth, reduce oxidative spoilage, and preserve sensory attributes during refrigerated storage. Rainbow trout fillets typically exhibit a short shelf life under cold storage due to their high water activity and susceptibility to microbial and oxidative deterioration. Therefore, extending the shelf life of this perishable product is of great importance for ensuring food safety, reducing economic losses, and meeting consumer demand for fresh and high-quality seafood. By addressing this gap, the study seeks to contribute to the development of natural and environmentally friendly preservation strategies for seafood.

## Materials and Methods

### Material

Sixty rainbow trout (*Oncorhynchus mykiss*) fillets, averaging  $250 \pm 10$  g in weight and  $27.0 \pm 1.2$  cm in length, were purchased skin-on from the Faculty of Fisheries at Atatürk University (Erzurum, Türkiye) and transported to the laboratory under cold-chain conditions. *Aloe vera* leaves were obtained from three-year-old plants harvested at maturity from a local herbal supplier in Erzurum, Türkiye. On average, 2.5–3.0 kg of leaves were used, each measuring approximately 50 cm in length and 7 cm in width, and the gel was extracted manually. Although *Aloe vera* gel is known to contain polysaccharides, amino acids, vitamins, minerals, and phenolic compounds that confer antioxidant, antimicrobial, and humectant properties (Nicolau-Lapeña et al., 2021), detailed compositional analyses were not performed in this study. Patchouli oil ( $\geq 98\%$  purity; Aksuvital, Türkiye), rich in sesquiterpenes such as patchoulol, was obtained from a commercial supplier. It is recognised for its antimicrobial and antioxidant activities (Isnain et al., 2025; Taupik et al., 2025), but its physical, chemical, and functional properties were not analysed within the scope of this work.

## Method

### Preparation of Aloe Vera Gel and Coating Solutions

*Aloe vera* gel was extracted following the procedure described by Chin et al. (2017) with slight modifications. Fresh leaves from three-year-old plants were washed, peeled, and the inner gel was collected. The gel was homogenised using a blender, filtered through muslin cloth to remove fibrous material, and stored at 4 °C until use. For coating preparation, *Aloe vera* gel was used at a concentration of 25% (w/v). Glycerol was added at 0.7% (w/v) as a plasticiser, corresponding to a ratio of 25:0.7 (AVG: glycerol). The mixture was stirred for 30 minutes to obtain a homogeneous base solution.

To prepare the coating formulations, patchouli oil (PY) was incorporated into the *Aloe vera* gel base at two concentrations (1% and 2%, v/v) to evaluate its antimicrobial and antioxidant effectiveness. Prior to mixing, the essential oil was emulsified with 0.25% (v/v) Tween 80 to ensure uniform dispersion. The emulsified oil was then blended with the AVG solution using a high-speed homogeniser at 12,000 rpm for 5 minutes to obtain a homogeneous mixture. The final coating formulations, therefore, contained 25% (w/v) *Aloe vera* gel, 0.7% (w/v) glycerol, 0.25% (v/v) Tween 80, and patchouli oil at either 1% or 2% (v/v).

Fillets were obtained from independent fish and randomly assigned to four experimental groups, each containing 15 fillets:

KO: Control (uncoated fillets)

K1: AVG coating

K2: AVG + 1% PY coating

K3: AVG + 2% PY coating

For coating, trout fillets were immersed in the respective solutions for 2 min to ensure uniform coverage, drained for 5 min to remove excess coating, and air-dried at room temperature for about 15 min on each side to allow film formation. The fillets were then placed in polyethylene containers, tightly sealed with lids to minimise exposure to air and microbial contamination, and stored at 4 ± 1 °C for a period of 12 days. Analyses were conducted on days 0, 3, 6, 9, and 12 of storage, with each measurement performed in triplicate (n = 3).

### Chemical Analyzes

For pH measurement, 5 g of trout fillet was homogenised with 50 mL of distilled water using an Ultra-Turrax, and values were recorded with a pH meter (Yavuzer, 2018). Lipid oxi-

dation was determined as thiobarbituric acid reactive substances (TBARS) following Malle & Poumeyrol (1989), and results were expressed as µmol MDA/kg. Total volatile basic nitrogen (TVB-N) was analysed according to Malle & Tao (1987) and expressed as mg/100 g.

### Microbiological Analysis

For microbiological evaluation, 10 g of trout fillet was aseptically transferred into sterile stomacher bags containing 90 ml of 0.1% buffered peptone water and homogenised for 2 minutes. Serial dilutions were prepared and spread on selective agar media using the spread plate method. Total mesophilic aerobic bacteria (TMAB) were enumerated after incubation at 37 °C for 2 days. Total psychrotrophic bacteria (TPB) were determined by incubation at 7 °C for 10 days. Yeast and mould (TYM) counts were obtained after incubation at 25 °C for 5 days (Halkman, 2005).

### Sensory Analysis

A panel of five trained assessors carried out sensory evaluation of trout fillets. Samples were judged using a five-point hedonic scale, where 1 corresponded to “extremely undesirable” and 5 to “extremely desirable,” with texture, colour, odour, and overall acceptability taken into account (adapted from Çoban et al., 2018). In this study, no strict cut-off value was established for sensory acceptability; instead, mean panel scores were used as the basis for interpretation, and values greater than 3 (“moderately desirable”) were considered indicative of acceptable quality during storage. All sensory procedures followed internationally recognised standards, ISO 8586 for panelist selection and training, and ISO 13299 for sensory analysis methodology, ensuring consistency and reproducibility of the evaluation.

### Statistical Analysis

All statistical procedures were performed using the SPSS software package (version 27.0, IBM Corp., Armonk, NY, USA). Differences among treatments (KO, K1, K2, K3) and storage periods (0, 3, 6, 9, 12 days), as well as their interaction, were tested for significance at  $\alpha = 0.05$  using two-way analysis of variance (ANOVA). When significant differences were detected, Duncan’s multiple range test was applied for post hoc comparisons. Results are expressed as mean ± standard deviation (SD).

## Results and Discussion

### Microbial Analysis Results

Edible coatings prepared with *Aloe vera* gel and patchouli oil at different concentrations, along with the microbial changes

observed during storage of coated trout fillets, are presented in Table 1. In the control group (KO), TMAB values increased markedly during storage. While the AVG coating (K1) slightly slowed microbial growth, the AVG+1% PY (K2) and, particularly, the AVG+2% PY (K3) coatings provided more effective microbial suppression. At the end of day 5, the TMAB value was 5.26 log cfu/g in the K3 group, compared to 7.11 log cfu/g in the control group. For seafood, the microbiological acceptability limit for total mesophilic aerobic bacteria (TMAB) was considered as 7 log cfu/g, in accordance with the criteria reported by Genç & Kayhan (2023). The control group reached this limit at day 12, whereas all coated groups remained below this threshold throughout the storage period. The findings indicate that the coating containing 2% patchouli oil (K3) significantly suppressed the growth of total mesophilic aerobic bacteria (TMAB) compared to the control group. These results highlight the potential of plant-derived antimicrobial compounds to extend the shelf life of fish products effectively. The film-forming capacity of *Aloe vera* gel reduces oxygen permeability on the food surface, thereby limiting microbial proliferation. In parallel, phenolic compounds and terpenoids present in patchouli oil compromise cell membrane integrity and inhibit bacterial metabolism. This synergistic interaction enhances the overall antimicrobial efficacy of the coatings. Our findings are consistent with previous reports where *Aloe vera*-based edible coatings containing essential oil nanoemulsions significantly reduced microbial counts and extended the shelf life of trout fillets (Jamali et al., 2023). Patchouli oil, rich in sesquiterpenes, has been reported to exhibit strong antimicrobial and antioxidant activities, similar to ginger oil, which has also been extensively documented for its preservative potential (Avci et al., 2020; Beşirik & Göger, 2023; Ayustaningwarno et al., 2024; Mrisho et al., 2025).

Total psychrotrophic bacteria counts increased progressively during cold storage in all groups, but the rate of growth was markedly different depending on the coating. The counts of psychrotrophic bacteria in trout fillets varied significantly depending on treatment type, storage period, and their combined interaction ( $p < 0.05$ ). In the control samples, TPAB reached 7.17 log cfu/g by day 12, indicating rapid spoilage under refrigeration. In contrast, the AVG+patchouli oil coatings significantly suppressed psychrotrophic growth. At the end of the 12th day of storage, the K1 group (AVG) maintained TPAB at 6.37 log cfu/g, while the K2 group (AVG + 1% PY) showed 5.73 log cfu/g, and the K3 group (AVG + 2% PY) exhibited the lowest value of 5.13 log cfu/g. These findings confirm that the incorporation of plant-derived antimicrobials into edible coatings can effectively delay the proliferation of cold-tolerant spoilage bacteria. Both the treatment and the storage duration had statistically significant effects on TPAB

counts ( $p < 0.05$ ). Similar results were reported by Hassanpour et al. (2024) in their study on *Oncorhynchus aguabonita* fillets coated with *Trachyspermum copticum* essential oil nanoemulsions, where psychrotrophic growth was significantly delayed during storage at 4°C. Likewise, Çoban & Ergür (2023) demonstrated that chia mucilage coatings enriched with gojiberry extract effectively extended the shelf life of trout fillets by exerting both antibacterial and antioxidative effects. The observed microbial suppression in these studies was attributed to the synergistic interaction between the biopolymer matrix and the bioactive compounds of the plant-derived additives. In both cases, the coating formulation and storage duration had statistically significant effects on TPAB counts ( $p < 0.05$ ), confirming the potential of natural antimicrobial agents in prolonging the shelf life of refrigerated fish products.

Yeast and mould counts increased progressively during storage. The values of yeast and mould varied markedly depending on treatment group, storage time, and the interaction of these variables ( $p < 0.05$ ). At day 12, the highest yeast and mould count was observed in the control group (3.37 log cfu/g), whereas the coated groups, particularly K2 and K3, maintained significantly lower values (around 2.08–2.18 log cfu/g). Statistical analysis confirmed that treatment, storage period, and the interaction between these factors had a significant effect on yeast and mould counts ( $p < 0.05$ ). *Aloe vera*-based coatings effectively suppressed yeast–mold growth compared to the control, with the K3 samples exhibiting the strongest inhibitory effect. These findings highlight the potential of *Aloe vera* as a natural preservative to extend the shelf life of refrigerated products. The results of this study also confirm the protective role of patchouli essential oil. In line with our findings, Kalkan et al. (2019) reported that chitosan films enriched with peppermint essential oil, when applied to bonito fillets, significantly reduced yeast–mold counts. Likewise, Faraj & Nouri (2024) demonstrated that mucilage coatings containing nanoencapsulated essential oils effectively delayed fungal proliferation in button mushrooms, thereby extending their shelf life.

### Chemical Analysis Results

The chemical variations observed during storage are illustrated in Figure 1 (a–c). A progressive increase in TVB-N values was observed in all samples during the storage period. The highest mean values were recorded in the control group, whereas lower TVB-N levels were detected in the coated groups. While the average TVB-N value at the end of storage in the control group reached 26.11 mg/100 g, the coated samples exhibited lower levels, with K3 maintaining 21.09 mg/100 g. Duncan's multiple comparison test revealed significant differences among the samples ( $p < 0.05$ ). This reduction clearly

indicates the effectiveness of the coating in slowing protein degradation and extending the shelf life of the product. Similarly, Waris & Pilavtepe-Celik (2025) reported that the application of *Aloe vera* gel coating markedly lowered TVB-N accumulation in cold-stored sea bass fillets, thereby prolonging their shelf life. In addition, Izadi et al. (2023) demonstrated that tomato seed mucilage coatings enriched with shallot essential oil effectively reduced chemical spoilage and preserved the quality of frozen rainbow trout fillets. These findings are consistent with the present study, further supporting the effectiveness of natural coatings in delaying chemical deterioration and extending the shelf life of fish products.

A marked increase in TBARS values was observed across all groups during storage. By the end of the storage period, the control group reached an average of 6.97 mg MDA/kg, whereas coated samples exhibited lower levels. This highlights the inhibitory effect of the coatings on oxidative deterioration. Statistical analysis revealed that both sample and storage duration had significant effects on TBARS values ( $p < 0.05$ ). In contrast, the sample  $\times$  storage interaction was not significant ( $p > 0.05$ ), suggesting that the protective role of the coatings is maintained regardless of storage time. In the study conducted by El-Chaghaby et al. (2024), it was reported that the edible coating prepared from *Aloe vera* gel combined with lemongrass extract significantly reduced lipid oxidation and limited TBARS accumulation in cold-stored Nile tilapia fillets. Similarly, Mohammadian et al. (2025) demonstrated that

innovative chitosan coatings enriched with *Cuminum cyminum* essential oil effectively suppressed oxidative spoilage and extended the shelf life of *Hypophthalmichthys molitrix* fillets. These findings are consistent with the present study.

By the end of the storage period, the highest average pH was recorded in the control group (7.23), whereas initial values were considerably lower. This highlights the progressive effect of storage duration on pH elevation. Statistical analysis revealed that both sample type and storage duration had significant effects on pH values ( $p < 0.05$ ). In contrast, the sample  $\times$  storage interaction was not significant ( $p > 0.05$ ), suggesting that the influence of storage time on pH increase is consistent across all samples. Similar trends have been reported in fish preservation studies. Fofandi & Tanna (2020) demonstrated that *Aloe vera* coating effectively slowed quality deterioration in Indo-Pacific King Mackerel chunks during chilled storage, as reflected in lower pH values compared to the control group. This indicates that coated samples maintained a more stable pH profile. In contrast, the control group exhibited a marked increase, underscoring the protective role of *Aloe vera* against biochemical changes during storage. Likewise, in the present study, coated samples consistently maintained lower pH values compared to the control group throughout storage, confirming the inhibitory effect of coatings on pH elevation.

**Table 1.** Microbial changes (log cfu/g) in trout fillets coated with *Aloe vera* gel and patchouli oil during cold storage

Analyses	Storage Time (days)	K0	K1	K2	K3	Mean (X±SD)
TMAB	0	3.15±0.21	2.95±0.14	2.62±0.21	2.45±0.19	2.79±0.33 <sup>a</sup>
	3	4.13±0.16	3.80±0.23	3.19±0.10	2.99±0.03	3.53±0.50 <sup>b</sup>
	6	5.34±0.11	4.35±0.45	3.99±0.12	3.82±0.10	4.37±0.65 <sup>c</sup>
	9	6.18±0.11	5.34±0.41	4.94±0.09	4.63±0.26	5.27±0.65 <sup>d</sup>
	12	7.11±0.18	6.35±0.26	5.68±0.26	5.13±0.16	6.07±0.81 <sup>e</sup>
	<b>Mean (X±SD)</b>	5.18±1.49 <sup>D</sup>	4.56±1.23 <sup>C</sup>	4.08±1.18 <sup>B</sup>	3.80±1.05 <sup>A</sup>	
TPAB	0	3.35±0.31	3.05±0.07	2.74±0.26	2.54±0.18	2.92±0.37 <sup>a</sup>
	3	4.17±0.23	4.05±0.09	3.10±0.11	3.08±0.10	3.60±0.55 <sup>b</sup>
	6	5.56±0.14	4.50±0.45	4.18±0.08	3.97±0.04	4.55±0.67 <sup>c</sup>
	9	6.15±0.09	5.20±0.28	4.99±0.07	4.54±0.32	5.22±0.65 <sup>d</sup>
	12	7.17±0.22	6.37±0.19	5.73±0.25	5.13±0.11	6.10±0.82 <sup>e</sup>
	<b>Mean (X±SD)</b>	5.28±1.45 <sup>D</sup>	4.64±1.19 <sup>C</sup>	4.15±1.19 <sup>B</sup>	3.85±1.00 <sup>A</sup>	
TYM	0	2.00±0.00	2.00±0.00	2.00±0.00	2.00±0.00	2.00±0.00 <sup>a</sup>
	3	2.00±0.00	2.00±0.00	2.00±0.00	2.00±0.00	2.00±0.00 <sup>a</sup>
	6	2.24±0.10	2.11±0.08	2.00±0.00	2.00±0.00	2.08±0.11 <sup>b</sup>
	9	2.98±0.05	2.60±0.22	2.02±0.02	2.00±0.00	2.40±0.44 <sup>c</sup>
	12	3.37±0.20	2.96±0.06	2.18±0.04	2.08±0.04	2.65±0.58 <sup>d</sup>
	<b>Mean (X±SD)</b>	2.52±0.59 <sup>C</sup>	2.33±0.41 <sup>B</sup>	2.04±0.07 <sup>A</sup>	2.01±0.03 <sup>A</sup>	

KO: control (uncoated fillets), K1: AVG-coated, K2: AVG+1% PY-coated, K3: AVG+2% PY-coated samples. Values are expressed as mean  $\pm$  standard deviation (SD). Significant differences among storage days are indicated by lowercase superscript letters (a–f), while differences among treatment groups within the same day are denoted by uppercase letters (A–D) ( $p < 0.05$ )

### Sensory Analysis Results

The sensory evaluation results are illustrated in Figure 2 (a-d). Sensory analysis results demonstrated that storage time had a significant effect on all parameters. Storage duration created statistically significant differences in texture, colour, odour, and overall acceptability values ( $p < 0.05$ ). Although the sample factor showed some initial differences, the sample  $\times$  storage interaction was not statistically significant ( $p > 0.05$ ). At day 0, all samples received high scores for texture (range 4.2–4.8). However, texture scores steadily decreased as storage progressed. By day 9, values had dropped to 1.4–2.0, and by day 12, they reached their lowest levels (1.0–1.4). Similarly, colour scores decreased significantly with storage time. Samples that were initially bright and acceptable (4.0–5.0) declined to their lowest values (1.0–1.4) on day 12. Odour was among the most sensitive attributes to storage. Initial odour scores (4.0–4.8) decreased to 1.2–2.0 on day 9 and further to 1.0–1.4 on day 12. The observed decline in odour is thought to be associated with the characteristic volatile components of patchouli oil. Patchouli oil contains compounds such as patchoulol,  $\alpha$ -bulnesene, and seychellene, which are known for their intense, woody, and earthy aromatic properties. Pannellists perceived this distinctive aroma as divergent from the product's natural profile, leading to reduced sensory acceptability. This finding suggests that while natural additives may initially enhance sensory quality, their dominant aromatic profiles can ultimately limit consumer preference. Overall acceptability values also showed a consistent decline across all samples with increasing storage time. Samples that initially scored high reached their lowest values, particularly on days 9 and 12. This indicates that the products were unable to maintain sensory quality throughout their shelf life, and consumer acceptance remained restricted by storage duration. Pannellists noted that acceptability levels, evaluated on a 5-point hedonic scale, were initially higher in the groups treated with additives, but this effect diminished progressively as storage time increased. In this study, mean scores above 3 (“moderately desirable”) were considered indicative of acceptable quality, and values declined below this threshold by days 9 and 12. From day 6 onwards, the K1 group consistently exhibited superior sensory properties compared to the other treatments. Although *Aloe vera*–patchouli coatings effectively delayed microbial and chemical deterioration, the strong aromatic profile of patchouli oil negatively influenced odour acceptability. This trade-off underscores the balance between preservation efficacy and sensory quality, as reduced odour scores directly affect consumer acceptance and practical applicability. Therefore, while the coatings enhanced shelf life, their sensory impact must be carefully considered in future applications, particularly in relation to consumer preferences and product marketability. Similar trade-offs have been reported

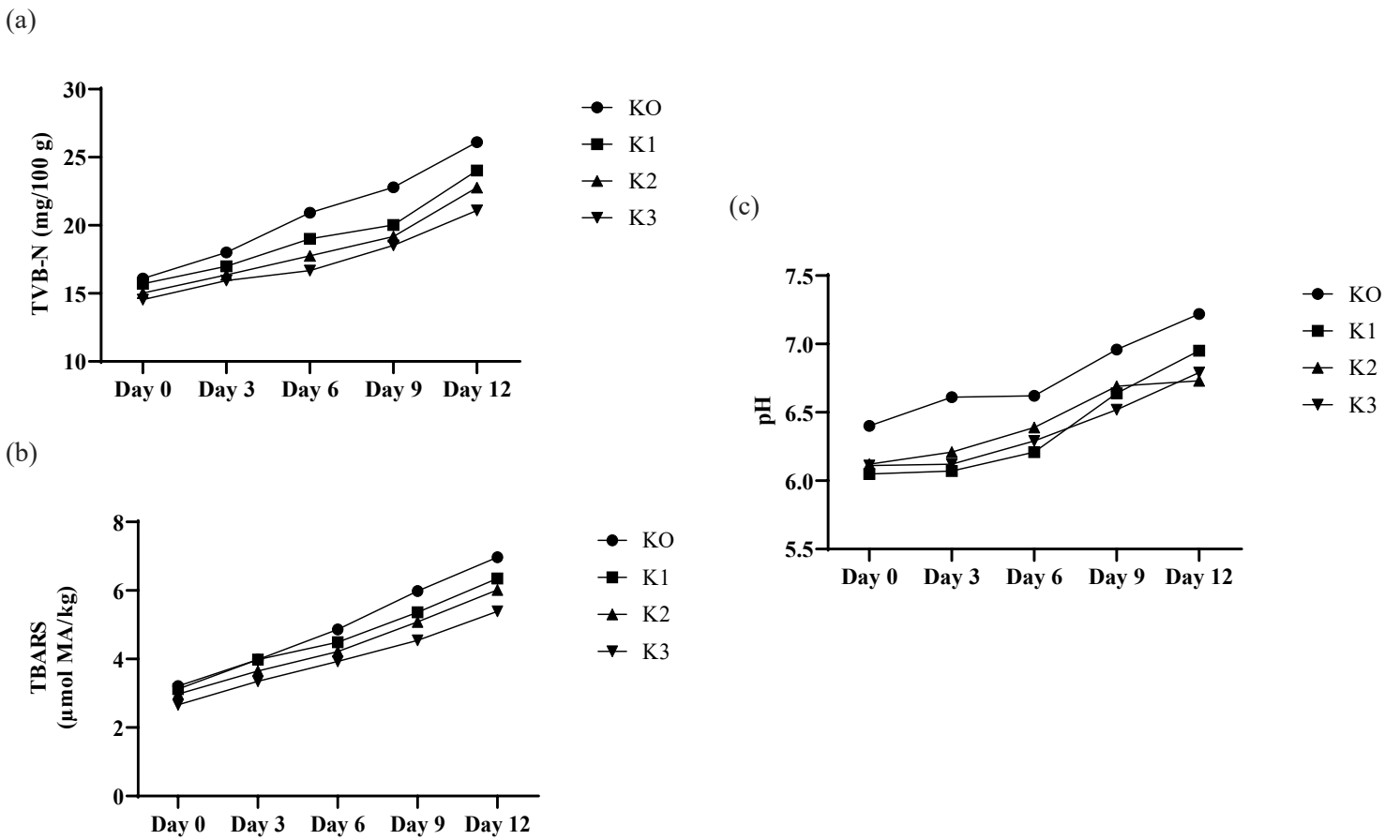
in previous studies. Vital et al. (2018) reported that alginate-based coatings containing essential oils applied to Nile tilapia fillets maintained higher sensory acceptability scores during storage compared to controls, confirming the protective role of natural coatings in delaying sensory deterioration. Similarly, Zomorodian et al. (2023) demonstrated that *Zataria multiflora* essential oil incorporated into chitosan coatings significantly improved sensory characteristics in salmon fillets, highlighting that essential oil-based coatings can effectively preserve sensory quality during cold storage. These studies are consistent with the present findings.

### Limitations and Opportunities

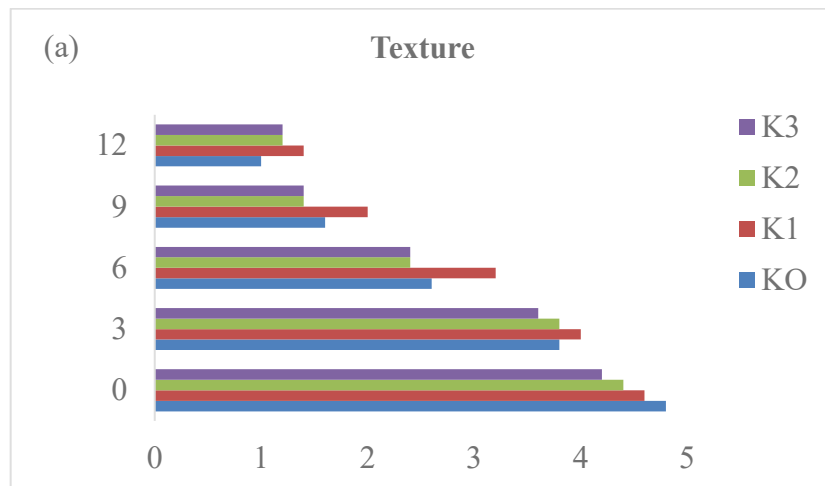
The present study has several limitations that should be acknowledged. First, although the novelty of combining *Aloe vera* gel with patchouli oil was emphasised, the absence of direct chemical characterisation of the patchouli essential oil (e.g., GC–MS analysis) limits the ability to link the observed preservative effects to specific bioactive compounds. It may affect reproducibility, given the known variability of essential oil composition. Similarly, the physicochemical properties of *Aloe vera* gel and patchouli oil were not experimentally analysed in this work; instead, their functional attributes were discussed based on literature reports. In addition, while statistical analyses were performed using ANOVA and Duncan's test, the study was restricted to the parameters measured. It did not include advanced modelling approaches that could further strengthen the interpretation of results. Finally, the findings are based on rainbow trout fillets under refrigerated storage, and broader validation across different seafood species and storage conditions would be valuable to generalise the applicability of this preservation strategy.

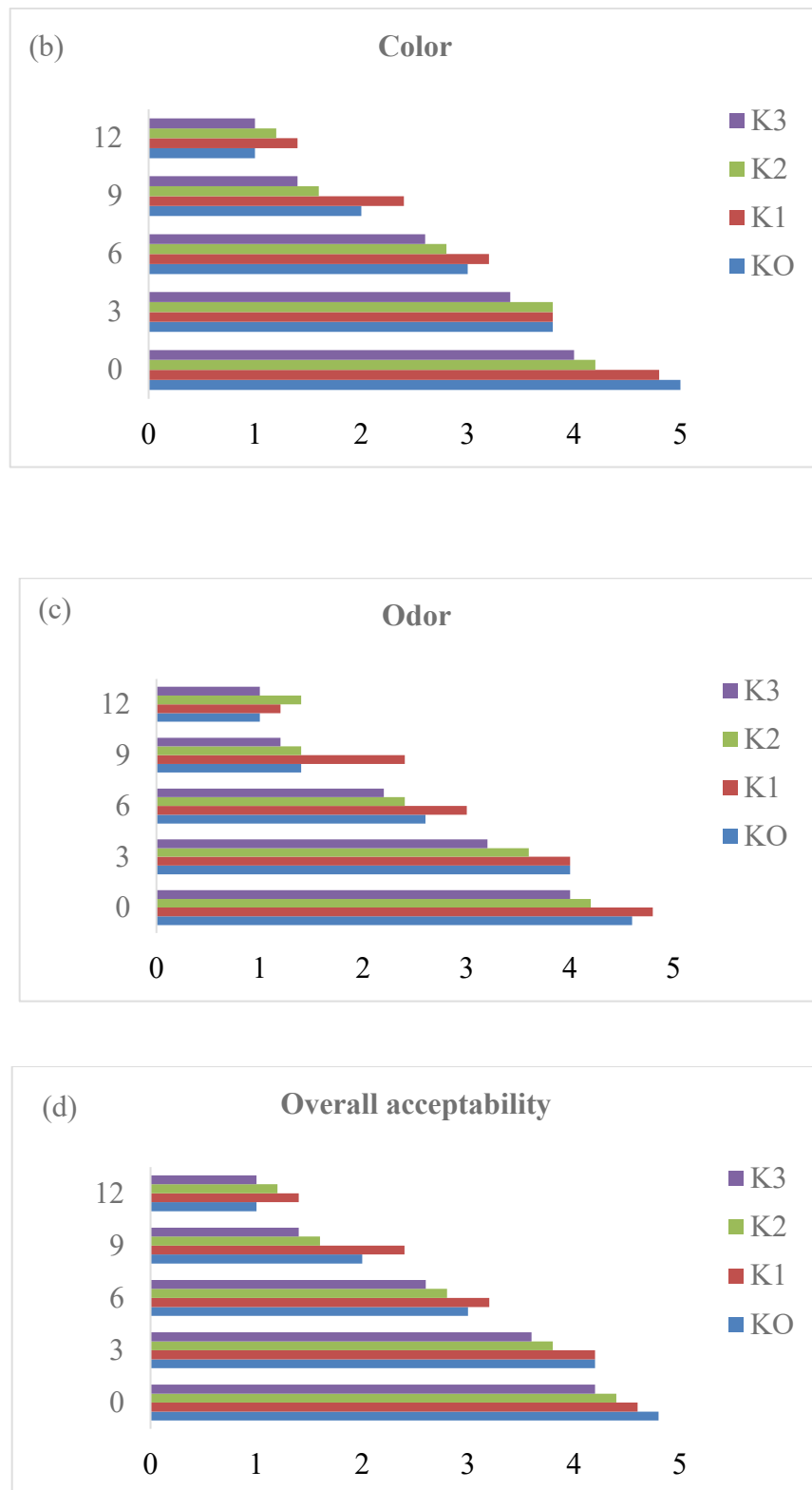
### Conclusion

*Aloe vera*–patchouli coatings effectively suppressed microbial growth, delayed chemical spoilage, and supported sensory quality in trout fillets during refrigerated storage. The coatings maintained acceptable quality for at least 12 days, providing a clear shelf-life extension compared to the control group. The AVG+2% patchouli oil formulation exhibited the strongest protective effect, maintaining lower microbial counts and chemical deterioration indicators compared to the control group. However, the distinctive volatile compounds of patchouli oil influenced odour perception, which limited consumer preference over extended storage. These findings highlight the potential of *Aloe vera*–based coatings enriched with essential oils as natural preservation strategies for aquaculture products. Future studies should focus on optimising additive concentrations, exploring microencapsulation or controlled release systems, and combining essential oils with other natural preservatives to balance functional efficacy with sustained sensory quality and consumer acceptance.



**Figure 1.** a) TVB-N, b) TBARS and c) pH changes in trout fillets coated with changes in trout fillets coated with *Aloe vera* gel and patchouli oil during cold storage. KO: control (uncoated fillets), K1: AVG-coated, K2: AVG+1% PY-coated, K3: AVG+2% PY-coated samples





**Figure 2.** a) Texture, b) Color, c) Odor and d) Overall acceptability changes in trout fillets coated with changes in trout fillets coated with *Aloe vera* gel and patchouli oil during cold storage. KO: control (uncoated fillets), K1: AVG-coated, K2: AVG+1% PY-coated, K3: AVG+2% PY-coated samples

### Compliance with Ethical Standards

**Conflict of interest:** The author(s) declare no actual, potential, or perceived conflict of interest for this article.

**Ethics committee approval:** This study was conducted in accordance with ethics committee procedures, with no animal experiments.

**Data availability:** The data will be made available upon request from the author.

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**Disclosure:** -

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