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Exploring the use of quince seed mucilage as novel coating material for enhancing quality and shelf-life of fresh apples during refrigerated storage

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Valorisation of quince seeds was performed for the extraction of mucilage. Five composite coatings of quince seed mucilage (QSM) and sodium alginate *viz.* 100 : 0 (QAH_1), 80 : 20 (QAH_2), 60 : 40 (QAH_3), 40 : 60 (QAH_4), and 20 : 80 (QAH_5) were developed and incorporated with vanillin (1%). The effect of quince seed mucilage-sodium alginate composite hydrogel coatings incorporated with vanillin on the postharvest quality of apples stored under refrigerated conditions for a period of 180 days was studied. Coatings helped to reduce weight loss, and weight loss of 5.98% and 3.48% was reported in control and QAH_1 coated samples, respectively, after 180 days of storage. Better firmness, color, anthocyanin content, vitamin C and antioxidant activity were retained in coated samples than in control samples. Significantly ($P \leq 0.05$) higher microbial counts (6.04 $\log_{10}$ cfu g^{-1}) were reported in control samples as compared to samples coated with QAH_1 (4.72 $\log_{10}$ cfu g^{-1}) due to the antimicrobial properties of vanillin and QSM. These findings confirm potential benefits of QSM-based edible coatings for shelf-life extension and quality maintenance of this commercially important fruit crop.

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Sustainability spotlight

The valorisation of quince seed for the extraction of mucilage and its subsequent use in composite hydrogel coatings, along with the incorporation of vanillin, presents a sustainable solution for enhancing the postharvest quality and shelf-life of apples. By utilizing natural and renewable resources such as quince seed mucilage (QSM) and sodium alginate, this approach reduces dependency on synthetic coatings and chemical preservatives. The reported benefits, including reduced weight loss, improved retention of firmness, color, anthocyanin content, vitamin C, and antioxidant activity, highlight the efficacy of this eco-friendly coating. Furthermore, the antimicrobial properties of vanillin contribute to reduced microbial growth, potentially minimizing the need for synthetic antimicrobials. This sustainable innovation underscores the potential of bio-based materials in agri-food applications, promoting both environmental stewardship and food security through improved preservation techniques.

1. Introduction

Apple (*Malus domestica* Borkh.; family-Rosaceae) is an important climacteric fruit of the temperate region and is most frequently consumed in different parts of the world. Health benefits from apples are attributed to the presence of polyphenolic compounds, which can be divided into five main groups: phenolic acids (chlorogenic acid and its derivatives), flavanols (catechin, epicatechin and procyanidins), flavonols (quercetin glycosides), dihydrochalcone (phloretin glycosides), and anthocyanins (cyanidin and its glycosides). The phenolic compounds protect cell walls against damage from free radicals and inhibit the oxidation of low-density lipoproteins by acting as antioxidants. The postharvest life of fruits is mainly affected by fruit tissue softening.[1] Softening of fruits is considered an undesired phenomenon during apple fruit ripening because more the firmness more the juiciness and lesser the mealiness. Fruit ripening-related changes to the cell wall and cuticle largely determine softening, which results in damage, microbial colonization and overall product losses. Thus, the postharvest treatment of fresh horticultural produce becomes imperative for maintenance of the quality and enhancement of the shelf-life of the fruit. Significant advancements have been made in the postharvest handling of fresh produce in the form of various postharvest treatments and modern storage methods for maintenance or improvement in fruit quality characteristics without compromising the consumer acceptability of fruits.[2] Commonly, cold storage is used for shelf-life improvement in apples; however, this is not enough to retain the quality attributes of fruits during long-distance transportation and marketing. There are also chances of chilling injury in these stores. So, there is a need for appropriate technologies that can be employed in combination with cold storage.

Edible coatings are a potential tool for food preservation with some added advantages such as controlled release of

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bioactive substances and delayed deterioration in sensory, chemical and microbiological properties of the food. Lipid, protein and carbohydrate-based coatings have been used in different fruit crops. There is a need to explore newer coating materials with improved properties, and quince seed mucilage is one such option. Structurally, mucilage mainly comprises branched carbohydrates consisting of monomers of L-arabinose, D-xylose, L-rhamnose, D-galactose, and galacturonic acid. Besides carbohydrates, extracted mucilage has been found to contain small quantities of moisture, protein, ash and fat.[3]

The quince seed mucilage (QSM) is mainly composed of glucuronic acid.[4] The mucilage from quince seed has excellent biological and mechanical attributes, making it valuable as a stabilizer and an edible coating/film-forming material. The mucilage has a good tensile strength in combination with good barrier properties, acting as a semipermeable membrane against various gases that reduce the activity of fruit softening and weight loss in coated fruits.[5] Quince seed mucilage (QSM) is a promising natural and biodegradable coating material for fresh produce, offering several advantages over other commonly used edible coatings. Unlike chitosan, which can cause allergic reactions, QSM is plant-derived and suitable for all dietary preferences. Compared to aloe vera gel, QSM demonstrates superior moisture retention and is more cost-effective due to its availability as a by-product of the food industry.[6] Additionally, QSM forms stronger, more elastic films than pectin, which tends to be brittle and exhibits better antimicrobial properties. These attributes make QSM a superior coating material for extending the shelf life and maintaining the quality of fresh produce.[7]

Alginates have an inherent ability to form transparent, uniform and thermo-irreversible gel networks at room temperature with the aid of di or trivalent ions.[8] Natural vanillin that is found in sugar beet pulp and vanilla pods is a bio-based cross-linker because of the presence of aldehyde. It possesses both antimicrobial and antioxidant properties. This study was aimed at developing composite hydrogels based on quince seed mucilage and sodium alginate incorporated with vanillin and evaluating the effect of these hydrogel coatings on the quality of apples during storage.

2. Materials and methods

2.1 Materials

Apples cv. Red Delicious were purchased from Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, (J & K) India. Fruits, harvested in the second week of September (149 days after full bloom) after developing 75% color, starch rating of 3.5 and TSS of 12.2%, having uniform size, shape, and color and without external injury were selected.

All the chemicals obtained from Hi-Media Pvt. Ltd, Mumbai, India, were of analytical grade.

2.2 Mucilage extraction

After cleaning for any extraneous material, dried seeds of quince (*Cydonia oblonga*) were soaked at room temperature while maintaining the seed-to-distilled water ratio of 1 : 25 (w/v) for 24 h. Mucilage was precipitated by the addition of 97% ethanol, and an ethanol/mixture ratio of 3 : 1 was maintained. The resulting precipitate was dried overnight in an oven at a temperature of 40 ± 1 °C. Approximately 8% mucilage yield was obtained on a dry weight basis.

2.3 Preparation and application of coatings

Different proportions of QSM and sodium alginate were mixed to prepare QSM-alginate composite hydrogels for coatings. Distilled water was used as a medium for the preparation of coatings and solid concentration was maintained at 1% (w/v). Five different proportions of QSM and sodium alginate were mixed *viz.* 100 : 0 (QAH_1), 80 : 20 (QAH_2), 60 : 40 (QAH_3), 40 : 60 (QAH_4), and 20 : 80 (QAH_5).

Each of the five coatings was incorporated with an antimicrobial agent (1% vanillin) and applied to the apples. Apples without coating served as control. For each treatment, 450 apples were used. Apples were washed, sanitized with sodium hypochlorite solution (100 ppm), rinsed and dried prior to coating operations. Apples were dipped in the prepared solutions for 5–10 min. and then air-dried under ambient conditions (20 ± 1 °C) till coatings were fully dried. Apples were stored in plastic crates under refrigerated conditions (4 ± 1 °C and 85 ± 5% RH) for 180 days and analyzed for different quality attributes at 0, 30, 60, 90, 120, 150 and 180 days of storage. At each interval, 90 apples were sampled to evaluate various quality parameters.

2.4 Firmness

The flesh firmness (N) of apples was recorded with the help of a texture analyzer (Stable Microsystems, Model-TA HD plus 5092, Godalming Surry, UK). The approach speed of 2 mm s^{-1} and penetration depth of 5 mm for the probe was maintained.

2.5 Weight loss

Ten apples of each treatment were selected and assigned with a code number for each apple. Weighing of apples was done with the help of electronic balance (Wensar, PGB 200) throughout the storage period. The change in weight from initial and final was determined as the weight loss (%) using the eqn (1):

$$\text{Weight loss}(\%) = \frac{\text{initial weight of sample} - \text{final weight of sample}}{\text{initial weight of sample}} \times 100 \quad (1)$$

2.6 Instrumental color values (L^*, a^*, b^*)

Color of apple samples was determined with the help of a lab digital colorimeter (Accuracy Micro sensors, New York; Model SN3001476) and measured as L^*, a^*, b^* values where 'L' value indicated the lightness or darkness, 'a' value indicated the redness or greenness, and 'b' value indicated the yellowness or blueness of the samples. Initially, calibration of the instrument

was done, and mean values of three readings taken at equally distant spots across the height of the fruit were recorded. Spots for color measurement were marked on the fruit, and observations were recorded from the same spots at each storage interval.

2.7 Total soluble solids

Apple juice was extracted using a lab scale juice extractor, filtered through a Whatman filter paper 2 and TSS was measured using a hand-held refractometer (Atago-Japan, Model- PAL 1).

2.8 Titratable acidity

The titratable acidity was estimated by titrating a known amount of homogenized and filtered apple juice against 0.1 N NaOH solution. Phenolphthalein was used as an indicator, and the acidity was expressed in terms of percent malic acid (eqn (2)):

$$\text{Titratable acidity}(\%) = \frac{\text{titrate value} \times \text{normality of alkali} \times 0.1 \times \text{dilution factor} \times 100}{\text{weight of sample} \times \text{volume of filtrate for estimation} \times 100} \quad (2)$$

2.9 Ascorbic acid content

Vitamin C, expressed as mg/100 g, was estimated using 2,6-dichlorophenolindophenol (DCPIP) following the method 967.21.[9] Homogenization of apple pulp (10 g) was done with 3% metaphosphoric acid (90 mL). This was followed by centrifugation at 8000×*g* for 15 min. and filtration. Titration of 10 mL of supernatant was done against 2,6-dichlorophenol indophenol dye till pink rose color was obtained, which persisted for about 20 s.

2.10 Anthocyanin content

Spectrophotometric measurement of anthocyanins was done following the AOAC[10] protocol 10 g of the apple pulp was macerated with 10 mL of ethanolic HCl, volume made up to 100 mL. After keeping the extract overnight at a temperature of 4 °C, absorbance was measured at 535 nm with the help of a UV-VIS spectrophotometer (Hitachi High-Tech, India, Model U2900). Results were expressed as mg/100 g fresh weight of the sample.

2.11 Antioxidant activity and total phenolic content

2.11.1 Extract preparation. For extraction, 2 g of apple pulp was mixed with 8 mL of solvent. The mixture was subjected to centrifugation for 10 minutes at 10 000×*g*, and the supernatant was recovered. The extract was then kept at 4 °C for further analysis.

2.11.2 Total phenolic content. A modified method of Chandra *et al.*[11] was adapted for the determination of TPC. Briefly, 0.2 mL of sample extract and 0.6 mL of distilled water were mixed. Then, Folin-Ciocalteu's reagent (0.2 mL) in a ratio of 1 : 1 was added to the solution. After 5 min of incubation, the mixture was added with saturated (8% w/v) sodium carbonate solution (1 mL) and the final volume was made to 3 mL by the addition of distilled water. The solution mixture was incubated for 30 min in the dark. Using a UV-VIS spectrophotometer (Hitachi High-Tech, India, Model-U2900), absorbance was taken at 765 nm against the blank. Gallic acid was used as a standard for the calculation of total phenolic content, and results were expressed as mg GAE/100 g fresh weight.

2.11.3 DPPH radical scavenging activity. Antioxidant properties, determined as scavenging activity of DPPH radicals, were done by the method of Matthaus[12] with modifications. The extract was mixed with 1.0 mL of 0.01% methanolic solution of DPPH (1,1-diphenyl-2-picrylhydrazyl). Incubation of the mixture was done in the dark for 30 minutes and with the help of UV-VIS spectrophotometer (Hitachi High-Tech, India, Model-U2900), absorbance was taken at 515 nm. The calculated values were taken against a control using eqn (3):

$$\text{AA inhibition activity}\% = \frac{A(\text{control}) - A(\text{sample})}{A(\text{control})} \times 100 \quad (3)$$

2.12 Microbiological assay

Ten grams of fruit was mixed with 90 mL sterilized saline solution followed by homogenization for 10 min. Each sample (1 mL) was poured into plates containing plate count agar (PCA) and incubation was done at 5 °C for determination of total psychrophilic bacterial count (TPBC). Potato dextrose agar (PDA) and chloramphenicol glucose agar (CGA) were used to determine yeast and mold count (YMC). The Petri plates were incubated for 7 days at 37 °C. The assay was performed in three replicates, and the result was expressed as $\log_{10}$ cfu g^{-1}.

2.13 Sensory evaluation

The sensory evaluation was carried out by ten semi-trained panelists with prior experience in the sensory profiling of apples. Sensory parameters considered for scoring were color, flavour and texture. Overall acceptability was determined based on these parameters. The sensory procedure was carried out on the basis of a nine-point hedonic scale[13] (like extremely = 9, like very much = 8, like moderately = 7, like slightly = 6, neither like nor dislike = 5, dislike slightly = 4, dislike moderately = 3, dislike very much = 2, dislike extremely = 1).

2.14 Statistical analysis

The experimental data was represented as an average of triplicates. Analysis of variance (ANOVA) at 5% level of significance was used to test the significance of different variables and data were analysed using SPSS statistics software (v.250 16, Inc., Chicago, IL) while Duncan's multiple range test (DMRT) was used to describe the means.

3. Results and discussion

3.1 Firmness

The most notable change in the apples was the decrease in firmness resulting from the degradation of the cell wall. Data in Fig. 1 shows that the use of coatings containing vanillin

retained the texture of apples longer than that of the control sample. Significantly ($p < 0.05$), the highest firmness of 73.75 N and the lowest of 62.36 N were observed in QAH_1 and control samples, respectively, at the end of storage. The firmness of the horticultural crops is influenced by ripening processes and enzyme activity. Edible coatings containing vanillin result in modification of the internal gaseous composition of fruits, thereby decreasing O_2 and increasing CO_2 concentrations. This change in the atmosphere inside the fruit has a beneficial effect by reducing the activities of cell-wall degrading enzymes. As a result, the firmness of horticultural crops can be preserved or enhanced, contributing to prolonged shelf life and improved quality of the fruits. This method effectively regulates the ripening process and enzyme activity, thereby maintaining fruit firmness and freshness for a longer period.[14] Inthamat *et al.*[14] reported maintenance of firmness in cucumber by application of quince seed mucilage. Del-Valle *et al.*[15] observed that nopal mucilage helped in texture retention of strawberries stored under refrigerated conditions. Several studies have also reported that the application of coatings enriched with essential oils and some antioxidant agents was very effective in controlling the activities of enzymes like peroxidase, polyphenol oxidase, and cellulase in jamun fruit.[16] These results confirm that the degradation of pectic substances is slowed down, thus maintaining the rigidity of the fruit.

3.2 Weight loss

Transpiration and respiration processes in fresh fruits are the main reasons for weight loss. As expected, there was an increase

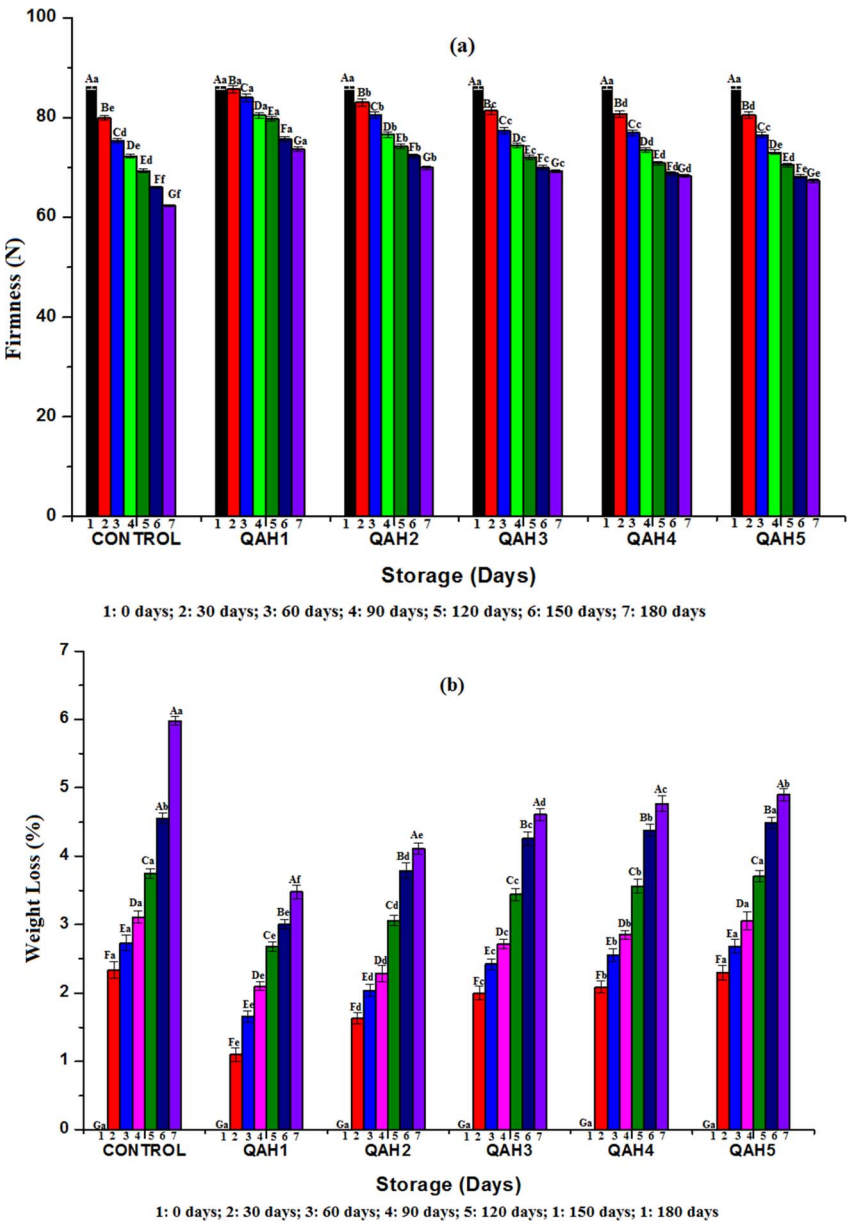

Fig. 1 Effect of QSM-alginate coatings on firmness (a) and weight loss (b) of apple during refrigerated storage. Note: different letters in the graph (A–G) and (a–f) indicate significant differences ($P \leq 0.05$) with respect to storage period and coating treatment type, respectively.

in weight loss during storage in all the apple samples and loss was more pronounced in control (5.98%) and less in QAH_1 (3.48%) after 180 days of storage (Fig. 1b). Among coatings, QAH_1 was found to be more effective, which may be due to the lesser ability of alginates to reduce water loss. Quince seed mucilage was found to extend the shelf-life of cucumber by slowing down weight loss under refrigerated conditions.[17] Edible coatings limit water vaporization by creating a protective layer on the fruit surface, effectively reducing rates of respiration and other metabolic processes. This treatment results in a smoother pericarp and covers stomata, which are the pores through which gases like oxygen and carbon dioxide pass. By sealing these stomata, edible coatings significantly decrease both transpiration (the loss of water through the skin) and respiration rates in apples. This dual effect helps in maintaining optimal moisture levels within the fruit, slowing down the ripening process and extending shelf life.[18] Reduction in moisture loss because of blocking stomata and pores in litchi fruit has also been reported by Dong *et al.*[17] Gardesh *et al.*[19] also observed a decrease in weight loss in apple fruit compared to control by application of chitosan-based coatings. Reduction in weight loss by alginate coatings has demonstrated reduced weight loss in plum fruit.[20] In the present study, results showed that QSM-alginate composite coatings with vanillin as an antimicrobial agent significantly ($p < 0.05$) limited the weight loss of apples during storage.

3.3 Instrumental color (L^*, a^*, b^* values)

Color is an important determinant of the degree of ripeness and quality of fruits. Changes in apple peel color values (L^*, a^*, and b^*) of apple fruits during storage are shown in Table 1. A decreasing trend in L^* values with an increase in storage days was observed, while the a^* value increased up to 30 days of storage and decreased afterwards. Coated fruits, however, showed significantly ($P \leq 0.05$) lower changes and higher retention of peel color. L^* value of control fruits decreased from the initial value of 42.77 to 37.29 after 180 days of storage. QAH_1 coated fruits recorded the highest L^* values of 40.25 after 180 days of storage. Similar trends were observed for a^* value during the storage, with QAH_1 coated fruits showing the highest value of 28.06 and control samples showing the lowest value of 23.31 at the end of the storage period. The dynamics of anthocyanin biosynthesis and degradation may be responsible for changes in the redness values of apples during storage. There is more accumulation of anthocyanins in apples during the initial days of storage and subsequently a decrease was observed with the advancement of storage. There was an increasing trend observed in b^* value during the storage, and a lower increase was observed in coated fruits. The highest b^* value of 21.62 and the lowest b^* value of 16.78 were observed in control and QAH1 coated samples at the end of the storage period. The reason could be that the edible coatings result in decreased ripening processes and prevent oxidative damage by controlling the moisture loss in apples, which contributes to minimizing the overall color changes. QSM coating was effective in preventing the ΔE change and maintaining L^*, a^* and b^* values in mandarin samples during storage.[21] Gardesh *et al.*[19] reported a significant drop in the L^* value of control apple samples as compared to fruits coated with nanochitosan. Zambrano-Zaragoza *et al.*[22] associated the changes in the L^* value with

Table 1 Effect of QSM-alginate coatings on instrumental color values (L^*, a^*, b^*) of apple[a]

	0 day	30 days	60 days	90 days	120 days	150 days	180 days
(L^*)							
CONTROL	42.77 ± 0.04^{cA}	41.84 ± 0.05^{eB}	41.19 ± 0.03^{eC}	40.58 ± 0.04^{eD}	40.13 ± 0.04^{eE}	39.73 ± 0.05^{fF}	39.29 ± 0.04^{eG}
QAH_1	43.98 ± 0.05^{aA}	42.92 ± 0.03^{aB}	42.81 ± 0.04^{aC}	42.79 ± 0.04^{aC}	41.71 ± 0.05^{aD}	40.80 ± 0.04^{aE}	40.75 ± 0.06^{aF}
QAH_2	43.95 ± 0.05^{aA}	42.88 ± 0.04^{bB}	42.77 ± 0.01^{bC}	42.70 ± 0.04^{bC}	41.63 ± 0.01^{bD}	40.74 ± 0.01^{bE}	40.68 ± 0.03^{bF}
QAH_3	43.91 ± 0.05^{bA}	42.86 ± 0.04^{bB}	42.75 ± 0.01^{bC}	42.69 ± 0.03^{bD}	41.63 ± 0.02^{bE}	40.72 ± 0.05^{cF}	40.65 ± 0.04^{cG}
QAH_4	43.83 ± 0.05^{bA}	42.78 ± 0.03^{cB}	41.90 ± 0.04^{cC}	41.42 ± 0.05^{cD}	41.09 ± 0.03^{cE}	40.67 ± 0.03^{dF}	40.61 ± 0.04^{cG}
QAH_5	43.79 ± 0.05^{bA}	42.73 ± 0.03^{dB}	41.32 ± 0.05^{dC}	41.00 ± 0.04^{dD}	40.72 ± 0.05^{dE}	40.34 ± 0.03^{eF}	40.17 ± 0.08^{dG}
(a^*)							
CONTROL	33.03 ± 0.15^{aB}	35.80 ± 0.17^{aA}	33.25 ± 0.15^{aB}	30.10 ± 0.16^{dC}	28.35 ± 0.16^{dD}	26.29 ± 0.14^{eE}	23.31 ± 0.12^{eF}
QAH_1	33.09 ± 0.15^{aB}	34.99 ± 0.16^{cA}	32.05 ± 0.15^{bC}	30.98 ± 0.17^{aD}	30.05 ± 0.18^{aE}	28.95 ± 0.15^{aF}	28.06 ± 0.15^{aG}
QAH_2	33.09 ± 0.14^{aB}	35.10 ± 0.14^{cA}	31.85 ± 0.16^{cC}	30.32 ± 0.15^{cD}	29.22 ± 0.17^{dE}	28.34 ± 0.14^{dF}	27.78 ± 0.15^{bG}
QAH_3	33.06 ± 0.14^{aB}	35.29 ± 0.16^{bA}	31.51 ± 0.17^{dC}	30.64 ± 0.15^{bD}	29.75 ± 0.16^{bE}	28.71 ± 0.16^{bF}	27.54 ± 0.13^{cG}
QAH_4	33.04 ± 0.15^{aB}	35.45 ± 0.17^{bA}	31.29 ± 0.18^{eC}	30.42 ± 0.15^{cD}	29.53 ± 0.15^{cE}	28.48 ± 0.13^{cF}	27.40 ± 0.12^{dG}
QAH_5	33.03 ± 0.14^{aB}	35.58 ± 0.18^{bA}	31.16 ± 0.15^{eC}	30.29 ± 0.17^{cD}	29.48 ± 0.16^{cE}	28.31 ± 0.14^{dF}	27.32 ± 0.14^{dG}
(b^*)							
CONTROL	15.70 ± 0.25^{aG}	16.20 ± 0.23^{aF}	17.21 ± 0.24^{aE}	17.95 ± 0.24^{aD}	18.36 ± 0.21^{aC}	19.20 ± 0.19^{aB}	21.62 ± 0.17^{aA}
QAH_1	15.70 ± 0.23^{aG}	15.15 ± 0.24^{bF}	15.35 ± 0.24^{bE}	15.80 ± 0.23^{bD}	16.00 ± 0.20^{bC}	16.46 ± 0.23^{bB}	16.78 ± 0.21^{bA}
QAH_2	15.70 ± 0.25^{aF}	15.51 ± 0.24^{cF}	15.89 ± 0.20^{cE}	16.28 ± 0.23^{cD}	16.56 ± 0.22^{cC}	17.20 ± 0.20^{cB}	17.66 ± 0.20^{cA}
QAH_3	15.70 ± 0.24^{aF}	15.88 ± 0.25^{dF}	16.21 ± 0.23^{dE}	16.60 ± 0.21^{dD}	16.95 ± 0.19^{dC}	17.59 ± 0.21^{dB}	18.04 ± 0.23^{dA}
QAH_4	15.70 ± 0.23^{aG}	16.10 ± 0.23^{dF}	16.45 ± 0.21^{eE}	16.83 ± 0.19^{eD}	17.26 ± 0.22^{eC}	17.81 ± 0.24^{eB}	18.39 ± 0.21^{eA}
QAH_5	15.70 ± 0.23^{aG}	16.18 ± 0.24^{dF}	16.56 ± 0.22^{eE}	16.94 ± 0.21^{eD}	17.34 ± 0.18^{eC}	17.94 ± 0.21^{eB}	18.52 ± 0.21^{eA}

[a] All values are mean ± standard deviation of three replicates. Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). Means with different uppercase superscripts in the same row (storage months) indicate significant differences ($p < 0.05$).

polyphenol oxidase activity; the application of oxygen barrier coating restricts the action of this enzyme. This data reveals that QSM-alginate composite coatings have the potential to act as a barrier to oxygen and slow down the ripening processes, which effectively lessens the rate of color change.

3.4 Total soluble solids

Total soluble solids (TSS) include fructose, glucose, sucrose, minerals, organic acids and proteins. TSS increased up to 120 days of storage and then decreased in QAH_1, QAH_2, QAH_3 and QAH_4 samples while as in control and QAH5 samples, a decrease in TSS was observed after 90 days of storage (Table 2). A significant ($P \leq 0.05$) difference was observed between the TSS content of coated and control samples and the lowest changes were observed in samples coated with QAH_1, which reported a TSS of 13.36 after 180 days of storage. The control sample observed the lowest TSS of 12.48 at the end of the storage period. The increase in total soluble solids (TSS) in edible coated apples up to 120 days of storage can be attributed to the ongoing metabolic activities within the fruit, such as the conversion of starches into sugars, primarily fructose, glucose, and sucrose. This conversion is part of the fruit's natural ripening process, which is initially slowed down by the edible coating that acts as a semi-permeable barrier, reducing respiration and moisture loss. However, after 120 days, the decline in TSS can be due to the breakdown of sugars and other soluble compounds into simpler substances through processes such as respiration. Additionally, prolonged storage can lead to the deterioration of the structural integrity of the fruit, leading to increased metabolic degradation of TSS.[23] Also, diffusion of essential oil components towards the fruit surface inhibits sudden TSS rise during storage.[24] These findings are similar to the studies of de Matos Fonseca *et al.*[25] Gardesh *et al.*[19] reported non-significant changes in TSS in nanochitosan-coated apples during storage.

3.5 Titratable acidity

The main acids present in apples include malic acid, tartaric acid, and citric acid, and their content depends on the extent of ripening and cultivar variation. There was a significant ($P \leq 0.05$) effect of storage periods on the titratable acidity (TA) of apples (Table 2). The titratable acidity decreased progressively from the initial value of 0.42% during storage in both control and coated samples but the coatings were helpful in retaining the acidity. The decrease in titratable acidity is an indication of increased maturity. Among coated samples, the highest value (0.31%) was observed in QAH_1 and the lowest in $QAH5_5$ (0.23%) while the control sample recorded a value of 0.19% after 180 days of storage period. The decrease in titratable acidity during storage of both coated and uncoated apples can be attributed to several biochemical and physiological factors. Initially, apples undergo metabolic processes such as respiration, which consumes organic acids stored in the fruit tissues. Additionally, enzymatic activities involved in the breakdown of acids and other organic compounds continue during storage. In the case of coated apples, the coating can initially slow down these processes by reducing respiration and moisture loss; over extended storage periods, enzymatic activity and metabolic processes can still lead to a reduction in titratable acidity.[26] Fruits treated with okra mucilage-quince seed mucilage edible coatings significantly delayed the changes in titrable acidity and pH compared to the uncoated fruits.[27] The decline in acidity was prevented by vanillin-incorporated chitosan coatings, as examined by Takma & Korel[28] in grapes.

3.6 Ascorbic acid content

Ascorbic acid, a bioactive compound possessing antioxidant properties, helps prevent several diseases. Its stability is influenced by several factors, including oxygen, temperature, metal ions, pH and ascorbate oxidase enzyme and serves as a nutrient quality index for fruits. The data pertaining to ascorbic acid

Table 2 Effect of QSM-alginate coatings on total soluble solids (%) and titratable acidity (%) of apples[a]

	0 day	30 days	60 days	90 days	120 days	150 days	180 days
Total soluble solids							
CONTROL	12.20 ± 0.21^{aG}	13.05 ± 0.20^{aE}	14.24 ± 0.22^{aC}	15.38 ± 0.19^{aA}	14.72 ± 0.19^{aB}	13.27 ± 0.16^{bD}	12.48 ± 0.18^{cF}
QAH_1	12.20 ± 0.23^{aF}	12.73 ± 0.21^{bE}	12.91 ± 0.23^{bE}	13.57 ± 0.20^{bC}	14.62 ± 0.21^{bA}	14.17 ± 0.18^{aB}	13.36 ± 0.19^{aD}
QAH_2	12.20 ± 0.22^{aE}	12.59 ± 0.23^{bD}	12.74 ± 0.19^{cD}	13.44 ± 0.20^{bC}	14.43 ± 0.18^{bA}	13.87 ± 0.21^{cB}	13.29 ± 0.20^{aC}
QAH_3	12.20 ± 0.23^{aF}	12.48 ± 0.20^{bE}	12.57 ± 0.21^{dE}	13.37 ± 0.20^{bC}	14.35 ± 0.22^{bA}	13.83 ± 0.20^{cB}	12.82 ± 0.19^{bD}
QAH_4	12.20 ± 0.24^{aE}	12.39 ± 0.23^{bE}	12.48 ± 0.21^{dE}	13.29 ± 0.19^{bC}	14.29 ± 0.20^{bA}	13.75 ± 0.19^{cB}	12.67 ± 0.17^{bD}
QAH_5	12.20 ± 0.23^{aC}	12.27 ± 0.21^{bC}	12.39 ± 0.20^{dC}	13.18 ± 0.22^{bA}	12.73 ± 0.19^{cB}	12.64 ± 0.17^{dB}	12.56 ± 0.16^{bB}
Titratable acidity							
CONTROL	0.42 ± 0.03^{aA}	0.35 ± 0.02^{bB}	0.32 ± 0.03^{bC}	0.28 ± 0.02^{dD}	0.25 ± 0.02^{fE}	0.23 ± 0.02^{fF}	0.19 ± 0.01^{dG}
QAH_1	0.42 ± 0.04^{aA}	0.41 ± 0.03^{aA}	0.40 ± 0.03^{aA}	0.38 ± 0.04^{aA}	0.36 ± 0.02^{aA}	0.34 ± 0.03^{aB}	0.31 ± 0.03^{aC}
QAH_2	0.42 ± 0.03^{aA}	0.38 ± 0.04^{bB}	0.36 ± 0.03^{bB}	0.35 ± 0.01^{bB}	0.33 ± 0.01^{bC}	0.31 ± 0.03^{bD}	0.29 ± 0.01^{aD}
QAH_3	0.42 ± 0.03^{aA}	0.36 ± 0.02^{bB}	0.35 ± 0.04^{bB}	0.34 ± 0.03^{cB}	0.30 ± 0.02^{cC}	0.28 ± 0.02^{cD}	0.26 ± 0.02^{bE}
QAH_4	0.42 ± 0.03^{aA}	0.36 ± 0.02^{bB}	0.34 ± 0.03^{bC}	0.32 ± 0.03^{cC}	0.27 ± 0.01^{dD}	0.26 ± 0.02^{dE}	0.24 ± 0.02^{cF}
QAH_5	0.42 ± 0.04^{aA}	0.35 ± 0.04^{bB}	0.33 ± 0.02^{bB}	0.29 ± 0.03^{dC}	0.26 ± 0.01^{eD}	0.24 ± 0.01^{eE}	0.23 ± 0.01^{cF}

[a] All values are mean ± standard deviation of three replicates. Means in the same column with different lower case superscripts differ significantly ($p < 0.05$). Means with different uppercase superscripts in the same row (storage months) indicate significant differences ($p < 0.05$).

Table 3 Effect of QSM-alginate coatings on ascorbic acid (mg/100 g) and anthocyanin (mg/100 g) of apples[a]

	0 day	30 days	60 days	90 days	120 days	150 days	180 days
Ascorbic acid							
CONTROL	12.50 ± 0.16^{aA}	11.89 ± 0.15^{dB}	10.40 ± 0.15^{eC}	10.01 ± 0.17^{cD}	8.90 ± 0.14^{eE}	7.11 ± 0.16^{fF}	6.06 ± 0.15^{eG}
QAH_1	12.50 ± 0.14^{aA}	12.60 ± 0.15^{aA}	11.31 ± 0.16^{aB}	10.42 ± 0.14^{aC}	9.80 ± 0.16^{aD}	8.95 ± 0.15^{aE}	8.12 ± 0.13^{aF}
QAH_2	12.50 ± 0.17^{aA}	12.39 ± 0.16^{bA}	10.98 ± 0.13^{bB}	10.71 ± 0.15^{bC}	9.55 ± 0.17^{bD}	8.70 ± 0.16^{bE}	7.81 ± 0.15^{bF}
QAH_3	12.50 ± 0.16^{aA}	12.18 ± 0.15^{cB}	10.77 ± 0.15^{cC}	10.38 ± 0.16^{bD}	9.22 ± 0.16^{cE}	8.35 ± 0.14^{cF}	6.95 ± 0.16^{cG}
QAH_4	12.50 ± 0.15^{aA}	12.01 ± 0.17^{dB}	10.59 ± 0.16^{dC}	10.16 ± 0.16^{cD}	9.04 ± 0.15^{dE}	7.92 ± 0.14^{dF}	6.88 ± 0.14^{cG}
QAH_5	12.50 ± 0.16^{aA}	11.92 ± 0.17^{dB}	10.44 ± 0.14^{eC}	10.08 ± 0.15^{cD}	8.98 ± 0.14^{dE}	7.46 ± 0.13^{eF}	6.21 ± 0.14^{dG}
Anthocyanin							
CONTROL	32.20 ± 0.40^{aB}	35.16 ± 0.37^{aA}	31.10 ± 0.36^{bC}	29.12 ± 0.39^{dD}	26.14 ± 0.38^{dE}	24.12 ± 0.35^{dF}	21.10 ± 0.36^{fG}
QAH_1	32.20 ± 0.37^{aB}	33.18 ± 0.38^{bA}	32.06 ± 0.35^{aB}	31.72 ± 0.36^{aB}	31.41 ± 0.38^{aB}	30.58 ± 0.37^{aC}	29.61 ± 0.37^{aD}
QAH_2	32.20 ± 0.39^{aB}	33.20 ± 0.36^{bA}	30.41 ± 0.37^{cC}	29.93 ± 0.40^{bD}	29.82 ± 0.39^{bD}	28.42 ± 0.37^{bE}	27.62 ± 0.40^{bF}
QAH_3	32.20 ± 0.40^{aB}	33.61 ± 0.38^{cA}	30.12 ± 0.38^{cC}	29.62 ± 0.39^{bD}	29.45 ± 0.40^{bD}	28.27 ± 0.36^{bE}	26.45 ± 0.36^{cF}
QAH_4	32.20 ± 0.38^{aB}	33.26 ± 0.35^{cA}	30.23 ± 0.36^{cC}	29.33 ± 0.37^{bD}	29.11 ± 0.37^{bE}	28.10 ± 0.40^{bF}	25.85 ± 0.35^{dG}
QAH_5	32.20 ± 0.37^{aA}	32.33 ± 0.36^{cA}	29.91 ± 0.35^{cB}	28.66 ± 0.38^{cC}	28.55 ± 0.35^{cC}	27.32 ± 0.40^{cD}	24.62 ± 0.39^{eE}

[a] All values are mean ± standard deviation of three replicates. Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). Means with different uppercase superscripts in the same row (storage months) indicate significant differences ($p < 0.05$).

content in control as well as treated apple fruit are recorded in Table 3, which revealed a decreasing trend in ascorbic acid content throughout storage, but coatings proved beneficial in slowing down the decrease. Ascorbic acid was maximum in QAH_1 (8.12 mg/100 g), followed by QAH_2 (7.81 mg/100 g) and the lowest values were recorded for the control sample after 180 days of storage. In the control sample, ascorbic acid content significantly ($P \leq 0.05$) decreased from an initial value of 12.50 mg/100 g to 6.06 mg/100 g after 180 days of storage. Maintenance of ascorbic acid content in coated samples during storage can be ascribed to good barrier characteristics of the coatings against oxygen. The loss of ascorbic acid is attributed to its irreversible oxidation during storage. Enzymes like ascorbic acid oxidase, cytochrome oxidase and peroxidase are also responsible for the loss of potency of vitamins caused by their oxidation. By regulating the cytosolic oxidative processes and lowering respiration rates, coatings resulted in more ascorbic acid retention. Reduction in vitamin C loss by olive leaf extract incorporated chitosan and alginate coatings was reported by Zam[29] in sweet cherry. Sangsuwan *et al.*[30] reported the protective effect of vanillin film on ascorbic acid content in pineapple.

3.7 Anthocyanin content

One of the significant factors in the economics of the apple industry is the skin color of fruits, as it plays a prominent role in consumer appeal. There is a direct correlation between skin color intensity and anthocyanin content. Anthocyanin content is highly influenced by pre- and post-harvest factors and even varies between the fruits of the same cultivar. Table 3 shows the changes in anthocyanin content of both the control as well as coated apple samples during storage. There was an initial increase in anthocyanin content in all the samples up to 30 days of storage. After 180 days of storage, the lowest value of anthocyanin content was determined in the control sample (21.10 mg/100 g) while the highest value of anthocyanin content was recorded in QAH_1 (29.61 g/100 g). The increase in anthocyanin content in apples up to 30 days of storage is primarily due to the ongoing biosynthesis of these pigments, which continues post-harvest under appropriate storage conditions. However, after 30 days, the decline in anthocyanin content can occur due to the degradation of these pigments, which can be catalyzed by factors, such as increased enzymatic activity, oxidation, and changes in pH as the fruit continues to age and its cellular structure deteriorates. This degradation can also be influenced by temperature and storage conditions, which may not fully preserve the stability of anthocyanins over extended periods.[31] These results are in conformity with those of Diaz-Mula *et al.*,[32] who reported increased anthocyanin content during storage; however, a lower increase was observed in plums coated with alginate than control. Similar findings have been observed in strawberries treated with chitosan-oleic acid edible coatings and stored under cold conditions.[33]

3.8 Total phenolic content

The phenolic compounds contribute to fruit quality in terms of aroma, colour, taste and flavour. During the extended storage of fresh horticultural commodities, a higher phenolic content is found to be helpful in maintaining the quality by the prevention of oxidative reactions due to their free radical scavenging properties. Storage time significantly ($p \leq 0.05$) influenced the total phenolic content (mg/100 g) of apple samples (Table 4). The total phenolic content of the control sample at day 0 was 112.30 mg GAE/100 g, which decreased up to 83.64 mg GAE/100 g during 180 days of storage. For coated samples, after 180 days of storage, the highest value of the total phenolic content (101.09 mg GAE/100 g) was found in QAH_1 and the minimum value (92.58 mg GAE/100 g) in QAH_5. As fruits age, cellular integrity declines, leading to the enzymatic breakdown of phenolic compounds. However, when fruits are coated with edible coatings, such as those containing chitosan or other barrier materials, oxygen permeability is reduced. This lowered permeability limits the access of oxygen to the fruit surface and

Table 4 Effect of QSM-alginate coatings on total phenolic content (mg GAE/100 g) and DPPH radical scavenging activity (%) of apples[a]

	0 day	30 days	60 days	90 days	120 days	150 days	180 days
Total phenolic content							
CONTROL	112.30 ± 0.21^{aA}	110.14 ± 0.19^{eB}	107.78 ± 0.20^{eC}	102.46 ± 0.18^{eD}	96.06 ± 0.32^{fE}	90.96 ± 0.31^{fF}	83.64 ± 0.18^{fG}
QAH_1	113.16 ± 0.26^{aA}	112.09 ± 0.31^{aB}	110.93 ± 0.33^{aC}	109.01 ± 0.22^{aD}	106.17 ± 0.25^{aE}	103.85 ± 0.18^{aF}	101.09 ± 0.14^{aG}
QAH_2	112.94 ± 0.32^{aA}	111.73 ± 0.22^{bB}	110.43 ± 0.25^{bC}	108.12 ± 0.33^{bD}	105.69 ± 0.27^{bE}	103.59 ± 0.24^{bF}	100.64 ± 0.20^{bG}
QAH_3	112.82 ± 0.25^{aA}	111.39 ± 0.28^{cB}	109.60 ± 0.24^{cC}	107.23 ± 0.20^{cD}	104.63 ± 0.24^{cE}	101.13 ± 0.24^{cF}	97.19 ± 0.17^{cG}
QAH_4	112.78 ± 0.26^{aA}	111.62 ± 0.32^{cB}	109.42 ± 0.28^{cC}	107.10 ± 0.28^{cD}	103.87 ± 0.26^{dE}	100.43 ± 0.31^{dF}	94.30 ± 0.14^{dG}
QAH_5	112.51 ± 0.24^{aA}	110.20 ± 0.27^{dB}	107.47 ± 0.29^{dC}	104.42 ± 0.27^{dD}	100.30 ± 0.32^{eE}	95.24 ± 0.27^{eF}	92.58 ± 0.18^{eG}
DPPH radical scavenging activity							
CONTROL	63.71 ± 0.29^{bA}	61.53 ± 0.29^{aB}	58.41 ± 0.27^{eC}	54.49 ± 0.25^{dD}	49.32 ± 0.24^{dE}	47.18 ± 0.24^{fE}	44.16 ± 0.24^{fG}
QAH_1	64.83 ± 0.31^{aA}	63.67 ± 0.29^{aB}	62.46 ± 0.30^{aC}	60.11 ± 0.27^{aD}	57.57 ± 0.25^{aE}	56.32 ± 0.24^{aF}	55.04 ± 0.21^{aG}
QAH_2	64.56 ± 0.31^{aA}	63.33 ± 0.30^{aB}	62.16 ± 0.30^{bC}	60.04 ± 0.29^{aD}	57.43 ± 0.27^{aE}	54.25 ± 0.26^{bF}	52.20 ± 0.25^{bG}
QAH_3	64.32 ± 0.30^{aA}	63.03 ± 0.29^{aB}	61.71 ± 0.28^{cC}	59.24 ± 0.26^{bD}	56.30 ± 0.26^{bE}	53.16 ± 0.25^{cF}	51.42 ± 0.27^{cG}
QAH_4	64.20 ± 0.29^{aA}	62.88 ± 0.28^{aB}	61.56 ± 0.27^{cC}	59.15 ± 0.25^{bD}	56.12 ± 0.24^{bE}	52.74 ± 0.25^{dF}	49.38 ± 0.24^{dG}
QAH_5	64.14 ± 0.30^{aA}	61.82 ± 0.27^{aB}	59.37 ± 0.26^{dC}	56.23 ± 0.24^{cD}	52.13 ± 0.21^{cE}	51.62 ± 0.19^{eF}	48.10 ± 0.23^{eG}

[a] All values are mean ± standard deviation of three replicates. Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). Means with different uppercase superscripts in the same row (storage months) indicate significant differences ($p < 0.05$).

slows down enzymatic activities responsible for the degradation of phenolic compounds. Consequently, the rate of decrease in total phenolic content is mitigated in coated samples compared to uncoated ones.[34] Kozlu and Elmaci[21] observed the preventive effect of QSM edible coating on the loss of total phenolic content. Alginate coating delayed the physiological ripening process and preserved phenolic compounds during the overall storage period, as reported by Díaz-Mula *et al.*[32] Plesoianu and Nour[35] showed the effectiveness of edible coatings in maintaining total phenolic content in fresh-cut pears.

3.9 DPPH radical scavenging

Percentage inhibition of the activity of DPPH radicals, which is an indicator of antioxidant activity, decreased in all samples coated with QSM-alginate-containing vanillin hydrogels during the storage period of 180 days. However, it is clear from Table 4 that the antioxidant activity of the coated samples was significantly ($p \leq 0.05$) higher than that of the control, which may be attributed to the presence of different phenolic compounds in plant-derived polymers. The fall in antioxidant activity can be attributed to the degradation of antioxidant substances like polyphenols and ascorbic acid. The lowest decrease in DPPH radical scavenging activity was recorded in treatment QAH_1 (64.83 to 55.04%) and the highest decrease in treatment QAH_5 (64.14 to 48.10%), but all the treated samples showed better antioxidant activity than the control sample (44.16%). QSM edible coating was determined to be effective in preventing the loss of antioxidant activity in fruit samples.[21] The results of our study are in agreement with the results reported by Takma & Korel,[28] who explained that alginate coating incorporated with vanillin retains antioxidant activity in grapes during storage.

3.10 Microbiological assessment

Microbiological growth is one of the important causes of food spoilage during postharvest handling and storage of fruits. Results in Table 5 show that total bacterial count significantly ($p \leq 0.05$) increased in the control apple sample compared to the coated apples. The control sample showed a bacterial count of 6.04 $\log_{10}$ cfu g^{-1} after 180 days of storage while all the treated samples showed significantly ($p \leq 0.05$) lesser bacterial counts. Lowest bacterial count of 4.72 $\log_{10}$ cfu g^{-1} was observed in apples coated with QAH_1 mucilage.

There was an increase in yeast and mold count of the control sample during storage, which increased to 7.93 from 1.51 $\log_{10}$ cfu g^{-1}. However, a lower increase in yeast and mold count was observed in coated samples and the lowest count (5.96 $\log_{10}$ cfu g^{-1}) was recorded in treatment QAH_1 on the 180th day of storage. Vanillin present in the coatings possesses antifungal properties and inhibits the growth of yeasts and molds. Mucilage obtained from various sources like chia seed, cress seed, okra seed, and quince seed have antifungal and antibacterial properties that prevent food spoilage and minimise the risk of food-borne diseases when used as coatings over the fruits.[36] Jouki *et al.*[37] found a lower total viable count in QSM-wrapped rainbow trout fillet samples during storage time as compared to control. At the same time, edible coatings serve as carriers for antimicrobial agents. QSM-alginate coatings containing vanillin exhibit antibacterial properties as these can bind to the membranes of bacteria and subsequently damage the nucleus, DNA protein, cell membrane and mitochondria. The antibacterial activity of QSM films incorporated with thyme essential oil against Gram-positive and Gram-negative bacteria has been reported by Jouki *et al.*[37]

3.11 Overall acceptability

Although coatings with active agents are helpful for the prevention of biochemical and microbial spoilage of fruits, the impact on sensory quality should be considered. The results in Table 5 show that, regardless of the treatments, overall acceptability (OA) scores decreased significantly ($P \leq 0.05$) during the entire storage. Panelists gave significantly ($p \leq 0.05$) higher overall acceptability scores to coated apples than control.

Table 5 Effect of QSM-alginate coatings on microbial assessment (log_{10} cfu g^{-1}) and overall acceptability scores of apples[a]

	0 day	30 days	60 days	90 days	120 days	150 days	180 days
Total viable bacteria (log_{10} cfu g^{-1})							
CONTROL	1.35 ± 0.15^{aG}	2.71 ± 0.09^{aF}	3.23 ± 0.08^{aE}	4.64 ± 0.10^{aD}	5.12 ± 0.09^{aC}	5.59 ± 0.14^{aB}	6.04 ± 0.11^{aA}
QAH_1	1.09 ± 0.11^{aG}	2.31 ± 0.05^{bF}	2.69 ± 0.12^{cE}	3.89 ± 0.13^{cD}	4.26 ± 0.07^{dC}	$4.45 \pm 0.08c^{B}$	4.72 ± 0.12^{cA}
QAH_2	1.11 ± 0.10^{aF}	2.51 ± 0.11^{aE}	2.79 ± 0.10^{cD}	4.25 ± 0.13^{bC}	4.46 ± 0.06^{cB}	4.68 ± 0.11^{bA}	4.84 ± 0.12^{cA}
QAH_3	1.15 ± 0.09^{aE}	2.54 ± 0.08^{aD}	2.86 ± 0.11^{cC}	4.28 ± 0.11^{bB}	4.64 ± 0.10^{bA}	4.76 ± 0.15^{bA}	4.88 ± 0.17^{cA}
QAH_4	1.26 ± 0.09^{aF}	2.62 ± 0.07^{aE}	2.88 ± 0.08^{cD}	4.34 ± 0.11^{bC}	4.72 ± 0.15^{bB}	4.85 ± 0.14^{bB}	5.18 ± 0.11^{bA}
QAH_5	1.34 ± 0.10^{aF}	2.67 ± 0.08^{aE}	3.09 ± 0.05^{bD}	4.41 ± 0.13^{bC}	4.82 ± 0.13^{bB}	4.89 ± 0.12^{bB}	5.38 ± 0.11^{bA}
Yeast and mould count (log_{10} cfu g^{-1})							
CONTROL	1.51 ± 0.07^{aG}	2.85 ± 0.05^{aF}	4.44 ± 0.07^{aE}	5.98 ± 0.08^{aD}	6.88 ± 0.09^{aC}	7.38 ± 0.09^{aB}	7.93 ± 0.10^{aA}
QAH_1	1.30 ± 0.05^{bG}	2.45 ± 0.07^{dF}	3.83 ± 0.09^{cE}	4.23 ± 0.05^{dD}	5.49 ± 0.10^{dC}	5.76 ± 0.09^{dB}	5.96 ± 0.10^{dA}
QAH_2	1.32 ± 0.06^{bG}	2.59 ± 0.03^{cF}	3.91 ± 0.06^{cE}	4.44 ± 0.09^{cD}	5.79 ± 0.09^{cC}	6.23 ± 0.09^{cB}	6.65 ± 0.07^{cA}
QAH_3	1.34 ± 0.06^{bG}	2.68 ± 0.04^{bF}	3.96 ± 0.06^{cE}	4.55 ± 0.07^{cD}	5.86 ± 0.10^{cC}	6.54 ± 0.15^{bB}	6.82 ± 0.08^{bA}
QAH_4	1.34 ± 0.05^{bG}	2.70 ± 0.05^{bF}	3.98 ± 0.07^{cE}	4.58 ± 0.06^{cD}	5.92 ± 0.10^{cC}	6.66 ± 0.09^{bB}	6.86 ± 0.08^{bA}
QAH_5	1.36 ± 0.05^{bF}	2.80 ± 0.04^{aE}	4.12 ± 0.07^{bD}	4.73 ± 0.07^{bC}	6.26 ± 0.08^{bB}	6.76 ± 0.09^{bA}	6.91 ± 0.10^{bA}
Sensory evaluation (overall acceptability)							
CONTROL	8.2 ± 0.15^{cA}	7.4 ± 0.17^{dB}	6.7 ± 0.15^{dC}	6.2 ± 0.16^{dD}	4.8 ± 0.16^{eE}	4.3 ± 0.13^{eF}	3.8 ± 0.15^{eG}
QAH_1	8.7 ± 0.14^{aA}	8.4 ± 0.18^{aB}	8.1 ± 0.17^{aC}	7.8 ± 0.16^{aD}	7.1 ± 0.16^{aE}	6.6 ± 0.15^{aF}	6.1 ± 0.13^{aG}
QAH_2	8.6 ± 0.14^{aA}	8.1 ± 0.17^{bB}	7.6 ± 0.15^{bC}	6.9 ± 0.13^{bD}	6.5 ± 0.15^{bE}	5.8 ± 0.14^{bF}	5.4 ± 0.14^{bG}
QAH_3	8.3 ± 0.15^{bA}	7.9 ± 0.15^{cB}	7.2 ± 0.16^{cC}	6.5 ± 0.15^{cD}	5.9 ± 0.14^{cE}	5.5 ± 0.14^{cF}	5.0 ± 0.15^{cG}
QAH_4	8.3 ± 0.14^{bA}	7.8 ± 0.15^{cB}	6.7 ± 0.18^{dC}	5.5 ± 0.16^{eD}	5.2 ± 0.18^{dE}	4.8 ± 0.12^{dE}	4.4 ± 0.12^{dF}
QAH_5	8.3 ± 0.15^{bA}	7.8 ± 0.17^{cB}	6.7 ± 0.16^{dC}	5.3 ± 0.14^{eD}	5.2 ± 0.15^{dD}	4.7 ± 0.13^{dE}	3.9 ± 0.12^{eF}

[a] All values are mean ± standard deviation of three replicates. Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). Means with different uppercase superscripts in the same row (storage months) indicate significant differences ($p < 0.05$).

Among the samples, QAH_1 (6.1) showed the best results for overall acceptability after 180 days of storage. The higher scores indicate that the QSM/alginate coating has properties like preventing dehydration, oxidative rancidity and surface browning. Data from the sensory analysis was well correlated with the objective evaluation of firmness, weight loss, TA, instrumental color and other parameters. The decrease in the flavor of the apple during storage may be essentially related to a decrease in fructose content observed during the storage. The coatings establish a barrier against moisture and gases, thereby minimizing excessive degradation in biological substances and changes in physicochemical properties such as soluble solids, organic acids and pigments. Vanillin significantly inhibits the growth of postharvest pathogenic fungi, which contributes to improvement in fruit quality.[23] Similarly, QSM coating has been reported to preserve characteristics such as appearance, texture and taste in mandarin fruit.[21] The sensory attributes of the strawberry samples coated with OM-GSM gels were significantly higher than the uncoated group.[25]

Quince seed mucilage (QSM) demonstrates competitive advantages when compared to other commonly used coatings for fresh produce. Research indicates that QSM exhibits effective preservation capabilities, including a reduction in weight loss, maintenance of firmness, and delay of senescence, which are comparable to or better than traditional coatings such as synthetic waxes and petroleum-based films.[1,2] Furthermore, QSM is a natural and biodegradable material sourced from quince seeds, aligning with sustainable practices and consumer preferences for eco-friendly products. In terms of cost-effectiveness, QSM may offer economic benefits due to its potential availability as a by-product of quince processing, contrasting with the higher costs associated with synthetic formulations.[38] Overall, QSM emerges as a promising alternative in the landscape of fruit coatings, combining effective preservation capabilities with sustainability and potential cost-effectiveness. The QSM coatings retain a better quality of apples/fresh produce, which will fetch better prices in the market thereby increasing income of growers.

4. Conclusion

Quince seeds contain significant amounts of mucilage, which has not been fully explored for industrial and food applications. Quince seed mucilage was explored as edible coating in combination with sodium alginate while vanillin was added as an antimicrobial agent. The results of the current investigation showed that apples coated with QSM-alginate-based hydrogels significantly suppressed changes in weight loss, firmness, decay, color characteristics, titratable acidity and total soluble solids. This work reported the efficacy of QSM edible coating in maintaining the total phenolic content and antioxidant activity of coated apples compared to control during refrigerated storage. The study concluded that the use of QSM-alginate-based coatings successfully preserved the postharvest quality of apples up to 180 days under refrigerated storage conditions. Future research could explore the long-term effects of quince seed mucilage (QSM) coatings on different apple varieties and under varied storage conditions to enhance their understanding and application in food preservation. Additionally, investigating the efficacy of QSM coatings for other fruit and

vegetable crops under different storage conditions would provide insights into optimizing its preservation capabilities across diverse kinds of food commodities.

Data availability

Data will be made available on request.

Conflicts of interest

There are no conflicts to declare.

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