

Edible chitosan in preserving the quality and shelf life of fresh-cut mango (*Mangifera indica* L.)

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Abstract: Mango (*Mangifera indica*) is extremely perishable with a short shelf life that limits its marketability. Chitosan may extend mango storage by preventing moisture loss and gaseous exchange while preserving the nutritional quality. Therefore, the current study was designed to assess the effect of chitosan on the shelf life and quality of fresh-cut mangoes. Manually cubed mango was dipped into 0 (control), 10, 15, 20, 30, and 50 ppm chitosan solution in airtight jar and stored at ambient (25–28 °C) and refrigeration (4 °C) condition. Changes in various microbial, physical, and chemical characteristics were documented to evaluate the effectiveness of treatments in prolonging and sustaining the freshness and quality of mango. Treated mangoes significantly retarded growth of total mold and bacterial counts compared to the control sample in both storage conditions and found it lower under refrigeration. Likewise, chitosan also preserved various fruit quality attributes to a significant extent by retaining vitamin C, fat, titratable acidity, soluble sugar, and protein. However, the refrigerator stored mangoes have better ability to retard moisture loss and drop in sensory quality. Among the other solutions, 10 ppm chitosan solution exhibited better performance in reducing perishability of mango while maintaining prolonged shelf life and quality attributes. Overall, the findings revealed that chitosan solution at low temperature effectively preserves mango quality during storage and offers promising approach for the successful commercialisation of chitosan as a natural preserver for mango sellers and consumers to prolong shelf life.

Keywords: edible-coating; fresh-cut fruit; hormone; ambient condition; temperature

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Mango (*Mangifera indica* L.) is known to be one of the most commercially important tropical fruits in Asia and is contemplated as the king of all fruits (Tharanathan et al. 2006). It has been cultivated for over 4 000 years within a large area of Southeast Asia and eventually distributed to other parts of the world in the near fourteenth century for its excellent flavour and other health properties (Wang et al. 2020). Bangladesh ranked 9th among the major markets in the world mango industry in 2022, producing around 1.2 million tons of mango in 121×10^3 ha of land (BBS 2022; Report Linker 2023). Bangladesh earned only USD 31.9 thousand by exporting 1 136 tons of mango which is low compared to other mango-producing countries (FAOSTAT 2022). The worldwide increasing trend of using mango in the beverage industry, processing, and confectionery items is driving demand for the global mango market. However, being a 'climacteric fruit', mango suffers from 25–45% losses each year due to postharvest decay (Parvin et al. 2023). At ambient temperature, mango ripens rapidly, leading to discolouration, spongy tissue, softening, and off flavour. Additionally, the commercialisation phase of mango is mainly prone to fungal contamination that causes rot during storage and transport. Thus, it becomes more difficult to store the fresh-cut mango in the store as it is more perishable than the intact fruit.

In recent years, income growth and the work patterns of families have influenced their purchasing and consumption habits (Eldesouky and Mesias 2014). The changes in family lifestyles cause a greater demand for minimally processed food, which in turn increases the development and use of food additives of both artificial and natural origin. Food preservatives make it possible to have a variety of foods in the form of ready to cook or ready to eat foods without the stress of cutting and cooking different cuisines in a diurnal pattern. In addition, it helps the food industry provide food on the market in a timely manner to fulfill the requirements of consumers (Carocho et al. 2015). Mango is one of the most popular fresh-cut fruits on the market, and research showed that fresh-cut mango had a 3.3% increase in dollar velocity during the first half of 2020 (USDA 2023). However, the fresh-cut mangoes have a short shelf life of up to 7 days as the processing of the product triggers enzymatic browning and black stains, off flavour, physical integrity breakdown, alteration in organic acid and soluble solid content, development of spoilage microorganisms, production of ethylene, and accumulation of ethanol and acetaldehyde (Treviño-Garza et al. 2019).

Fruit industries prefer chemical additives rather than natural preservation for commercialisation as they are most effective in contributing to fruit's prolonged shelf life by icing product thickness, delaying pathogenic growth, inhibiting the reaction with oxygen or heat, and reducing postharvest loss (Sharma 2015). The most common chemicals used to preserve are calcium propionate, sodium nitrate, sodium benzoate, sodium nitrite, sulfites, and disodium, however, extensive use of these chemicals causes health hazards such as cardiovascular diseases, asthma, cancer, bronchospasm, and neurotoxicity (García-García and Searle 2016). Moreover, the use of chemicals in food is increasingly rejected by consumers and governments, which is further strengthened by the health scandals all around the world (Mesías et al. 2021). Therefore, the use of natural substances to preserve fruits is warranted, and there is certainly an increasing trend toward using more natural and less processed food among consumers. Considering this scenario, there is an urgent need to explore alternatives to generate natural substances for consumers that can be used to preserve fruits for an extended period while preserving quality. Chitosan is one of the very promising edible biocompatible polymers can be used for fruit preservation. It is safe, effective, and accepted since it could prevent aroma and moisture loss, inhibit microbial growth and oxygen penetration to the plant tissue, and leave no residue in fruits (Jianglian 2013).

Chitosan is a well-studied nontoxic polymer derived from chitin, and its use in food science is justified by its physicochemical and biological properties. The antimicrobial, antioxidant, non-toxic, emulsifying, and film forming attributes make chitosan an excellent additive that can improve the nutritional, hygienic, and sensory quality of fruits and vegetables (Tamer and Copur 2010). Chitosan has been successfully used alone or in combination to prolong the shelf life of fresh-cut fruits and vegetables such as tomato, cucumber, pineapple, cantaloupe, apple, papaya, and melon (González-Aguilar et al. 2008; Sangsuwan et al. 2008; Parvin et al. 2018; Speranza et al. 2018; Olawuyi et al. 2019). Moreover, the degradation process of fresh-cut fruits is also influenced by temperature and humidity, which can increase the natural senescence mechanism and stress (Wills et al. 1981). Therefore, it could be helpful to modify storage temperature during different marketing levels to slow down the metabolic rate related to quality and shelf life degradation.

However, so far, there is no report of using chitosan solution dipping in jar to prolong the shelf life of fresh-cut mango to reduce the substantial economic loss caused by rapid development of microbes. Moreover, few works have been reported regarding the role of chitosan solution and temperature on the biochemical functions in mango. Keeping this in mind, the recent study was intended to investigate the shelf life and quality attributes of fresh-cut mango to identify the probable aspect of introducing an optimum temperature and chitosan dipping solution as a package of practices for a better marketing strategy.

MATERIAL AND METHODS

Plant material. Matured mango fruits (*Mangifera indica* L. cv. Langra) of around 100–120 days old were directly harvested from a local mango orchard located in Rajshahi district, Bangladesh, and immediately brought to the Institute of Radiation and Polymer Technology (IRPT) laboratory, Bangladesh Atomic Energy Commission, Savar, Dhaka, Bangladesh. As an experimental mango variety, we selected Langra because it has gained popularity in the international market for its delicious fruity sweet taste and size, which makes it very suitable for slicing and canning. Mangoes were standardised based on the uniformity of ripeness, colour, size, shape, and absence of injuries, defects, and microbial infection.

Preparation of chitosan solution. Prawn shells were collected from the local fish market. The deacetylation process described by Rashid et al. (2012) was used to extract chitosan from prawn shell waste in the laboratory. A dose of 3.2 kGy per hour generated from a 120 k Curie radiation source was used to achieve high molecular weight chitosan solution [molecular weight = $83 K_D$ (K_D – equilibrium dissociation constant), viscosity less than 200 mPa·s, deacetylation degree 82.7%, 2% acetic acid in 55 °C]. Based on initial observational test on the colour, weight loss, texture and smell of mango samples, we selected 40 kGy within different doses of gamma irradiation to prepare 1 L of 20 000 ppm chitosan solution (20 g chitosan was dissolved in 2% acetic acid solution). Required quantity of 20 000 ppm chitosan solution was taken to prepare 10, 15, 20, 30, and 50 ppm chitosan solution respectively. All the chemicals used in the research were laboratory grade.

Treatments and sample preparation. The experimental design and preservation procedure are depicted in Figure 1. Briefly, the selected mangoes were washed with 70% ethanol followed by sterilised dis-

tilled water, peeled, and cut into cubes with sharp and sterilised knife inside the incubator with a controlled laminar flow. The samples were packed inside the incubator in a sterilised airtight jar containing different irradiated chitosan solution of 0, 10, 15, 20, 30, and 50 ppm, respectively. The control samples were also stored in a sterilised jar with sterilised distilled water. All the prepared samples were stored at ambient (25–28 °C) and refrigeration (4 °C) temperatures, respectively, and 70% to 85% of relative humidity were maintained during the entire storage period. The biochemical analysis of chitosan treated and untreated samples for all conditions were done after 6 months of storage periods. All experiments were performed in three replications.

Total bacteria count and total mold count determination. To estimate the total bacterial count (TBC), plate count agar (PCA) media was used, while total mold count (TMC) was estimated using potato dextrose agar (PDA) media. In this regard, 1 g of fruit sample was mixed with 10 mL of saline water. After that, 10 µL of prepared sample was spread on PCA and PDA plates. The plates were incubated for 24 h at 37 °C and 25 °C, respectively. Lastly, the colony forming units (CFU·g⁻¹) were counted with three replications.

Determination of titratable acidity. To determine the titratable acidity (TA), approximately 5 g of homogenised and filtered mango pulp was dissolved in 40 mL of distilled water and filtered the solution with the help of cotton wool. After that, 5 mL filtrate was titrated against 0.1 N NaOH using 1% phenolphthalein solution as an indicator (Ranganna 1986). The presence of a pink colour signaled the endpoint of the titration reaction (pH = 8.1). The results were stated as the percentage of citric acid (%) per 100 mL of juice (Silva et al. 2018; Shah and Hashmi 2020).

Determination of ash content. The total ash content was determined using the AOAC (Association of Official Analytical Chemists) method (AOAC 1975). For this, 2.0 g of mango pulp was computed and transferred into a clean and dry crucible. After that, the crucible was kept in a muffle furnace at 550 °C for 6 h, cooled in a desiccator, and weighed.

The ash content was calculated using the following formula:

$$\text{Ash (\%)} = \frac{W_A}{W_S} \times 100 \quad (1)$$

where: W_A – weight of ash (g); W_S – weight of sample (g).

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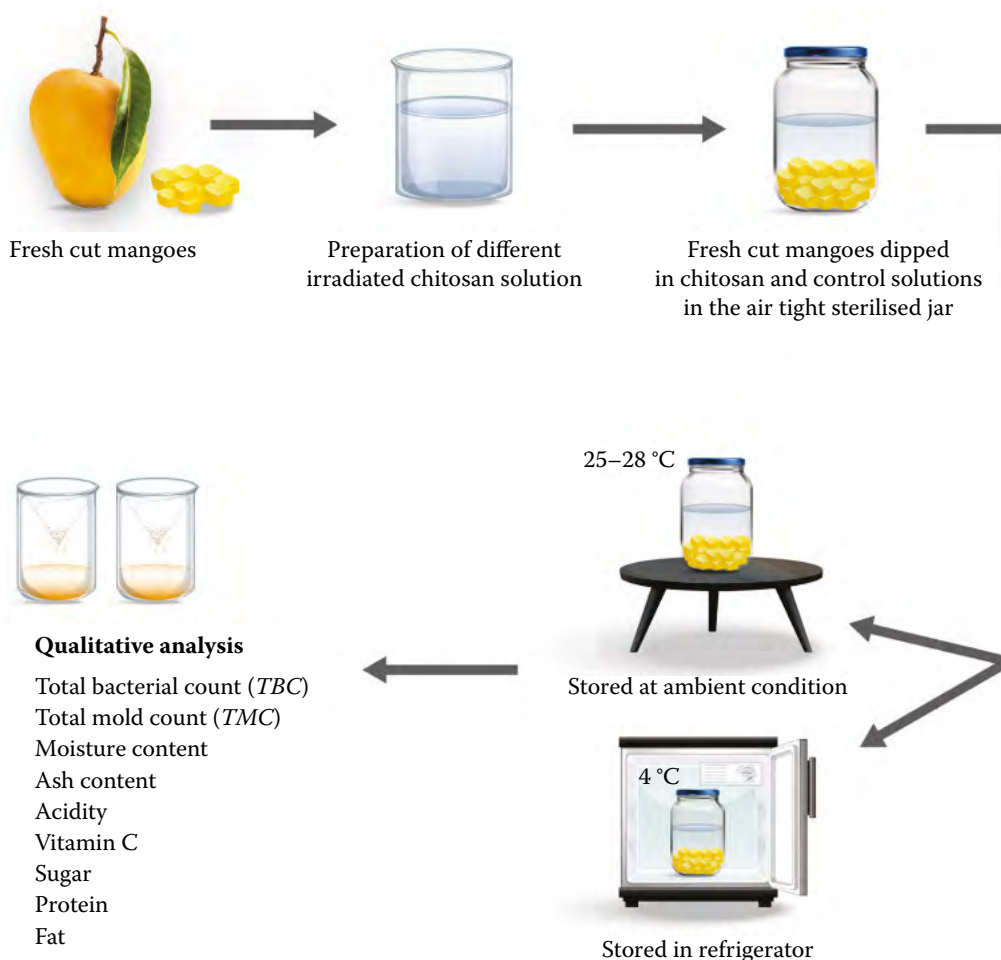


Figure 1. Schematic diagram of the experimental procedure

Total fat content. Fat content was estimated using the Soxhlet method described by AOAC (1997). The dried sample was placed into a thimble, and 70 mL of anhydrous ether was poured into the extraction tube. Fat was extracted from samples using the Soxtec system HT6, and the extraction cups were dried in the oven and cooled. The percent of fat was expressed as follows:

$$Fat (\%) = \frac{W_b - W_a}{W_s} \times 100 \quad (2)$$

where: W_b – weight of extraction tube before drying (g); W_a – weight of extraction tube after drying (g); W_s – weight of the dried sample (g).

Moisture content. Moisture content was determined by the oven dry using AOAC method (AOAC 1980). The fruit sample was dried at 105 °C overnight and transferred to desiccators to cool.

The moisture content was calculated by the difference in weight before and after drying using the following equation:

$$Moisture (\%) = \frac{W_i - W_f}{W_i} \times 100 \quad (3)$$

where: W_i – initial weight of the sample (g); W_f – final weight of the sample (g).

Determination of total protein content. The protein content of mango pulp was determined using the AOAC method (AOAC 1997) with some modifications. The following formulas were used for the calculation of nitrogen (N) and protein content:

$$N (\%) = B \times NA \times N_{meq} \quad (4)$$

where: B – burette reading; NA – normality of H_2SO_4 ; N_{meq} – mL equivalent of nitrogen (N).

The normality of $\text{H}_2\text{SO}_4 = 0.2$ and the mL equivalent of $\text{N} = 1.4$. The following equation was used to calculate protein content:

$$\text{Protein (\%)} = \text{N (\%)} \times 5.5 \quad (5)$$

where: 5.5 – protein factor.

Determination of sugar content. The total soluble sugars of mango pulp were calculated using the approach described by DuBois et al. (1956). Nearly 0.5 g of filtered mango pulp was mixed with 10 mL of 80% ethanol following centrifugation for 20 min. Then, the extraction solution was prepared by adding 1 mL of supernatant to the prepared 1 mL (5%) phenol solution. Following this, 5 mL of 95.5% H_2SO_4 was added and permitted to stand for 10 min before vortexing for 30 s. After that, the test tubes were kept in a water bath for colour development at ambient temperature for 20 min. In the end, with the help of a spectrophotometer (UV 1800 Shaanxi; China) the absorbance was documented at 490 nm, and the results were stated in $\mu\text{g}\cdot\text{g}^{-1}$ of the fresh weight of the mango pulp sample.

Determination of vitamin C content. The titrimetric method (Varley 2002) was used to determine the vitamin C concentration in fruit samples. The end point of titration was determined by using 2,6-dichlorophenol indophenol. The following formula was used for vitamin C content determination:

$$\text{Vit-C} = \frac{T \times DF \times V_u}{V_s} \quad (6)$$

where: Vit-C – vitamin C (mg of vitamin C per 100 g); T – titrate; DF – dye factor; V_u – volume; V_s – aliquot of extract taken of estimation (w/v) of sample.

Sensory evaluation. Generally, organoleptic tests of the cubed Langra mango depend on the first appearance, colour, texture, taste, and flavour of the samples. Sensory evaluation was carried out using 15 semi-trained and trained panelists four times: at 1-month, 2-month, 4-month, and 6-months after storage. The samples were given specific codes to distinguish between different chitosan-treated and untreated samples stored at different temperatures. For statistical analysis of sensory data, a 9-point hedonic rating test (9 = extremely like, 8 = much like, 7 = moderately like, 6 = slightly like, 5 = neither like nor dislike, 4 = slightly dislike, 3 = moderately dislike, 2 = much dislike, 1 = extremely dislike) was performed to assess the degree

of acceptability of chopped mangoes (Peryam and Pilgrim 1957).

Statistical analysis. The experiment was performed in a completely randomised design (CRD) with three replications with a two-factorial interaction. The first factor corresponded to different concentrations of chitosan solution, i.e. 0 (control), 10, 15, 20, 30, and 50 ppm. The second factor corresponded to two levels of storage conditions, i.e. ambient temperature (25–28 °C) and refrigeration (4 °C) temperature. The data analyses were performed using the statistical package 'R' (R Core Team 2022). All data were subjected to a two-way ANOVA (analysis of variance). The averages of treatment means were compared by a two way ANOVA followed by Tukey's post hoc test ($P = 0.05$).

RESULTS AND DISCUSSION

Microbiological changes

Cubed mangoes dipped in chitosan and control solution stored in ambient and refrigeration temperature were evaluated to estimate the microbial changes (TBC and TMC) after 6 months of storage period (Figures 2 and 3).

Total bacteria count. The amount of total bacteria count (TBC) was significantly ($P < 0.05$) decreased for chitosan-treated mangoes compared to the controls for both storage (ambient and refrigeration) environments (Figure 2). The incidence of TBC was recorded in terms of chitosan treatment and storage interaction, the amount of TBC on chitosan-treated mangoes stored at ambient temperature ranged from $1.87 \times 10^2 \text{ CFU}\cdot\text{g}^{-1}$ to $8.53 \times 10^2 \text{ CFU}\cdot\text{g}^{-1}$, which was comparatively higher than the samples kept at refrigeration temperature, varying from $1.0 \times 10^2 \text{ CFU}\cdot\text{g}^{-1}$ to $1.9 \times 10^2 \text{ CFU}\cdot\text{g}^{-1}$ (Figure 2). The lowest ($1 \times 10^2 \text{ CFU}\cdot\text{g}^{-1}$) amounts of TBC were recorded for 10 ppm chitosan solution, which was significantly different from 20 ppm and 30 ppm chitosan solution dipped mangoes stored at refrigerator temperature. Fresh-cut fruits treated with chitosan formulations were known to inhibit the incidence of storage bacterial diseases. Being a polycationic long chain molecule, chitosan can easily adhere to gram-positive bacterial members and cause cell lysis through electrostatic interaction (Duan et al. 2019). Moreover, low temperatures also inhibit bacterial growth and proliferation due to the decreased efficiency of transport proteins embedded in the membrane (Nedwell 1999). The reduction in the growth of bacterial count treated with chitosan is in agreement with previous studies observed by Amin et al. (2021) and Parvin et al. (2023).

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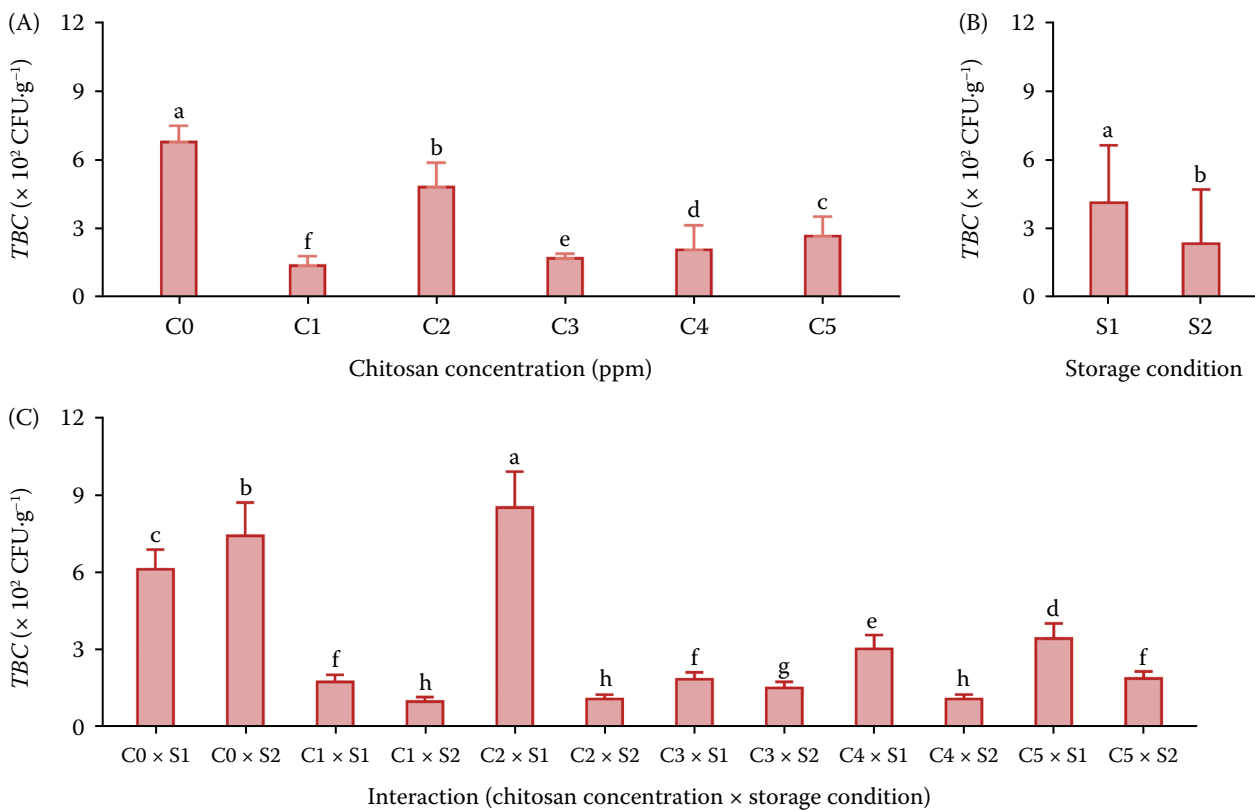


Figure 2. Effect of (A) chitosan treatment, (B) storage condition, and (C) their interaction on total bacterial counts (TBC) of cut mango

a–h – means with the same letters are not statistically different from each other as per Tukey's post hoc test ($P = 0.05$); C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; CFU – colony forming unit; S1 – ambient temperature; S2 – refrigeration

Total mold count. Like TBC, chitosan-treated mangoes had a significantly lower total mold count (TMC) than control samples under all storage conditions (Figure 3). In the case of chitosan dipped mangoes, the lowest ($1.34 \times 10^3 \text{ CFU} \cdot \text{g}^{-1}$) TMC was recorded in 15 ppm chitosan solution treatment. The occurrence of TMC ($4.13 \times 10^3 \text{ CFU} \cdot \text{g}^{-1}$) was higher in ambient temperature than the refrigeration temperature storage conditions. Similar trends were also observed in the case of chitosan and storage interaction. The lowest ($1.1 \times 10^3 \text{ CFU} \cdot \text{g}^{-1}$) TMC was found in 30 ppm chitosan-dipped mangoes, which was statistically identical to 10 ppm solution-treated mangoes stored at refrigerator temperature. The degree of pathogenicity of most of the postharvest pathogens were effectively inhibited below 5°C (Erkmen 2016), hence, we observed the lowest incidence of TMC growth when mangoes were stored in refrigeration conditions. The study results indicated that chitosan is effective in reducing TMC growth in fresh-cut mangoes. Chitosan disrupts the germination and hyphal morphol-

ogy of a wide range of post-harvest fungi and prolongs the shelf life of fruits by maintaining quality (Lopez-Moya et al. 2019). Chitosan also alters gene expression in fungi and stimulates cell death by triggering intracellular production of reactive oxygen species.

Nutritional changes

Chitosan-dipped and control fruits stored at ambient and refrigeration temperatures were subjected to biochemical analyses to determine the nutritional changes. Two way ANOVA results of the main effects of chitosan treatments and storage conditions, along with the interaction effects of storage conditions and chitosan treatments on titratable acidity, ash, fat, moisture, protein, sugar, and vitamin C content, were presented in Table 1 and Figure 4.

Titratable acidity. Titratable acidity (TA) in fruits is very important, as the amount of acid influences shelf life, texture, taste, and integrity. The level of acidity indicates the level of fruit ripeness. The titratable acidity values in chitosan-dipped fruits were found

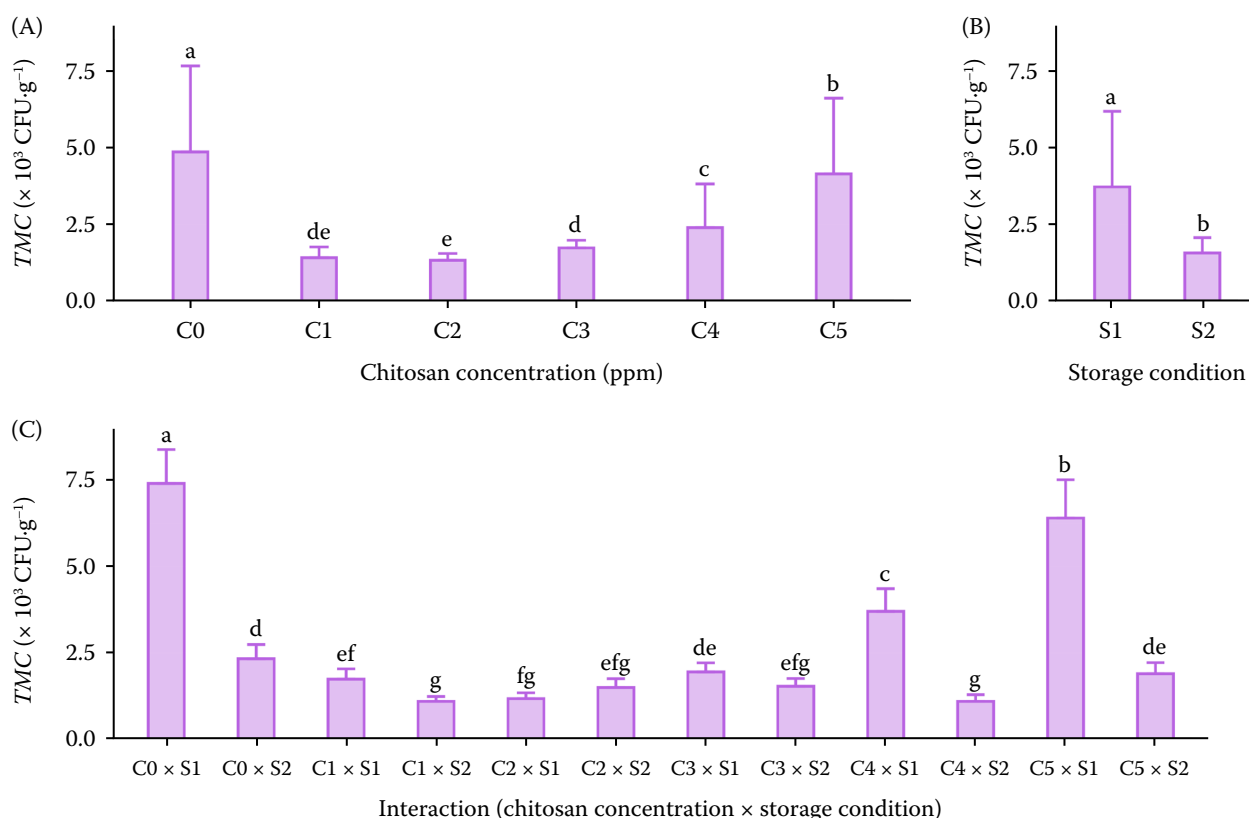


Figure 3. Effect of (A) chitosan treatment, (B) storage condition, and (C) their interaction on total mold counts (TMC) of cut mango

a–g – means with the same letters are not statistically different from each other as per Tukey's post hoc test ($P = 0.05$); C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; CFU – colony forming unit; S1 – ambient temperature; S2 – refrigeration

Table 1. Titratable acidity, ash, fat, moisture, protein, sugar, and vitamin C (Vit-C) content of chitosan-treated and untreated *Langra mango* stored at ambient temperature or refrigeration temperature

Treatment	TA (%)	Ash (%)	Fat (%)	Moisture (%)	Protein (%)	Sugar (%)	Vit-C (%)
Chitosan concentration							
C0	0.33 ± 0.08 ^b	0.37 ± 0.08 ^b	1.29 ± 0.16 ^a	91.97 ± 0.50	2.36 ± 0.39 ^a	15.42 ± 2.30 ^a	1.46 ± 0.22 ^b
C1	0.55 ± 0.04 ^a	0.44 ± 0.13 ^b	1.09 ± 0.08 ^a	93.42 ± 1.26	2.71 ± 0.39 ^a	9.58 ± 2.44 ^b	1.72 ± 0.33 ^{ab}
C2	0.48 ± 0.08 ^a	0.40 ± 0.02 ^b	1.12 ± 0.09 ^a	93.92 ± 1.64	3.29 ± 1.08 ^a	11.21 ± 2.36 ^b	2.20 ± 0.71 ^a
C3	0.36 ± 0.05 ^b	0.40 ± 0.01 ^b	1.13 ± 0.08 ^a	94.56 ± 0.56	2.75 ± 0.53 ^a	11.46 ± 2.21 ^{ab}	1.65 ± 0.17 ^{ab}
C4	0.36 ± 0.05 ^b	0.40 ± 0.08 ^b	1.24 ± 0.19 ^a	92.36 ± 4.18	3.06 ± 0.49 ^a	12.31 ± 2.43 ^{ab}	1.61 ± 0.21 ^{ab}
C5	0.33 ± 0.05 ^b	1.03 ± 1.55 ^a	1.24 ± 0.18 ^a	93.19 ± 0.85	3.23 ± 0.39 ^a	11.84 ± 1.99 ^{ab}	1.58 ± 0.24 ^{ab}
CV (%)	15.09	126.51	11.70	2.10	20.58	19.16	21.21
Storage temperature							
S1	0.42 ± 0.05 ^a	0.60 ± 0.90 ^a	1.30 ± 0.13 ^a	94.28 ± 0.99 ^a	3.40 ± 0.50 ^a	13.96 ± 1.88 ^a	1.44 ± 0.12 ^b
S2	0.39 ± 0.13 ^b	0.41 ± 0.06 ^b	1.07 ± 0.05 ^b	92.20 ± 2.27 ^b	2.41 ± 0.29 ^b	9.98 ± 1.97 ^b	1.98 ± 0.43 ^a
CV (%)	24.87	126.60	8.16	1.88	14.09	16.08	18.35

^{a, b} Values in the same column marked with different letters show significant differences ($P < 0.05$); values are mean ± standard deviation; TA – titratable acidity; C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; CV – coefficient of variation; S1 – ambient temperature; S2 – refrigeration

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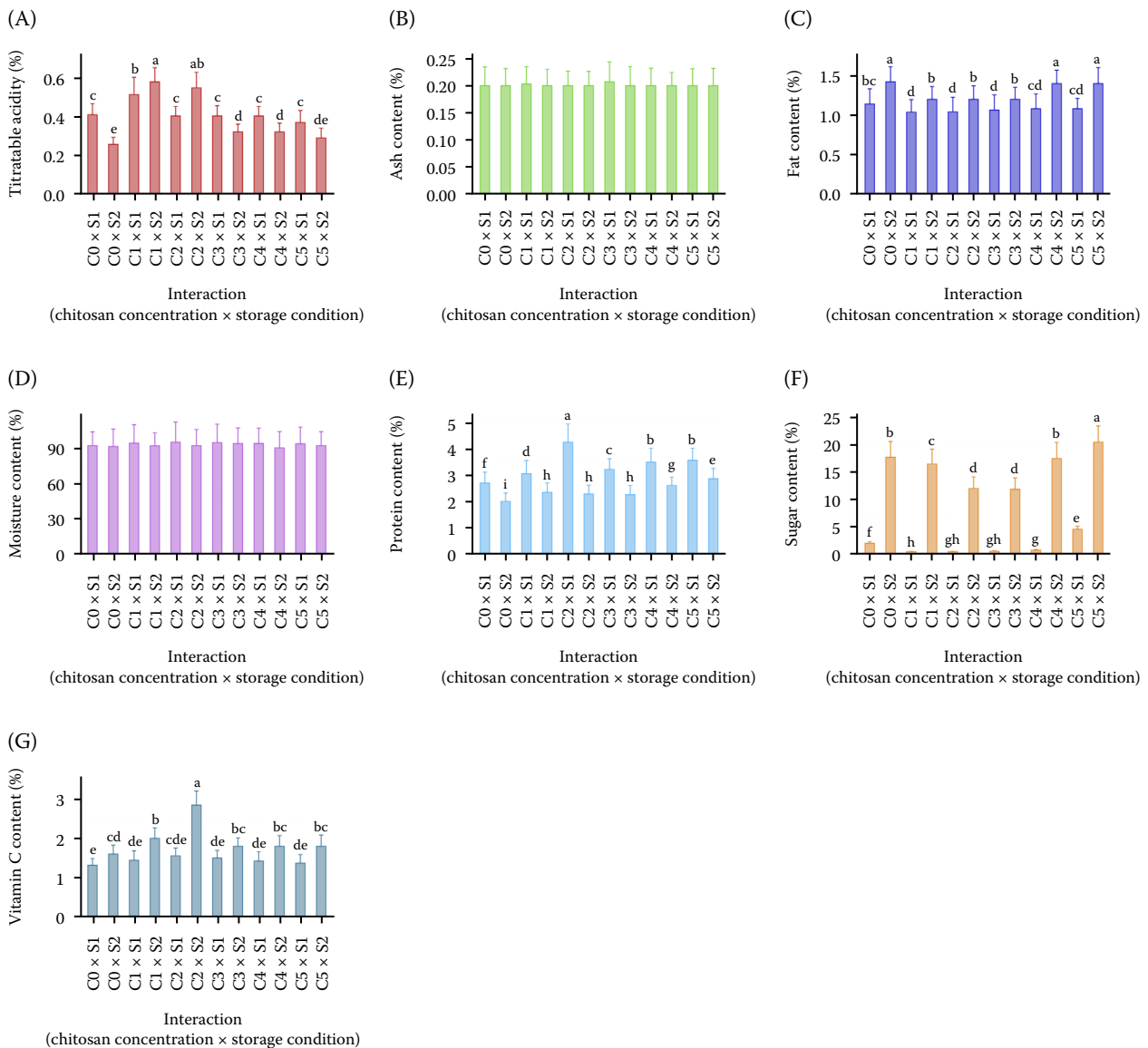


Figure 4. Effect of interaction between chitosan concentration and storage condition on the proximate components of cut mango after 6 months of storage

a–i – means with the same letters are not statistically different from each other as per Tukey's post hoc test ($P = 0.05$); C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; S1 – ambient temperature; S2 – refrigeration

to be higher than the untreated (control) mangoes, and the highest TA was recorded for 10 ppm chitosan solution (Table 1). The chitosan-treated mango showed about 0% to 67% more TA than control fruits, which is in agreement with other researcher findings (Silva et al. 2017; Parvin et al. 2023). The higher TA might be due to the low rate of respiration in chitosan treated mangoes. Organic acids are used as intermediate metabolites in the respiration process during ripening (Yin et al. 2019). Contrasting results were noticed in mangoes stored in the refrigerated state, where

a lower amount of TA was found compared to the ambient storage environment. In the case of chitosan and storage temperature interaction, the highest (0.58) TA was recorded for the mangoes dipped in a 10 ppm chitosan solution, and the lowest value (0.26) was observed in the control mangoes in refrigerator storage conditions. Consistent findings were observed by Hesami et al. (2021) and the observed fruits stored at low temperatures with chitosan treatment maintained a higher level of titratable acidity during the storage time.

Ash content. Ash content did not differ significantly for different chitosan concentrations and storage conditions (Table 1). However, a slight increase in ash content was recorded for chitosan-treated mangoes. A similar trend was also observed in the study conducted by Parvin et al. (2023) where they observed that chitosan-treated fruit had a higher ash content compared to control mangoes. Among the storage conditions, refrigerated mangoes showed about 8% less ash content than the mangoes stored at ambient temperature.

Fat content. The chitosan-treated mangoes were able to delay fat generation by 4% to 15% compared to control mangoes (Table 1). Among different chitosan treatments, the lowest (1.09) fat content was observed in 10 ppm dipping solution-treated mangoes. Mangoes stored in refrigerator conditions showed around 18% less fat content than those stored at ambient temperature. Fat content was high in control mangoes compared to the chitosan-treated mangoes in all storage environments. Fat development of chitosan-treated mangoes was delayed up to 2–20% and 8–11% when stored at ambient and refrigeration temperatures, respectively, compared to the control mangoes (Figure 4C).

Depending on the variety, mango flesh contains 0.8% to 1.36% fat (Pathak and Sarada 1974). The concentration of fat increases in mangoes during ripening and becomes stabilised after a certain point. Application of chitosan in fresh-cut fruits can suppress the respiratory rate and delay the ripening process by stimulating the antioxidant processes (Silva et al. 2018), which could be associated with the reduced fat accumulation in stored mangoes. Moreover, low-temperature storage could help to prevent fat accumulation and retain fruit quality, which we observed in our current study.

Moisture content. Moisture content is one of the most commonly used measurements to determine the quality of stored fruit. Moisture content was higher in chitosan-treated mangoes in all storage environments than in the control mangoes.

In all storage conditions, the chitosan-treated mangoes displayed up to 3% increase in moisture. Among different chitosan treatments, the highest moisture content was recorded for the mangoes treated with 20 ppm chitosan solution. In the case of the storage condition, the ambient temperature (94.28%) was able to hold more moisture than the refrigerator condition (92.2%). Numerically, the highest moisture retention was observed for 20 ppm chitosan-treated mangoes preserved in ambient storage conditions. Chitosan can create a crosslinked like structure on the surface of the fruits to hinder the passage of O₂, CO₂, and

water vapor, which ultimately slows down the moisture loss from the chitosan-treated fruits and retains fruit firmness (Algarni et al. 2022). Therefore, chitosan coating might work as a physical barrier to reduce the gas exchange and leakage of juice from fresh-cut fruits.

Protein content. The protein content of the chitosan-treated mangoes was higher in comparison to control mangoes in all storage environments. In ambient temperature, chitosan-treated mangoes showed 12% to 58% more protein compared to the control samples. A similar pattern was also noticed for refrigeration stored chitosan treated mangoes and the value ranged from 14% to 37%. A chitosan solution of 20 ppm preserved the most protein compared to the other chitosan treatments and untreated mangoes for ambient storage conditions. Similar results were also reported by Parvin et al. (2023). Agarwal et al. (2015) reported that chitosan contains around 9–10% nitrogen, which might serve as a factor in increasing protein content in the chitosan-treated samples. Moreover, the successful application of cooling temperature also resulted in a rise in amino acids in this study, which was also observed in kiwifruit and tomatoes (Gonzalez et al. 2019; Salzano et al. 2019).

Sugar content. The amount of sugar content in the mango samples was subsequently lower in chitosan-treated mangoes (Table 1). High sugar content was observed in control mangoes in all storage conditions. The chitosan-treated mangoes delayed sugar accumulation by around 24% to 45% when they were stored at refrigeration temperature. The 10 ppm chitosan treatment showed the lowest sugar content in all storage environments. In general, mangoes stored in refrigeration showed lower sugar accumulation than those stored at ambient temperature.

Fruit ripening accelerates the accumulation of sugar in fruit. Sugar accumulation was significantly delayed in chitosan-treated fruits, retarding fruit ripeness, which is in line with Eshetu et al. (2019) and Hesami et al. (2021) observations of chitosan-treated mangoes. Chitosan coatings form a thin layer on the fruit surface and create a physical barrier to retard physiological and biochemical processes and decrease the respiration rate, which in turn reduces the ethylene activity responsible for softening and sugar accumulation in treated mangoes.

Vitamin C content. Chitosan treatment and storage conditions maintained fruit quality by retaining the vitamin C (Vit-C) content. An increase in Vit-C content was observed in chitosan-treated mangoes, whereas the lowest value was recorded in control mangoes.

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In terms of storage environment, refrigerated mangoes were more efficient in maintaining Vit-C degradation than ambient temperature mangoes. The highest (2.85%) amount of Vit-C was observed for 20 ppm chitosan-treated mangoes stored in refrigerators, whereas the lowest value for Vit-C (1.32%) was recorded for ambient temperature control mangoes. Treating mangoes with chitosan and keeping them in refrigeration helps to preserve about 21–115% more Vit-C than control mangoes kept at ambient temperature. Ortiz-Duarte et al. (2019) reported that chitosan coating at 5 °C can stabilise Vit-C during storage due to its lower exposure to external oxidation

factors. Moreover, low temperatures provide a better environment to maintain relative humidity, lowering the cell metabolism rate and causing delayed ascorbic acid degradation, which in turn extends the fruit's shelf life.

Sensory evaluation

A significant ($P < 0.05$) difference in odour, colour, and texture was observed in the sensory evaluation of the control and chitosan-treated mangoes during different storage periods at ambient temperature and refrigerator storage conditions (Figure 5, Table 2). Chitosan treatments delayed the sensory quality attributes.

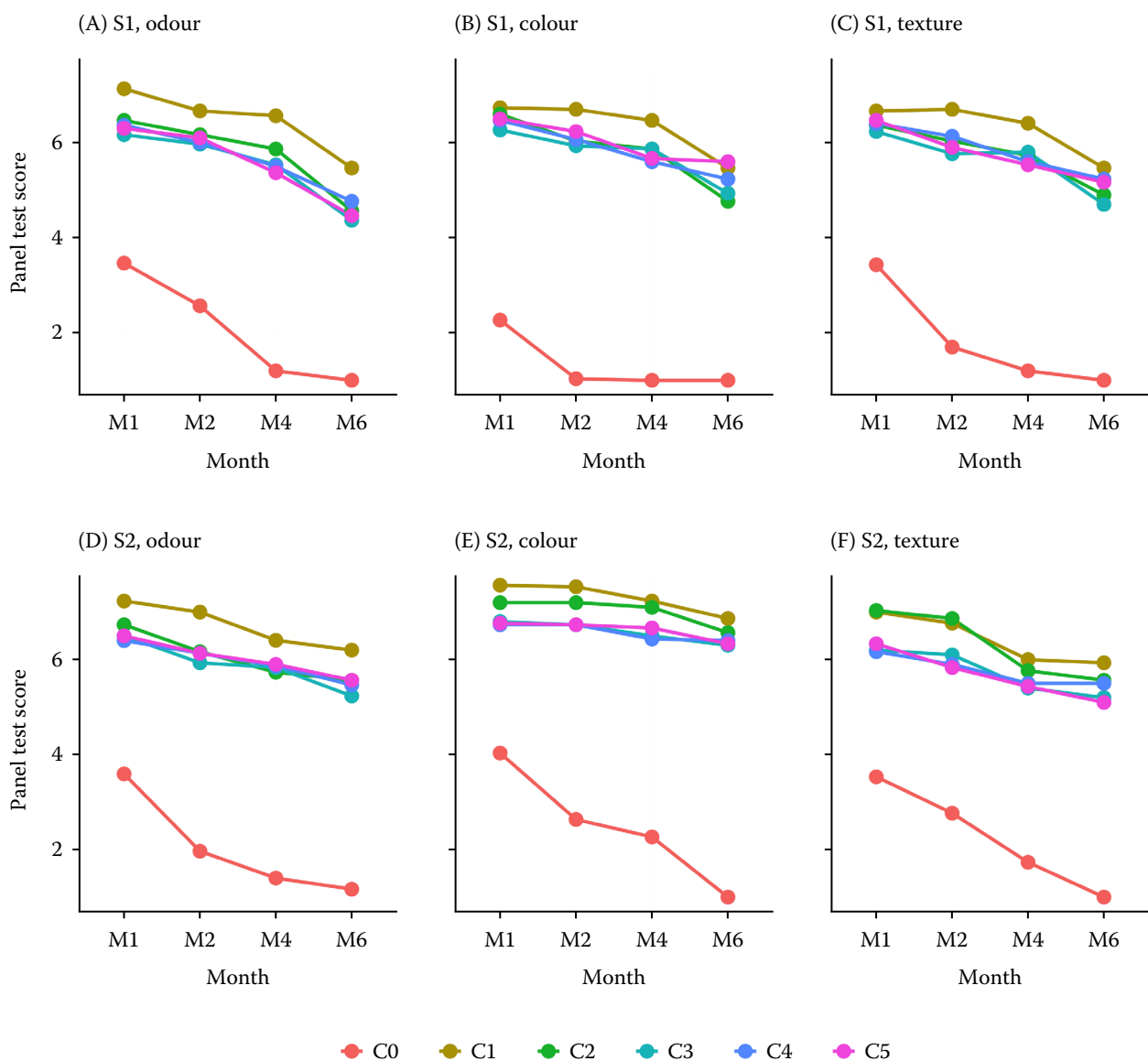


Figure 5. Effect of chitosan concentration and storage condition on the sensory evaluation of cut mango after 6 months of storage

C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; S1 – ambient temperature; S2 – refrigeration

Table 2. Effect of interaction of chitosan treatment and storage condition on the sensory parameters of cut mango after 6 months of storage

Treatment	Odour	Colour	Texture
C0 × S1	2.06 ± 1.10 ^e	1.32 ± 0.57 ^g	1.83 ± 1.06 ^d
C0 × S2	2.03 ± 1.03 ^e	2.48 ± 1.15 ^f	2.26 ± 1.08 ^d
C1 × S1	6.46 ± 0.79 ^{ab}	6.34 ± 0.67 ^{cd}	6.31 ± 0.68 ^{ab}
C1 × S2	6.71 ± 0.65 ^a	7.30 ± 0.49 ^a	6.42 ± 0.85 ^a
C2 × S1	5.77 ± 0.90 ^{cd}	5.82 ± 0.85 ^e	5.76 ± 0.81 ^c
C2 × S2	6.05 ± 0.75 ^{bc}	7.02 ± 0.59 ^{ab}	6.31 ± 0.86 ^{ab}
C3 × S1	5.51 ± 0.86 ^d	5.75 ± 0.77 ^e	5.62 ± 0.81 ^c
C3 × S2	5.88 ± 0.70 ^{cd}	6.58 ± 0.63 ^c	5.72 ± 0.79 ^c
C4 × S1	5.66 ± 0.86 ^{cd}	5.84 ± 0.71 ^e	5.84 ± 0.71 ^{bc}
C4 × S2	5.97 ± 0.60 ^{bcd}	6.58 ± 0.53 ^c	5.77 ± 0.74 ^c
C5 × S1	5.56 ± 0.91 ^{cd}	6.00 ± 0.70 ^{de}	5.77 ± 0.79 ^c
C5 × S2	6.03 ± 0.63 ^{bc}	6.62 ± 0.48 ^{bc}	5.68 ± 0.77 ^c
CV (%)	15.62	12.46	15.90

Values are mean ± standard deviation; values in the same column marked with different letters show significant differences ($P < 0.05$); C0 – control (no chitosan treatment); C1, C2, C3, C4, C5 – 10, 15, 20, 30, and 50 ppm chitosan treatment, respectively; S1 – ambient temperature; S2 – refrigeration

There is a decline in sensory characteristics with storage time in both storage conditions. Odour and browning were rapid in the case of control mangoes and were rejected by the panel just after the first evaluation. At room temperature, the chitosan-treated mangoes were stored for 6 months, and their acceptability was significantly lower than that of the refrigerated mangoes. The samples treated with 10 ppm chitosan and stored in the refrigerator showed the highest satisfactory sensory attributes even after 6 months of storage. Overall, mangoes treated with chitosan solution and stored at refrigerator temperature were able to stabilise the sensory attributes more efficiently than the control and ambient temperature stored mangoes.

Mechanical wounding in processed food causes physiological and metabolic changes that alter the odour, colour, and texture of the commodity. The application of polysaccharide based edible coating has the potential to stabilise the sensory profile at cooler temperatures due to their antimicrobial or antioxidant properties (Guerreiro et al. 2015; Li et al. 2021). Chitosan delays the ripening process and reduces the colour changes by decreasing carotenoid biosynthesis. De Leon-Zapata et al. (2015) also reported that edible coating delayed the undesirable changes in the organoleptic attributes and appearance for up to 8 weeks of the storage period. In our work, chitosan treatment on fresh-cut mangoes sustained their quality, odour, texture, and prevented enzymatic browning of tissues.

CONCLUSION

In this study, our results demonstrate that control mangoes were more prone to enzymatic colour changes and ultimately more perishable. The microbial activity, sugar, and fat contents are noticeably increased, whereas other quality attributes such as titratable acid, Vit-C, protein contents are decreased in control mangoes, indicating their rapid perishability. The control samples became unacceptable for the market, whereas the good quality of the chitosan-dipped chopped fruit was retained even after six months of storage. Significantly, the quality attributes were improved by chitosan treatment in fresh-cut mango samples. Our results revealed that a chitosan solution of 10 ppm at low temperatures may provide better performance to maintain and improve shelf life and quality attributes in fresh-cut mangoes. Chitosan formulation seems to be a promising and sustainable approach to maintaining the quality and sensory attributes of fresh-cut mangoes. However, a comprehensive study is needed for the successful commercialisation of chitosan dipping solution as a preservative for fresh-cut mangoes for long-term storage. Our future endeavours would be to study different parameters, such as enzymatic studies, antioxidant activity, gas exchange, etc., associated with the quality of fresh-cut mangoes.

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