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Original Article

Extending Post-harvest Shelf-life of Fresh Strawberry Fruits Using Edible Coating of *Plantago major* Seed Mucilage with Grapefruit Essential Oil

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ABSTRACT

Background and Objectives: Strawberries are prone to spoilage post-harvest majorly due to the mold growth and decay, leading to a shortened shelf life. This study aimed to investigate storage of fresh strawberries using *Plantago major* seed mucilage incorporated with grapefruit essential oil as an edible coating.

Materials and Methods: The study investigated storage of an edible coating prepared from *Plantago major* seed mucilage containing grapefruit essential oil on the physical and chemical characteristics (pH, acidity, total soluble solids and firmness), microbial quality (fungal count) and sensory attributes (color, odor, texture and overall acceptability) of refrigerated strawberries. Strawberries were coated with *Plantago major* seed mucilage alone or *Plantago major* seed mucilage with three various concentrations (0.2, 0.6 and 1%) of grapefruit essential oil and then stored at 4 °C for 10 d.

Results: Microbial load increased significantly with prolonged storage time in all the treatments. While *Plantago major* seed mucilage coating alone modestly slowed microbial growth, combining *Plantago major* seed mucilage with 1% grapefruit essential oil substantially delayed microbial growth by 18%, compared to the control sample. By the end of the storage, fungal counts orderly included 4.80, 3.95, 3.83, 3.66 and 3.45 log CFU/ml for the control, *Plantago major* seed mucilage, *Plantago major* seed mucilage and 0.2% grapefruit essential oil, *Plantago major* seed mucilage and 0.6% grapefruit essential oil, and *Plantago major* seed mucilage and 1% grapefruit essential oil coated strawberries, respectively. Physicochemical and sensory characteristics (pH, acidity, total soluble solids, firmness, color, odor, texture and overall acceptability) of strawberries treated with the coating consistently outcarried out those of the untreated control. While *Plantago major* seed mucilage coating alone showed preservation benefits, combination of *Plantago major* seed mucilage with grapefruit essential oil was further effective.

Conclusions: This study suggests that a *Plantago major* seed mucilage coating incorporating 1% of grapefruit essential oil can serve as a bioactive packaging solution to extend shelf life as well as serving as an alternative to pesticides.

Keywords: Edible coatings, Improved quality, *Plantago major*, Shelf life, Strawberries

Highlights

- Physicochemical characteristics of strawberries treated with the coating consistently were superior to those of the untreated control.
- A combination of *Plantago major* seed mucilage and grapefruit essential oil coatings significantly decreased the fungal growth, compared to uncoated strawberries.
- Sensory characteristics (color, odor, texture and overall acceptability) of strawberries treated with the coating were consistently superior to those of the untreated control.

Introduction

Strawberries are prone to spoilage post-harvest majorly due to the mold growth and decay, leading to a shortened shelf life. This rapid deterioration poses a challenge for producers and consumers as fresh strawberries need consumption by the consumers quickly to prevent wastes. In response to this problem, scientists have investigated use

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of edible coatings as potential solutions to extend shelf life of strawberries (1–3). Edible coatings serve as thin protective layers prepared from edible substances that are used on the surfaces of fruits and vegetables. These coatings are designed to shield the products from moisture loss, microbial contamination and oxidation, thereby enhancing their freshness and quality and enabling extended storage times (1, 4–6). A promising research investigates use of *Plantago major* seed mucilage (PMSM) as an edible coating for strawberries. The PMSM, a natural polysaccharide, transforms into a gel-like substance when mixed with water. Its exceptional film-forming characteristics have demonstrated its suitability for use as an edible coating (7, 8).

Researchers have not only investigated PMSM but also investigated use of plant extracts and essential oils with antioxidant and antimicrobial characteristics (9–20). Grapefruit (*Citrus paradisi* L.) essential oil (GEO) has been investigated as an additive to strengthen antimicrobial effects of coatings. The GEO is renowned for its potentially antimicrobial actions against various bacteria and fungi (21–23). Use of PMSM and GEO presents a natural eco-friendly approach to extend post-harvest life of the fresh strawberries, potentially curbing food waste, improving fresh product availability and enhancing sustainability of the food supply chain. This study aimed to investigate storage fresh strawberries using PMSM incorporated with GEO as an edible coating. The study assessed efficacy of the coating in preserving quality and prolonging shelf life of the strawberries during storage. Additionally, storage effects of the coating on sensory attributes of the strawberries such as color, odor, texture and overall acceptability were assessed.

Materials and Methods

Edible coating preparation and strawberry coating

The PMSM extraction process from *P. major* seeds involved specific parameters, including water-to-seed ratio of 60:1, pH 6.8, temperature set at 75 °C and extraction duration of 1.5 h. The extracted PMSM was filtered, dried at 45 °C overnight, milled, sieved and stored in cool dry conditions (8). Then, 2 g of PMSM were mixed with 1 ml of Tween-80 in distilled water (DW) to make up a total volume of 100ml, followed by stirring and heating. The resulting PMSM solution was treated with GEO at concentrations of 0, 0.2, 0.6 and 1% v/v. Strawberry samples were dipped into the PMSM-GEO solutions for 1 min, air-dried at 25 °C for 10 min and refrigerated at 4 °C for 10 d. Analysis of the coated samples was carried out to assess their physical, microbial and sensory changes at intervals of 1, 4, 7 and 10 d (8).

Firmness

Firmness of the strawberries was assessed by assessing the peak penetration force (N) at the point of texture rupture using flat probe with a diameter of 5 mm. The penetration depth and cross-head speed were set at 5 mm using TA-XT2 texture analyzer (Stable Micro Systems, Godalming, UK). Strawberries were separated and firmness measurements were carried out from the central region of each half. Firmness values were based on the average of 25 strawberries (24).

pH and acidity

Following the firmness assessment, strawberries were diced into small pieces and ground using grinder (TYB-317, China). Then, 10 g of the ground strawberry mixture were suspended in 100 ml of DW, filtered and processed for analysis. Moreover, pH and titratable acidity of the samples were assessed using pH meter and then titrated to pH 8.1 using 0.1 M NaOH. Titratable acidity was quantified as grams of citric acid per 100 g of the strawberry weight (24).

Total solid content

The total soluble solids (TSS) content in the juice extracted from ground strawberries was assessed using digital refractometer (Bellingham and Stanley OPTi, UK) at 20 °C and expressed as percentage. Measurements were carried out in triplicate (24).

Fungi count

Enumeration of total yeasts and molds on the surface of the strawberries involved a procedure of serial dilutions followed by spread plating on sterile Dichloran Rose-Bengal Chloramphenicol (DRBC) plates (Merck, Germany), following the guidelines by the International Standard Organization (ISO 21527-1, 2008) with minor adjustments. Strawberries from each treatment group and the untreated control were agitated at 150 rpm for 30 min in 20 ml of 0.1% (w/v) sterile peptone water using 150-ml Erlenmeyer flasks. The resulting suspension serially diluted ranging from 1:10 to 1:10^6. Then, 0.1 ml of each dilution was plated. Plates were incubated at 25 °C for 5 d. Results were quantified as log colony forming units per milliliter (CFU/ml) based on the average count of triplicate sets (25).

Sensory evaluation

The sensory evaluation of the strawberries over their shelf life involved 40 evaluators aged 20–45 years. Sequence of the sample presentation was randomized for each evaluator and the strawberries, stored in refrigerators for 1, 4, 7 and 10 d, were visually assessed by the same evaluator using 9-point hedonic scale (where, 1 = strongly dislike, 5 = neither like nor dislike and 9 = like very much). The sensory attributes included color, odor, texture and overall acceptability (26).

Statistical analysis

Experiments were carried out thrice and data analysis was carried out using Minitab software v.16 and completely randomized design in a factorial arrangement. Then, means were categorized further using Tukey post-test ($p < 0.05$).

Results

Characterization of the coated strawberries

Variations in pH of the samples over the storage are illustrated in Figure 1. All samples demonstrated a significant increase in pH (3.56–3.82) as time progressed. Significantly, coated samples enriched with GEO showed lower pH values, compared to the control sample.

Throughout the storage, acidity levels in the samples decreased (Figure 2). However, the coated samples, particularly those with 1% GEO coating, showed higher acidities, compared to the control sample.

Total soluble solid (TSS) content of the samples significantly increased from 5.79 to 7.63% as the storage time extended for 1 to 10 d (Figure 3).

A critical physical parameter for assessing fruit quality during ripening, storage and distribution decreased in uncoated and coated fruits over the storage (Figure 4). Use of PMSM and 1% GEO coating was particularly effective in preserving firmness of the strawberries, compared to PMSM, and PMSM and 0.2% GEO coatings.

Storage effects of PMSM and PMSM and GEO coatings on fungal growth during storage at 4 °C are shown in Figure 5.

Storage of PMSM and GEO treatments on the fruit sensory attributes such as color, odor, texture and overall acceptability are present in Figures 6–9. Results demonstrated significant decreases in scores for color, odor, texture and overall acceptability from Days 1–10 in all treatments. However, untreated control fruits showed greater decreases in ratings, compared to PMSM, and PMSM and GEO treated strawberries. Significantly, strawberries treated with PMSM and 1% GEO coating demonstrated higher scores for color, odor, texture and overall acceptability, compared to the untreated control, indicating significant preservation of sensory quality traits.

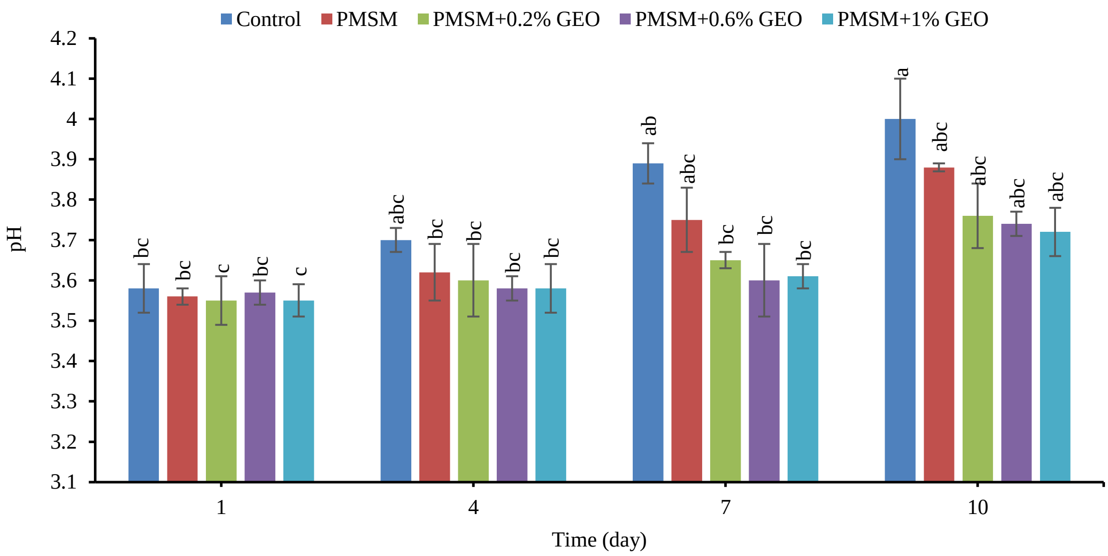

Figure 1. Changes in pH values of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

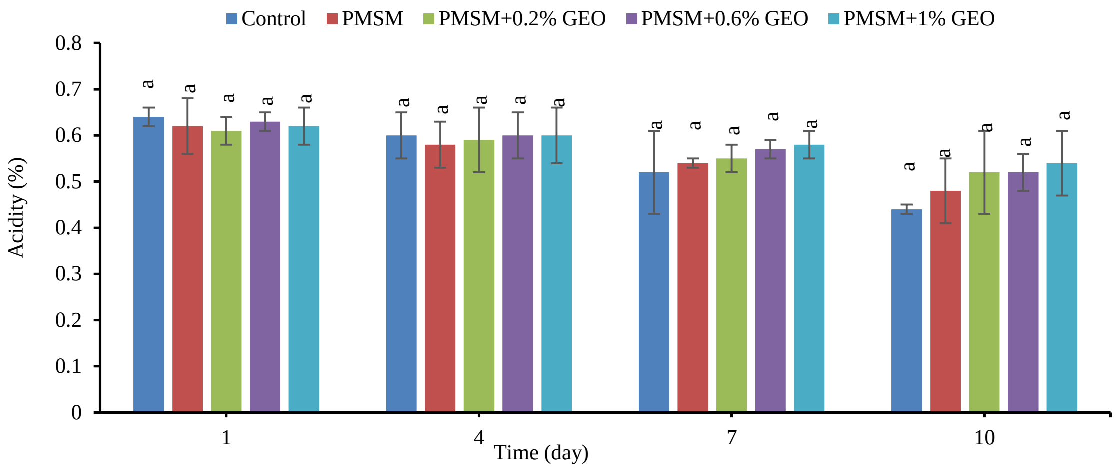

Figure 2. Changes in acidity of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

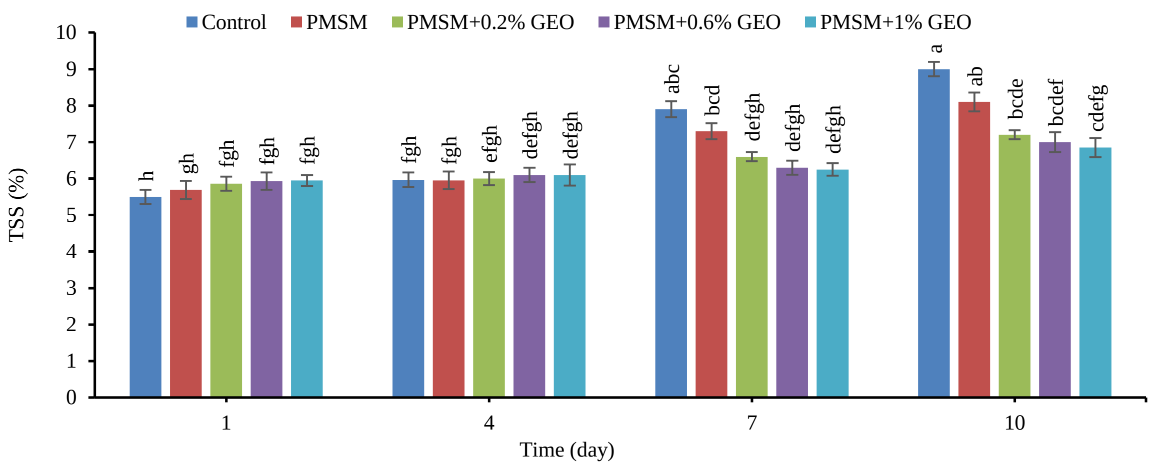

Figure 3. Changes in TSS of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

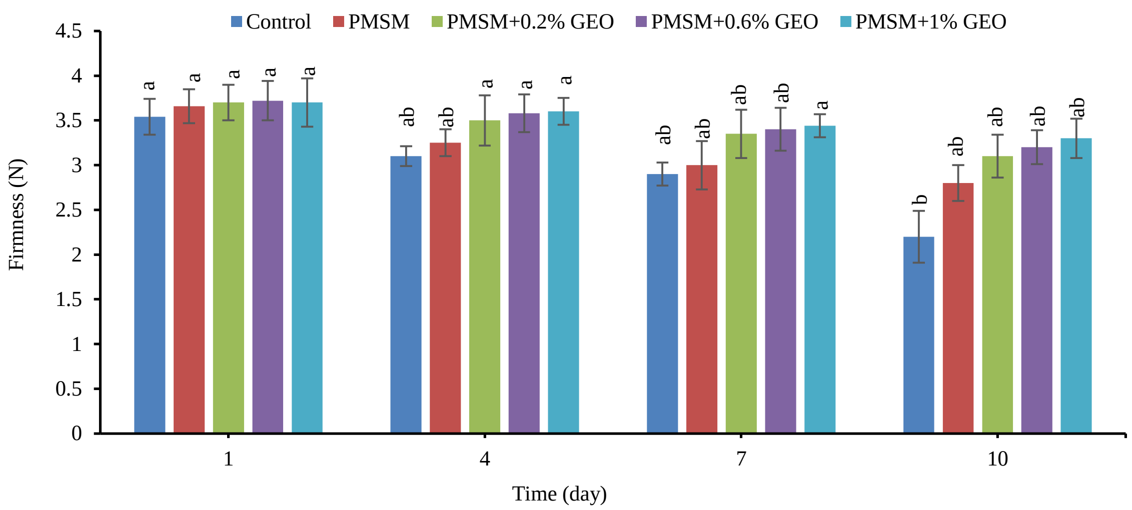

Figure 4. Changes in firmness of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

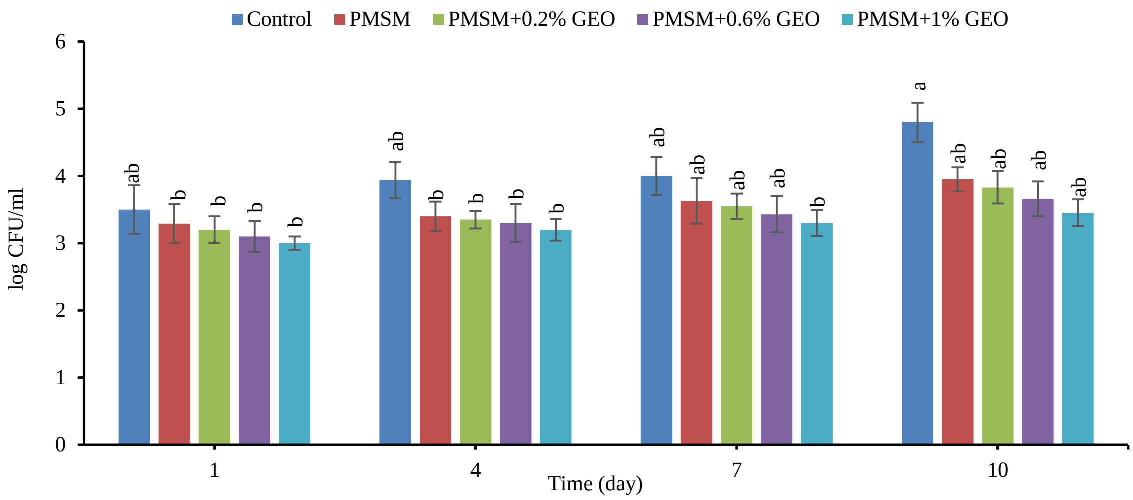

Figure 5. Changes in fungi count of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

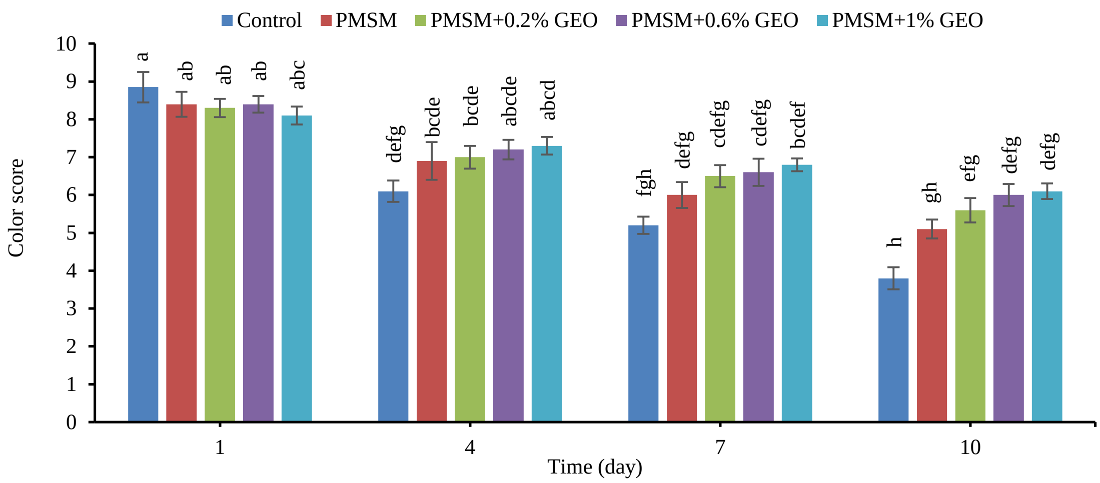

Figure 6. Changes in color score of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

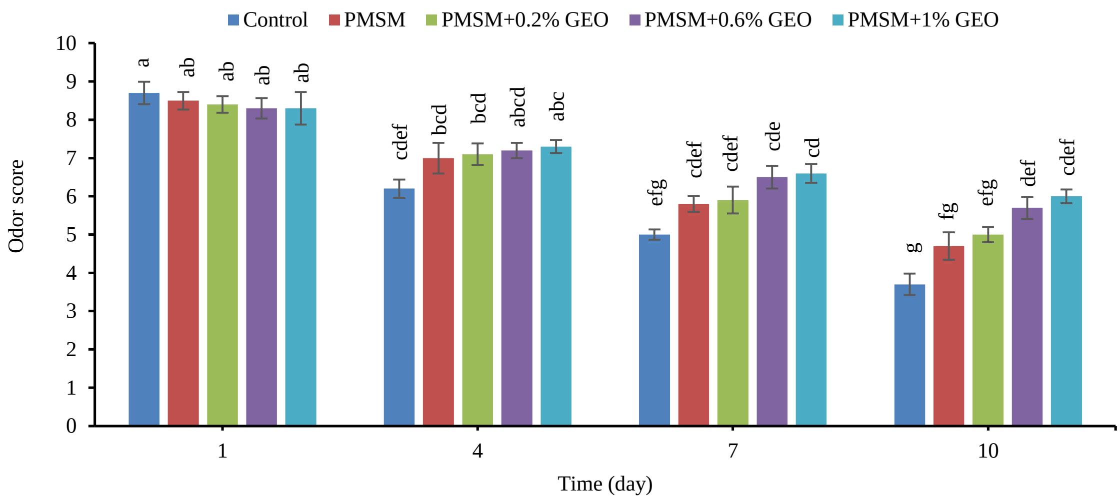

Figure 7. Changes in odor score of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

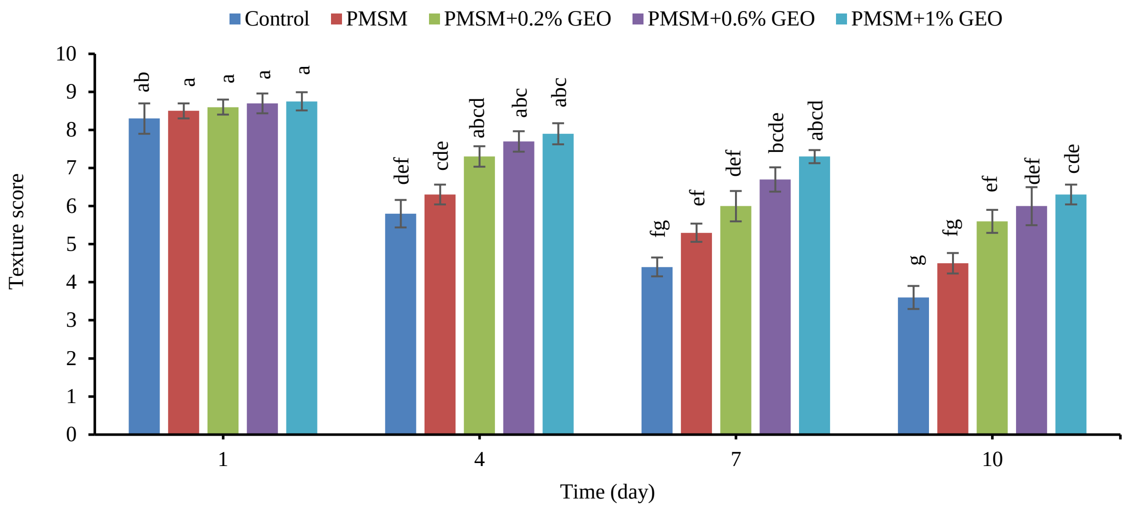

Figure 8. Changes in texture score of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

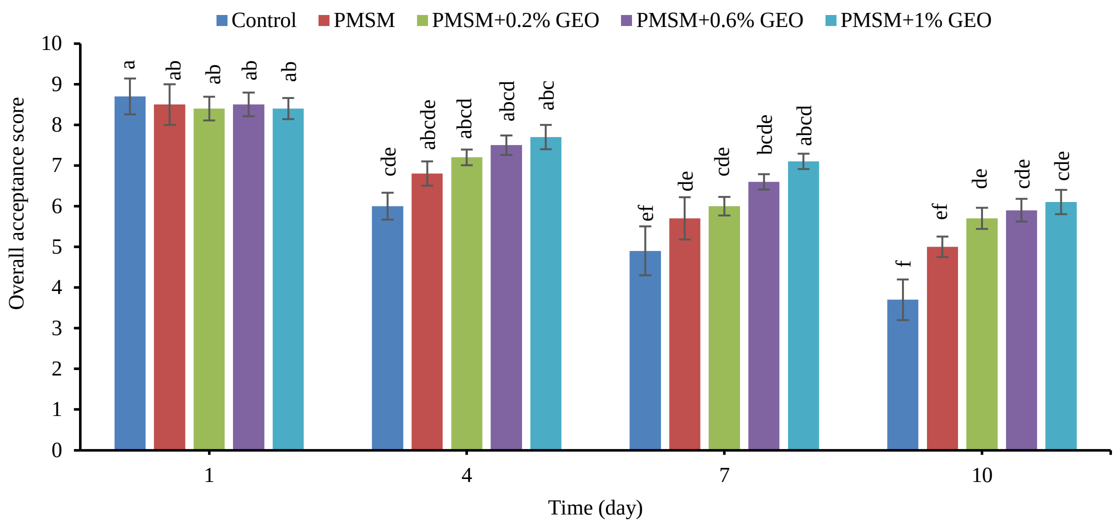

Figure 9. Changes in overall acceptability score of the strawberry samples during storage. GEO, grapefruit essential oil; and PMSM, *Plantago major* seed mucilage. Different superscript letters indicate significant differences between the means ($p < 0.05$).

Discussion

Variations in pH of the samples over the storage are illustrated in Figure 1. All samples demonstrated significant increases in pH (from 3.56 to 3.82) as time progressed. Significantly, coated samples enriched with GEO showed lower pH values, compared to the control sample. Throughout the storage, acidity levels of the samples decreased, as shown in Figure 2. Coated samples, particularly those with 1% GEO coating, showed higher acidities, compared to the control sample. Previous studies have suggested that increased oxygen levels affecting fruit respiration rates might lead to increases in fruit pH during storage (27). These findings were similar to studies such as those by Gol et al. (1), who observed further pronounced pH increases in uncoated strawberries, compared to the coated samples. Consumption of organic acids during fruit ripening could contribute to this phenomenon. Diaz-Mula et al. (28) explained the higher acidity loss in uncoated fruits as a result of their heightened respiration rates during storage, storing respiratory activity of the organic acids (Krebs cycle). Synthesis of the organic acids typically occurs during fruit maturation (29), leading to enhanced acidity and decreased senescence. These emphasize how the edible coating effectively preserved and enhanced the total acidity values.

Type of the edible coating included significant storing rates on TSS levels with higher levels of essential oil in the coating, resulting in significantly lesser changes in TSS contents. Samples treated with PMSM and 1% GEO and the control demonstrated the lowest (6.29%) and the highest (7.09%) TSS values, respectively. Increases in TSS could be attributed to increased hydrolysis of the fruit sugars and substantial water loss during the storage (30). Slight increases in TSS for coated fruits might indicate alterations in the internal fruit atmosphere, potentially linked to decreases in O_2 levels and/or increases in CO_2 levels, which could decrease respiration rates and metabolic processes converting sugars into CO_2 and H_2O (31). This indicated that postharvest treatment with PMSM and GEO significantly inhibited the softening of strawberry fruits, likely stemming from the degradation of the middle lamella of cortical parenchymal cell walls (32, 33). Previous studies have highlighted the positive effects of various coating uses on the texture of strawberries (3, 33).

The microbial load increased significantly with prolonged storage time in all treatments. While PMSM coating alone modestly slowed the microbial growth, combining PMSM with 1% GEO substantially delayed the microbial growth by 18%, compared to the control sample. By the end of the storage, fungal counts were ranked as 4.80, 3.95, 3.83, 3.66 and 3.45 log CFU/ml for the control, PMSM, PMSM and 0.2% GEO, PMSM and 0.6% GEO, and PMSM and 1% GEO coated strawberries, respectively. Extent of inhibition was correlated with the concentrations of GEO due to its demonstrated antibacterial and antifungal activities (22, 23). Results from Raquel et al. (34) and Shahbazi (2) supported these findings, indicating decreases in fungal counts following antimicrobial coating uses.

Selective permeability of PMSM and GEO to gases might create a barrier against oxygen, decreasing excessive degradations of biochemical attributes such as TSS and acidity. Additionally, the physical barrier induced by PMSM and GEO could hinder the release of volatile taste compounds from fully ripened fruits. The GEO antioxidant and antifungal characteristics include great potentials for preserving postharvest quality. Similar findings have been reported in previous studies (5, 35).

Conclusions

The study demonstrates efficacy of PMSM and GEO coating in preserving postharvest strawberries for up to 10 d by inhibiting microbial growth. Physicochemical and sensory characteristics (pH, acidity, TSS, firmness, color, odor, texture and overall acceptability) of the strawberries treated with the coating were consistently superior to those of the untreated control. While PMSM coating alone showed preservation benefits, combination of PMSM with GEO was further effective. Using this combination could serve as a viable option to prolong the shelf life of strawberries and decrease reliance on pesticides in postharvest interventions.

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Financial disclosure

The authors declare no conflict of financial interest.

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Availability of data and materials

Data supporting findings of this study are available from the corresponding author on request.

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