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RESEARCH ARTICLE

Effect of chia (*Salvia hispanica* L.) seed mucilage as novel edible coating for enhancing shelf-life of fresh tomato (*Solanum lycopersicum* L.) fruits

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Abstract

The present investigation was carried out at Indira College of Pharmacy, Pune, Maharashtra, India, during 2024-25. Tomato fruits are widely used in preparing various food items of Indian cuisine for taste, flavor and colour. However, fresh tomato fruits typically exhibit a short shelf life at room temperature. In this study, coating the tomato fruits with 1 % chia seed mucilage significantly prolonged their shelf life up to 21 days compared to untreated controls. This enhanced preservation is primarily attributed to the hydrophilic nature and effective barrier properties of the chia seed mucilage (CSM). These properties effectively reduced moisture loss and limit oxygen permeability, which are key factors in delaying spoilage. The coating was effective in maintaining critical quality parameters such as titratable acidity, total soluble solids and antioxidant activity, thereby preserving both nutritional and sensory attributes. The findings highlight the potential of chia seed mucilage as a natural and biodegradable alternative to synthetic coatings for the preservation of fresh tomato fruits. CSM coatings not only address consumer demand for sustainable and eco-friendly postharvest solutions but also offer an innovative approach to reduce postharvest losses. Overall, this research underscores the promising role of CSM coatings in enhancing shelf life and maintaining the quality of fresh tomato fruits.

Keywords: chia seeds; edible coating; Fourier Transform Infrared Spectroscopy (FTIR); mucilage; shelf-life; tomato

Introduction

Edible coatings are thin layers made from natural, edible substances like lipids, proteins, polysaccharides, or their combination, applied to the surface of horticultural produces. Common types of edible coatings include composite coatings,and those based on polysaccharides, proteins, or lipids. These coatings act as protective barrier, extending shelf life and improving the overall quality of the vegetables. The key benefits of edible coatings include increased safety, better quality, longer shelf life, less food waste and environment friendly. Edible coatings are a promising technology with the potential to revolutionize food packaging and preservation. They offer a sustainable and consumer-friendly approach to extend the shelf life and maintaining quality (1-3).

Chia seeds have become more popular due to their nutritional value and potential health benefits (4, 5). One of their unique properties is their ability to form mucilage when hydrated. This mucilage is a viscous, gel-like substance that functions effectively as a protective barrier. In the present study, an edible coating made from CSM was applied to tomato fruits to enhance shelf life, reduce water loss and prevent microbial growth, both of which contribute to spoilage of fresh produce. By creating a protective layer around the fresh produce, CSM has the potential to prolong freshness and delay the onset of decay. This study evaluated the effectiveness of CSM coating on tomato fruit in terms of reducing water loss and spoilage. Overall, this research provided valuable insights into the potential of natural, edible coatings of CSM for the preservation of fresh vegetables and the reduction of postharvest losses.

Materials and Methods

Materials

Chia seeds and tomato fruits were acquired from the local vegetable market in Nanded, India.

Extraction of chia seed mucilage

Chia seeds were hydrated in a 1:30 seed-to-water ratio by soaking them in distilled water and stirring mechanically at 25 ° C for two hr. The seeds were then separated from the mucilage solution by centrifugation and filtration, followed by passage through cheesecloth to remove remaining particles. The resulting mucilaginous gel of CSM was dried in a hot air oven at 25 °C and stored in vacuum-sealed bags (6).

Ash value

Two g of the sample were accurately weighed into a crucible. The crucible containing the sample was placed on an electric burner with the lid partially open. As the initial smoke was expelled, the organic matter began to burn. The crucible was then transferred to a muffle furnace and incinerated at 600 °C for two hr. At this temperature, all organic matter was combusted, leaving behind only mineral content. The crucible was removed and allowed to cool in a desiccator to room temperature before being weighed to determine the ash content (7).

Loss on drying

After precisely weighing one g of powder, it was dried at 105 °C in a hot air oven. Until a consistent weight was achieved, the weight was measured every ten min. The percentage of weight loss was calculated as percentage loss on drying using the formula below (7).

Percentage loss on drying =

$$\frac{(\text{Initial weight - Final weight})}{(\text{Initial weight})} \times 100 \qquad \text{(Eq. 1)}$$

Formulation of edible film

A film-forming solution was prepared by dissolving 0.5 % (w/v) CSM in purified water. A magnetic stirrer was used to mechanically stir the mixture for 3 hr at 25 °C to achieve uniform dispersions and break up the powder clumps. 0.1 M NaOH (sodium hydroxide) was used to bring the solutions' pH down to 9. The selection of this pH was made using the highest hydration capacity of CSM at pH 9. Next, the amount of glycerol used as a plasticiser 10 % (w/v) was added to solution and stirred for 30 min. The coating solution was casted on a petri plate. Film was developed by solvent evaporation in a hot air oven at 35 °C for 16 - 20 hr. The film was slightly opaque and brownish in colour (8).

Edible film evaluation test

Fourier Transform Infra-Red (FTIR) analysis was carried out to evaluate compatibility and blending of the components, which can influence the surface characteristics of the edible coating applied on tomato fruits. The films were analyzed using FTIR in transmittance mode. FTIR spectra (Bruker Alpha spectrometer) were obtained in a range from 4000 to 5000/ cm, with a resolution of 2 / cm and 64 scans. The IR spectra were expressed in percent transmittance.

Preparation of coating solution and coating process

CSM powder was mixed with distilled water at various concentrations 0.5 %, 1 % and 1.5 % (w/v). To each coating solution, 2 % (w/v) calcium chloride and 10 % glycerol were added as firming and plasticising agents respectively (Table 1). Tomato fruits were then dipped in the coating solution and air-dried at room temperature.

Freshly harvested tomato fruits (*Solanum lycopersicum* L. vc pyriform) were procured from a local market in Nanded, India. The tomato fruits with an average weight of 30 to 35 g were based on visual uniformity in size and colour and were free from defects or fungal infection. Selected tomatoes were washed with clean water, disinfected by immersion in 1 % sodium hypochlorite for ten min and allowed to air dry at room temperature.

Fruits were divided into four sections when they had completely dried on the surface. To ensure that the coating was consistent, they were dipped into the coating solution for two min. The concentration of CSM such as 0.5 %, 1 % and 1.5 % were used as coating material, while distilled water was used as control. The coated fruits were air dried for 30 min to remove surface water under an electric fan, packed in plastic boxes and stored at room temperature (25 ± 5 °C). Fruits were observed at four day intervals over a 21 day storage period, after which deterioration or spoilage rendered them unfit for consumption in the control group (9).

Weight loss

Weight loss of fruits for each treatment was tagged and weighed every four days. The percentage of weight loss was calculated as per the procedure (10).

$$\text{Weight loss (\%)} = \frac{W_0 - W_1}{W_0} \times 100 \qquad \text{(Eq. 2)}$$

Where, W_0=Initial weight of the fruit sample and W_1 = Weight at each storage interval.

Total soluble solids (TSS)

One or two droplets of clear juice were placed on the prism to estimate the TSS using a refractive index meter (Model Misco) with a resolution of 0.2 °Brix and a range of 0 to 32 °Brix. Distilled water was used as a standard for the refractometer (11).

Titratable acidity

Tomato juice was extracted using a juicer. After passing the fruit liquid through cheesecloth, 100 mL of the juice was centrifuged at 3000 rpm for 15 min. The clear supernatant (pH ~8.2) was used for analysis. Titratable acidity was determined by titrating 10 mL of tomato juice with 0.01 N NaOH and was expressed as a percentage of citric acid (11).

Table 1. Composition of novel edible coating solution

S. No.	Ingredients	Formulation 1	Formulation 2	Formulation 3	Formulation 4
1.	Chia powdered mucilage	0.5 g	1 g	1.5 g	_
2.	Glycerol	0.05 g	0.1 g	0.15 g	_
3.	Calcium chloride	0.01 g	0.02 g	0.03 g	_
4.	Distilled water	100 mL	100 mL	100 mL	100 mL

Antioxidant activity

Antioxidant activity during storage was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. For extract preparation, 5 mg of tomato sample was homogenised in 20 mL of methanol, sonicated in an ultrasonic bath at 4 °C for 30 min and then centrifuged. The supernatant was filtered and 0.1 mL of the extract was mixed with 3.9 mL of DPPH solution.

Absorbance was measured at 520 nm after 60 min of incubation in the dark using a Shimadzu UV-visible double-beam spectrophotometer. Methanol was used as the blank. Antioxidant activity was calculated as the percentage inhibition of DPPH radicals (12).

DPPH scavenging activity (%) =

$$\frac{\text{Absorbance Control - Absorbance Sample}}{\text{Absorbance Control}} \times 100 \qquad \text{(Eq. 3)}$$

Visual examination of fresh produce coated with CSM

The optimised CSM concentration was used for coating tomato fruits. Visual assessments were performed to evaluate appearance attributes such as surface shine, freshness and the development of wrinkles. These observations were recorded over a 21-day storage period. As appearance is the primary quality indicator assessed without instrumentation, it served as a clear marker of freshness and consumer appeal.

Statistical analysis

International business machines-statistical package for the social science (IBM-SPSS) software was used for statistical analysis (13). To determine the difference, one-way analysis of variance (ANOVA) and Tukey's post hoc analysis was performed with the statistical significance at $p<0.05$ among research data.

Results and Discussion

The method of extraction significantly influences the properties and yield of CSM (14, 15). CSM solution was extracted from chia seeds. After extraction, the yield of dried CSM was 6± 0.77 % (w/v). The loss on drying was recorded at 8.09 ± 0.61 % (w/w) and the ash value content was found to be 7.09 ± 0.33 %, indicating that CSM is primarily composed of organic matter. The powdered CSM was observed to be white, grey, black and brownish in colour, a characteristic odour, a bitter taste and oval shaped particles. Phytochemical screening of *S. hispanica* seeds confirmed the presence of glycosides, carbohydrates, phenols and flavonoids.

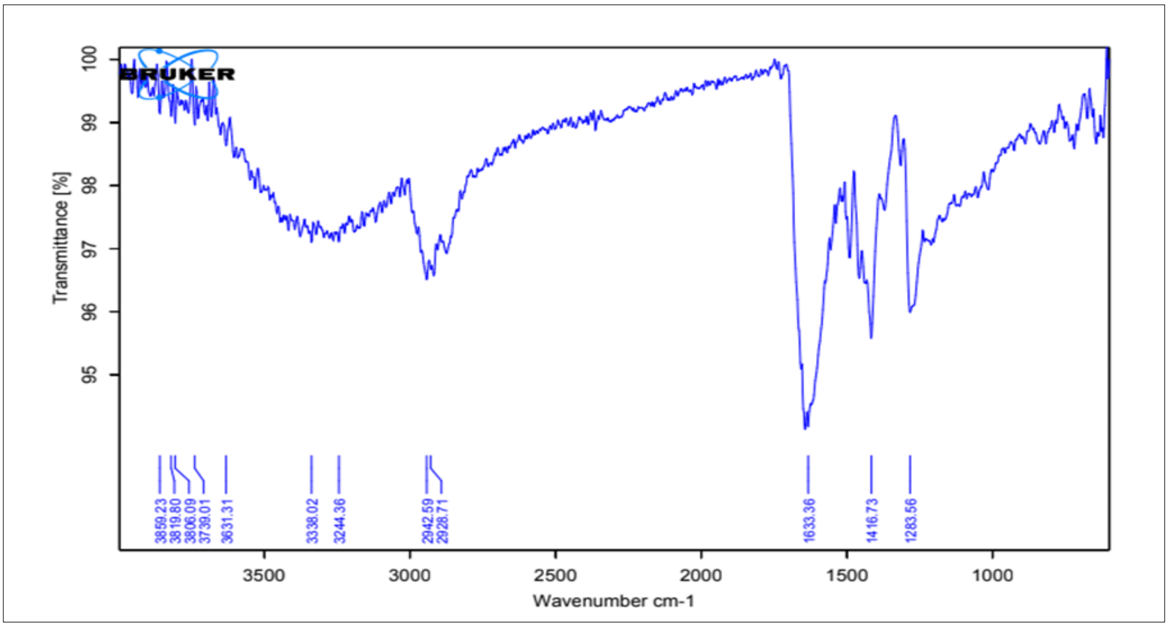
The coating solution was added with glycerol (10 % (w/w) of CSM) and calcium chloride (1 % (w/w) of CSM) for better spread ability and firmness. Glycerol acts as a plasticizer, enhancing film flexibility. Calcium chloride acts as a firming agent for the coating. Previous studies have shown that increasing glycerol content reduces the tensile strength (TS) and Young's modulus (YM) of chia mucilage (CM) films ($p<0.05$), while enhancing their water vapour permeability (WVP), elongation at break (EB) and solubility. CM films have also demonstrated excellent thermal stability and strong ultraviolet (UV) light absorption. Furthermore, the microstructural characteristics of CSM are greatly influenced by the drying technique employed (16). Calcium helps in interlinking the mucilage and acts as a firming agent in CSM coating (17). For every g of CSM, the ideal polyol concentration was 1.3 g of glycerol and 2.0 g of sorbitol (18). In this study, 2 % (w/w) of CSM was plasticized with glycerol, resulting in increased hydrophilicity and improved oxygen barrier properties. Microstructural changes enhance oxygen transport in tomato fruit during ripening (19).

The films prepared were firm and uniform after drying. The film showed brownish yellow color and translucent (Fig. 1). FTIR analysis of powder and film showed no differences in peaks suggesting that there are no new bonds formed in this film (Fig. 2).

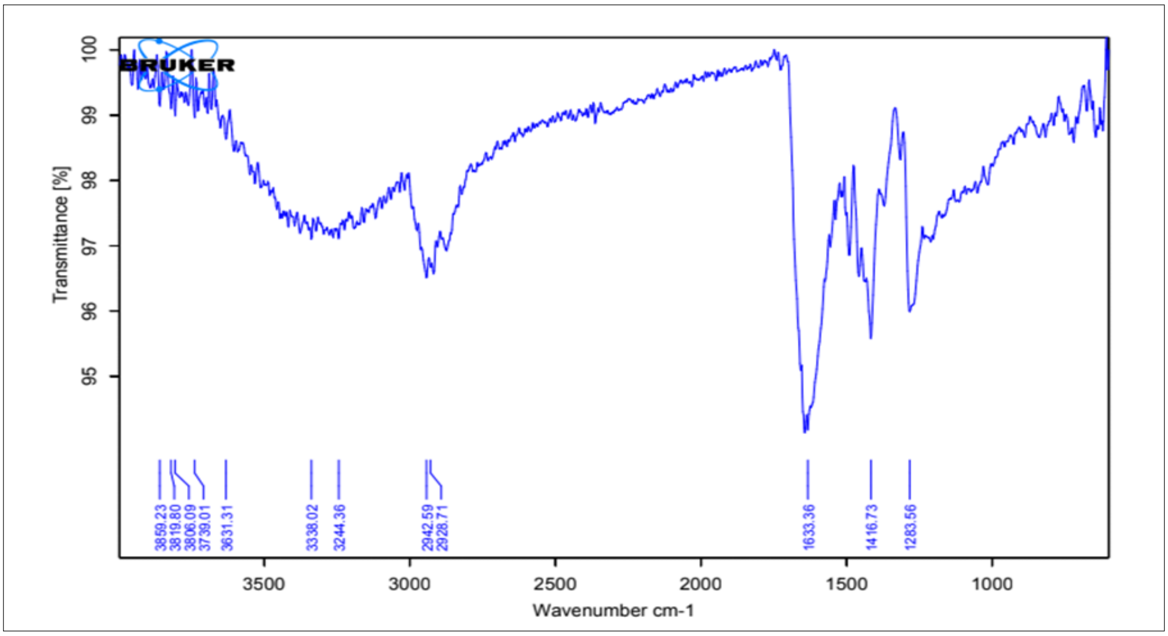
By day 14, the uncoated tomatoes exhibited clear signs of spoilage, including loss of surface shine and visible wrinkling (Fig. 3). When compared with the uncoated tomato fruits, 1 % CSM coated tomato fruits retained the freshness up to 21 days of storage. The CSM coating prolonged the shelf life of the tomato fruits for 21 days (Fig. 4). Notably, 0.5 % CSM coating also preserved fruit quality comparably to 1.5 % CSM, with no statistically significant differences observed in antioxidant activity, titratable acidity, weight loss and TSS over the 21-day storage period.

The quality of fruits varies with method of assessment (20). All tomato samples exhibited weight loss over time; however, coated fruits experienced significantly less reduction. The most substantial protection was seen in fruits coated with 1.5 % CSM, which recorded a weight loss of only 9.13 % on day 21. In comparison, uncoated fruits exhibited weight losses exceeding 6 %, further confirming the efficacy of the coating. Weight loss and softening are closely linked to water loss via transpiration and the depletion of respiratory substrates. The hydrophilic and barrier properties of CSM effectively reduce moisture and gas exchange, contributing to lower respiration and transpiration rates (21). CSM coating on fruits covers the stomata, lenticels and micropores entirely or in part, creating a semipermeable barrier that prevents gas exchange and ultimately reduces transpiration and respiration. Coatings provided a superior semi-permeable layer surrounding the fruit, which changes the fruits' internal environment by decreasing O_2 and increasing CO_2 generation (22). Edible coatings were found to prevent transpiration, protect the fruits peel from mechanical injuries resulting in delaying water loss (23).

Fig. 1. CSM film casted from 0.5 % CSM on a petri plate.



(A) FTIR spectra of CSM in powder form.



(B)FTIR spectra of CSM in film.

Fig. 2. FTIR spectra of CSM in powder form and its film.

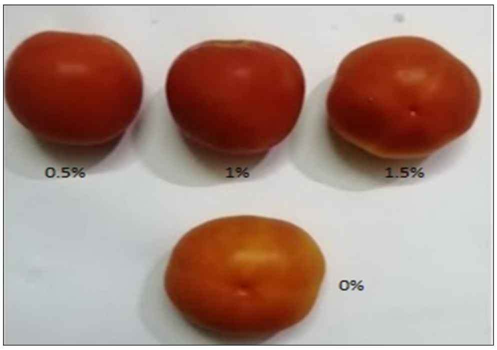
(a) Tomato fruits without coating on day 1 and day 14

(b) Tomato fruits coated with 1 % CSM at day 1 and day 14

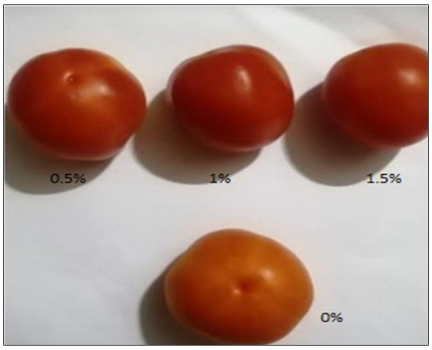
(c) Tomato fruits coated with 0.5 % CSM at day 1 and day 14

(d) Tomato fruits coated with 1.5 % CSM at day 1 and day 14

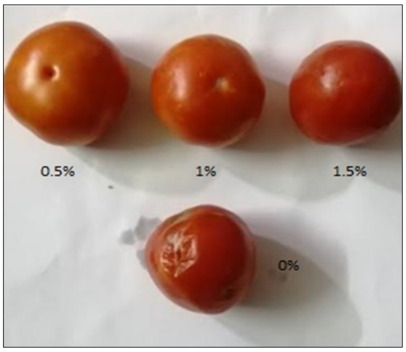
Fig. 3. Images showing the freshness of tomato fruits coated with CSM on day 1 and day 14.



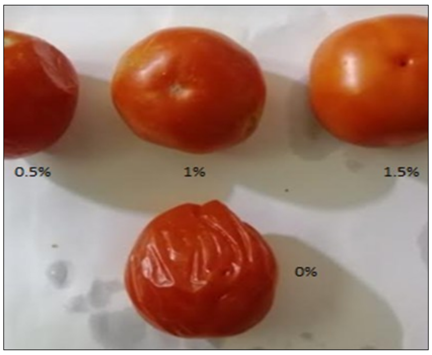
(a) Freshness of tomato fruits with CSM coating on day 1



(b) Freshness of tomato fruits with CSM coating on day 7



(c) Freshness of tomato fruits with CSM coating on day 14

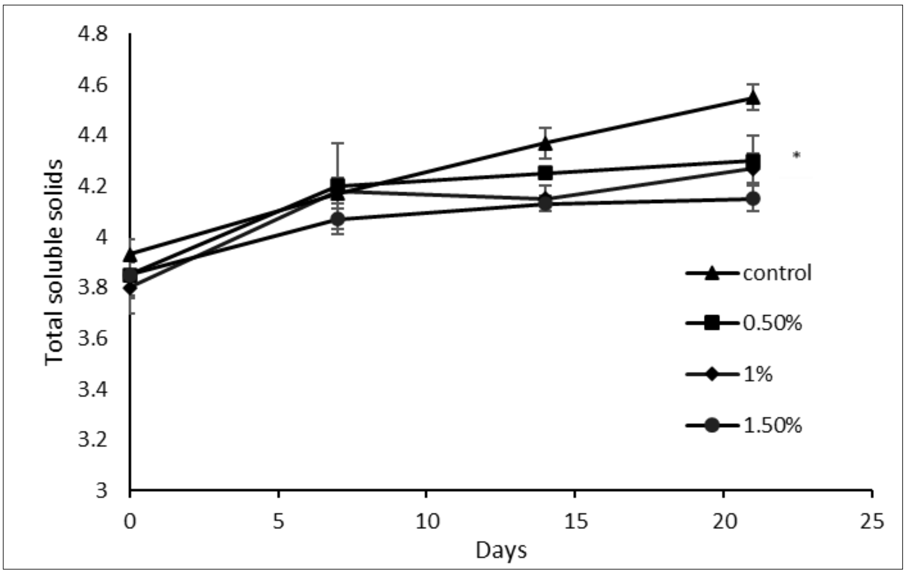


(d) Freshness of tomato fruits with CSM coating on day 21

Fig. 4. Freshness of tomato fruits coated with CSM during storage.

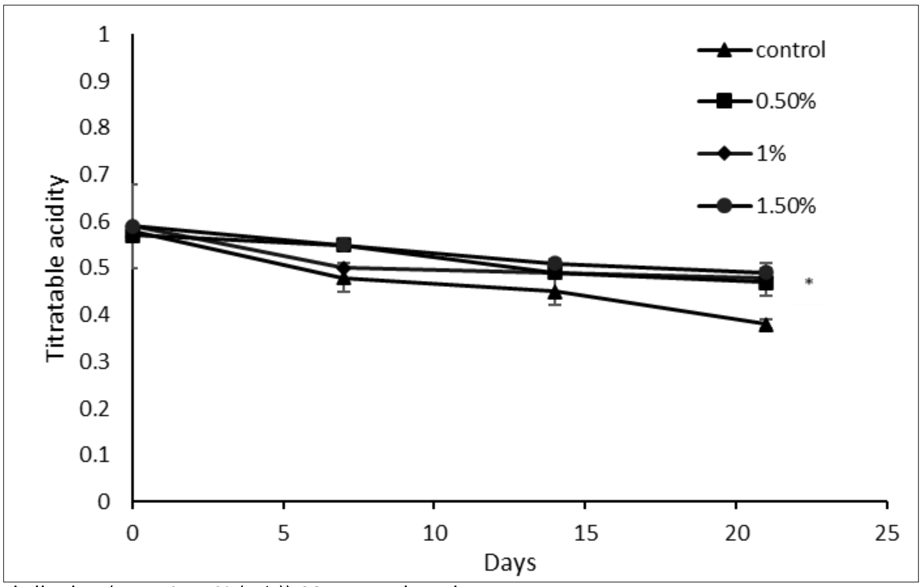
TSS gradually increased in both coated and untreated tomato fruits. The uncoated fruits exhibited the highest values on day 21 (4.55 ± 0.05 °Brix) as compared to the coated fruits (4.30 ± 0.10, 4.27 ± 0.06, 4.15 ± 0.05 °Brix for 0.5 %, 1 %, 1.5 % respectively) (Fig. 5). The higher soluble solids were recorded in coated berries compared to uncoated blue berries (24). The increase in TSS was less in coated tomato fruits during storage period of 21 days. Coating (1.5 %) showed better results among all coated tomato fruits.

Organic acids, particularly citric acid, are predominant substance of fruit respiration and are commonly measured as titratable acidity. Titratable acidity is the measure of acid content present in fruit and known to be the indicative of fruit maturity (25). The titratable acidity was decreased during storage in all the treatments. The percentage decrease in titratable acidity was highest in non-coated samples. On day 21, CSM-coated fruits maintained higher acidity levels: 0.47±0.03 %, 0.48±0.01 % and 0.49±0.02 % for 0.5 %, 1 % and 1.5 % CSM respectively, compared to 0.38±0.01 % in uncoated fruits (Fig. 6). The 1.5 % coating showed the least reduction in acidity, indicating effective respiration control. Coated cherry tomatoes have also been reported to show delayed reduction in acidity due to lower respiration rates (26, 27). Edible coating thus slows down respiration and acid degradation, prolonging fruit freshness (28).



*p<0.05 vs uncoated and all other (0.5, 1 & 1.5 % (w/v)) CSM coated produce

Fig. 5. Total soluble solids of CSM coated tomato fruits and uncoated fruits.



p<0.05 vs uncoated and all other (0.5, 1 & 1.5% (w/v)) CSM coated produce

Fig. 6. Titratable acidity in CSM coated tomato fruits and uncoated fruits.

Chia seeds are rich in antioxidants, which help neutralise free radicals and reduce oxidative stress. Antioxidant-rich diets are associated with a reduced risk of cardiovascular disease, cognitive decline and certain cancers (29). In the present study, antioxidant activity increased in all coated samples. On day 21, 1.5 % CSM-coated tomatoes exhibited the highest DPPH radical scavenging activity at 48.19±0.95 %, compared to 39.52±0.30 % in uncoated fruits (Fig. 7). These findings align with previous reports highlighting the antioxidant potential of chia seeds and their efficacy in edible coatings (30–33). Visual inspection of the coated fruits confirmed the efficacy of CSM in preserving appearance and freshness. Fruits coated with 1 % CSM retained shine, colour and firmness with no wrinkling for up to 21 days, whereas uncoated fruits showed significant deterioration. The optimised 1 % CSM coating was effective in maintaining tomato quality and extending shelf life. The visual results, coupled with biochemical analyses, indicate that CSM is a promising, biodegradable coating material. The simple dip-coating method used in this study offers a practical approach for reducing postharvest losses in fresh produce. The effectiveness of CSM appears comparable to other widely used natural coatings such as chitosan (34, 35).

Conclusion

In conclusion, the edible coating of 1 % CSM on tomato fruits had significantly increased the shelf life up to 21 days. The protective property of CSM was attributed to the hydrophilicity of the coating and its barrier properties to oxygen. The titratable acidity, antioxidant, moisture loss and TSS were better maintained in the treated tomato fruits compared to the uncoated controls. CSM can be further studied thoroughly for the activities of barrier properties of the coating and with other types of fruits. Overall, CSM coating is highly beneficial in improving the shelf life of the vegetables and fruits.

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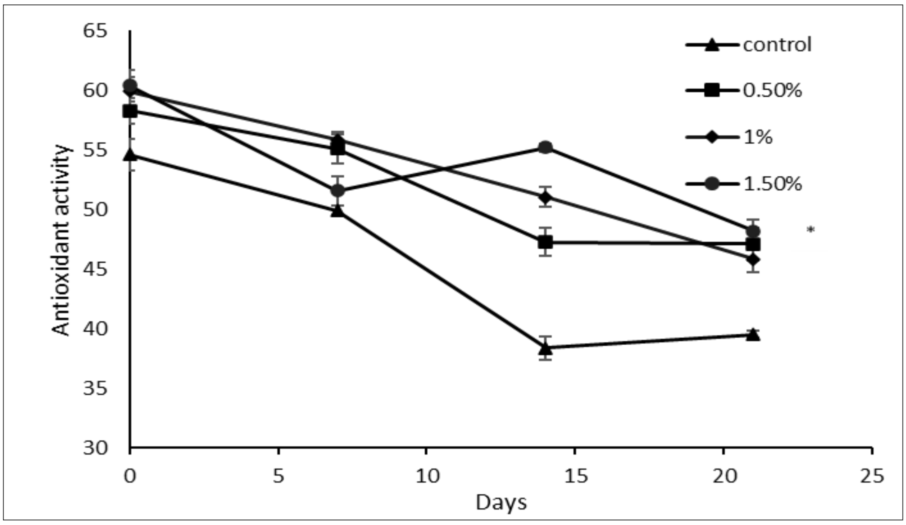

p<0.05 vs uncoated and all other (0.5, 1 & 1.5 % (w/v)) CSM coated produce.

Fig. 7. Antioxidant activity in CSM coated tomato fruits and uncoated fruits.

Authors' contribution

PK performed conceptualization, methodology design and critical review of the manuscript. SK carried out the laboratory work, data collection and initial draft preparation. JS performed supervision, project administration, final manuscript review and submission. KM performed literature review, evaluation studies, data interpretation and statistical analysis. VRD has done literature review, data collection and initial draft preparation. PKB carried out formulation development, optimization and visual documentation. HUJ contributed to stability studies, result interpretation, reference management. All authors equally contributed for manuscript correction. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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