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Original Research Paper

Effect of edible coatings on the physio-chemical and antioxidant quality of papaya fruits during low temperature storage

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ABSTRACT

An experiment was carried out using edible coatings *viz*., carboxymethyl cellulose (CMC), chitosan, gum arabica and sodium alginate, to extend the postharvest life of papaya fruits. Among the different edible coatings employed, CMC 1% allowed papaya fruits to be stored for 20 days under cold storage condition (15±1°C). Integration of CMC with low-temperature storage delayed the ripening rate and greatly conserved fruit quality by two-fold reduction in the rates of ethylene evolution, respiration, and physiological weight loss. At the end of storage period, CMC coated papaya fruits had superior marketable fruit quality parameters, including total sugars (10.22%), titratable acidity (0.25%), ascorbic acid content (51.36 mg/100 g) and antioxidant activity (13.08 mg AEAC/100 g) with the highly favorable sensory properties up to 20 days. Our findings enabled the extension of the postharvest shelf life of papaya fruits, allowing them to reach consumers with good sensory qualities.

Keywords: Papaya, polysaccharides, shelf-life, spoilage, surface coating

INTRODUCTION

In the world's tropical and subtropical climates, papayas (*Carica papaya* L.) are highly prized fruit crops for its taste and nutritional value (Lata et al., 2018). On 0.149 million hectares of land, India produces about 5.95 million metric tons of papaya every year (MoA & FW, GOI, 2024). Over the past ten years, production has somewhat decreased in several Indian states, primarily as a result of field-related pathological diseases, followed by postharvest decay and quality loss (Prasad et al., 2024). Papayas have a reduced shelf life and substantial postharvest losses annually due to their perishability and high moisture content (Menaka & Lekshmi, 2022). Controlling the ripening process and postharvest decay during storage and distribution is therefore vital to maintain the fruit quality during supply chain (Lartey et al., 2023).

Despite several attempts to reduce papaya postharvest losses only a few methods are deemed environmentally safe. These techniques include cold storage, edible coatings, ozonation, and modified atmospheric packaging (MAP) (Asrey et al., 2023). In light of consumers' growing worries about safety, postharvest horticulturists are becoming increasingly interested in managing fruit postharvest losses by using eco-friendly methods like hot water treatment, and natural alternatives like edible coatings. Derived from renewable resources like lipids, proteins, polysaccharides, and bioactive plant extracts, edible coatings form thin, biocompatible layers on fresh produce (Ribeiro et al., 2021).

There is limited information available on the effectiveness of the edible coatings *viz*. carboxy methyl cellulose, chitosan, sodium alginate and *Acacia* gum in preserving the quality and extending the storage life of papaya. Consequently, this study was undertaken to evaluate the impact of these edible coatings in extending marketability of papaya fruit under cold storage conditions.

MATERIALS AND METHODS

Papaya cv. Arka Prabhath fruits were harvested at breaker stage from fruit orchards of ICAR-Indian Institute of Horticultural Research, Bengaluru, India and transported to the Postharvest Research Laboratory during August, 2022. The fruits were sorted, graded, washed with potable water, and air dried prior to treatments.

Based on the preliminary trials, fruits were coated with 1% CMC (carboxymethyl cellulose), 1% chitosan, 10% gum Arabica and 1% sodium alginate. Calculated amount of CMC, gum Arabica and sodium alginate were dissolved separately and mixed with distilled water to a desired volume. For chitosan (which is partially water soluble), 1% glacial acetic acid solution in distilled water was used for making the coating solution. Fruits were treated by dipping in the coating solutions followed by surface drying and storage in paper lined plastic crates. Each treatment had three replications with ten fruits in each replication.

Storage

The treated fruits were stored under low temperature conditions (15±1°C; RH-85 to 90%) (Rao et al., 2018). Physiological observations were made at specific intervals (alternate days), and the quality parameters were obtained at different stages of ripening till the end of their storage life. During storage, the fruits stored at low temperature for 18 days have been shifted to ambient storage (23.4-34.4°C, 25-82% relative humidity) to observe their physiological and ripening behavior after removal from cold storage for assessing their consumer-ready quality.

Physiological parameters

The physiological loss in weight was calculated as percentage (PLW) of the initial weight while the respiration rate and ethylene evolution rate of treated and untreated papaya fruits were measured by enclosing individual fruits (in five replicates) in hermetically sealed desiccators of 5-liter volume for 45 to 60 min, following the headspace gas measurement method of Rao & Rao (2008) using auto gas analyzer (Model: Checkmate 9900 O_2/CO_2 analyzer, Dansensor, Denmark) and ethylene gas analyzer (Bioconservation, Germany), respectively. Respiration rate and ethylene evolution rates were expressed as mg CO_2/kg/h and ìl C_2H_4/kg/h respectively. Co-efficient of ripening was calculated by assigning a score to each ripening stage of the fruits based on visual colour to estimate the ripening rate. The stages categorized were defined as follows: breaker (1), quarter ripe (2), semi-ripe (3), three-quarters ripe (4), and fully ripe (5) and then the co-efficient of ripening was determined using the following formula:

$$\text{Co}-\text{efficient of ripening} = \frac{\sum(\text{No. of fruits at a particular ripening stage} \times \text{score of the ripening stage})}{\text{Total number of fruits observed}}$$

Physical parameters

The firmness of the fruits was measured by recording the force required to puncture the fruit with 8 mm probe using an Instron-Universal Testing Machine (Model 4201, USA) and the firmness was calculated and expressed as kg/cm². The surface and pulp color of the fruits were measured using a colorimeter (Model: Color Reader, CR-10, Konica Minolta, Japan), with values recorded for lightness (L*), a-value (a*), and b-value (b*). Later total color change (△E) was estimated using the formula (Reddy et al., 2016).

$$Colour\ change\ (\Delta E) = \sqrt{\Delta a*^2 + \Delta b*^2 + \Delta L*^2}$$

Quality parameters

At specified intervals during storage, three fruits were randomly selected from each treatment and sampled for analyzing biochemical changes. The sampled pulp was frozen and stored at -18°C until further biochemical analysis. Prior to analysis, the samples were thawed and homogenized using a VirTishear homogenizer (Virtis Company Inc., Gardiner, NY, USA). Quality attributes, including total soluble solids (°Brix), reducing and total sugars (%), titratable acidity (%), ascorbic acid (mg/100 g), total carotenoids (mg/100 g) and lycopene (mg/100 g) were determined using the standard methods of analysis (AOAC, 1995). Total phenols were estimated according to procedure given by Singleton & Rossi (1965) and expressed as mg of gallic acid equivalents (GAE), flavonoids were estimated by the procedure outlined by Chun et al. (2003) and expressed as mg of catechin equivalents (CE), and antioxidant capacity/ferric reducing antioxidant power (FRAP) was estimated and expressed as mg of ascorbic acid equivalent antioxidant capacity (AEAC) (Benzie & Strain, 1996). All these parameters were estimated on fresh weight (FW) basis.

Sensory evaluation

The sensory evaluation of fruits was carried out for fruit appearance, pulp color, pulp texture, taste and overall acceptability by ten semi-trained panelists familiar with sensory testing procedures and were briefed about 5-point hedonic scale (1=very bad, 2=poor, 3=fair, 4=good, 5=very good) used for assessing key attributes (Rao & Rao, 2008).

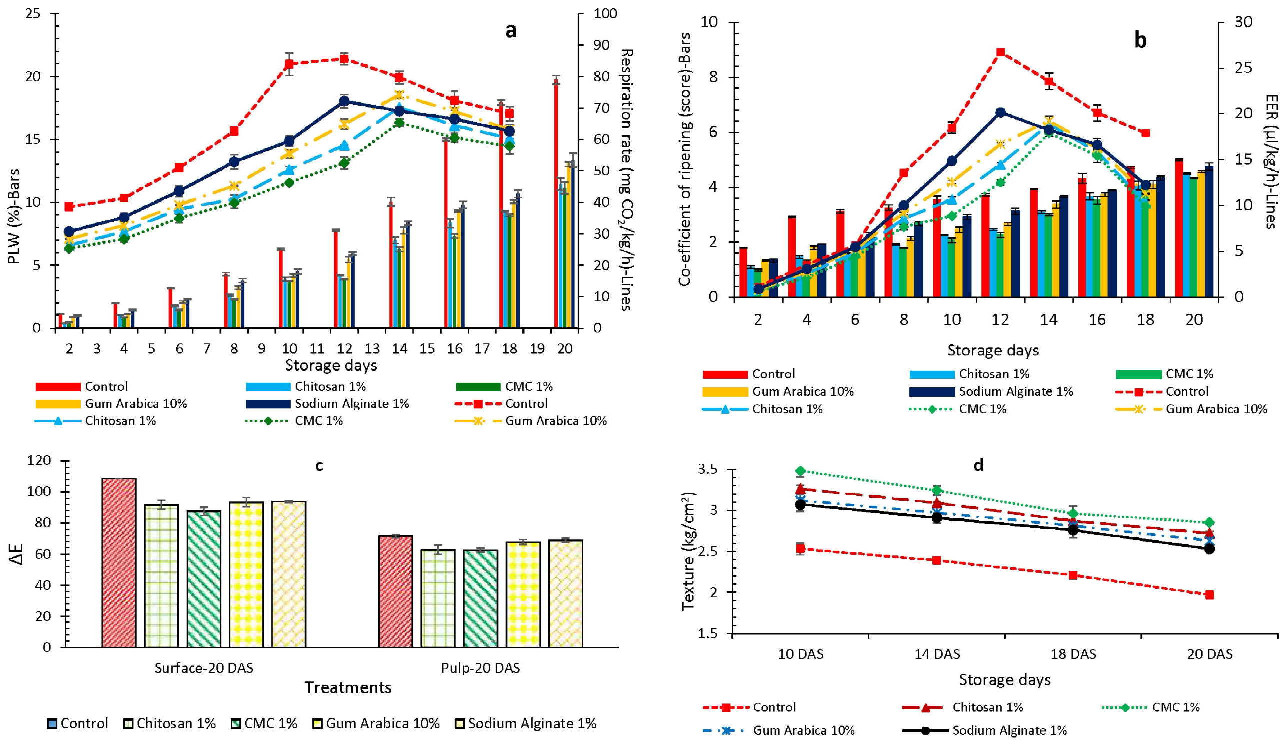

Fig. 1 : Edible coatings effect on (a) PLW & RR, (b) EER & Co-efficient of ripening, (c) fruit peel & pulp colour change (△E), and (d) fruit firmness of papaya fruits stored at 15°C (mean values are presented with SD)

Statistical analysis

The data recorded under different parameters were subjected to ANOVA in factorial completely randomized design and completely randomized design with 5% level of significance (p=0.05) and were analyzed using online statistical software GRAPES (Gopinath et al., 2021).

RESULTS AND DISCUSSION

Physiological loss in weight (PLW) and Respiration rate (RR)

Weight loss is a direct loss of saleable produce in economic terms coupled with the reduced acceptability by the consumer. The primary cause of quality decline after harvest is the weight loss brought by the ongoing respiration and transpiration processes (Kabir & Hossain, 2024). Irrespective of the treatments imposed, the PLW (%) of the fruits increased steadily till the end of the storage period with an increase in RR (Fig. 1a). As the coatings acts as a physical barrier for the exchange of gases, reduced rate of PLW was observed in the edible coated fruits due to lower RR and transpiration loss compared to control. Control fruits and sodium alginate 1% coated fruits reached respiratory climacteric peak of 85.62 mg CO_2/kg/h and 72.12 mg CO_2/kg/h, respectively on 12th day itself. In contrast, CMC 1% coated fruits achieved lower climacteric peak of 65.33 mg CO_2/kg/h more slowly compared to control and other treatment i.e. on 14th day of storage and it significantly reduced PLW (11.13%) till 20 days of cold storage. Followed by CMC, Chitosan 1% coating also resulted in lowest PLW (11.46%) till 20th day of storage. CMC 1% served as a better physical barrier around the fruit by partially closing the stomatal openings and lenticels thereby reducing the rates of transpiration and respiration (Hazarika et al., 2017). Compared to coated fruits, the significantly higher rate of PLW (19.74%) in the control might be caused by increased respiration through an uninterrupted air column and higher moisture loss. These observations are consistent with research conducted by Sebastian & Bindu (2024) on papaya and Ballesteros et al. (2022) on goldenberries.

Ethylene evolution rate and co-efficient of ripening

Ethylene is the hormone responsible for the ripening in climacteric fruits. Since the co-efficient of ripening and the ethylene evolution rate (EER) are intimately related, understanding the pace at which ethylene is evolved is crucial for handling the produce during storage. The effect of different edible coating treatments on EER and subsequent co-efficient of

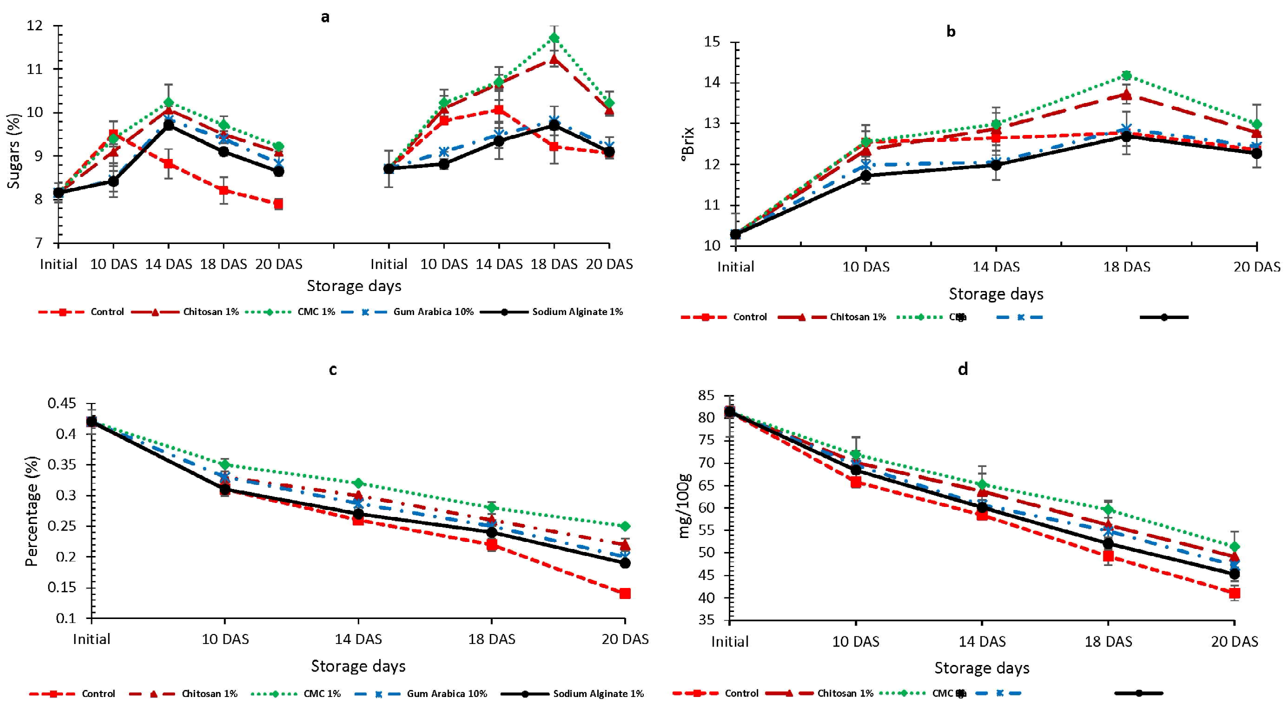

Fig. 2 : Edible coatings effect on (a) reducing & total sugars, (b) TSS, (c) Titratable acidity, and (d) Ascorbic acid of papaya fruits stored at 15°C (mean values are presented with SD)

ripening of papaya fruits during storage is presented in the Fig. 1b. Regardless of the treatment used, the EER increased with the advancement of storage period indicating progressive ripening of fruits. Among all the treatments, the lowest EER peak of 17.91 µl/kg/h was reported in CMC 1% followed by chitosan 1% (18.88 µl/kg/h) on 14th day of cold storage. Whereas significantly higher EER peak of 26.74 µl/kg/h and 20.17 µl/kg/h were recorded in control and sodium alginate coated fruits, respectively on 12th day of storage. CMC 1% coating resulted in lower rate of ripening (4.32/5.0) whereas the higher rate of ripening was observed in control (5.0/5.0) followed by sodium alginate 1% coated fruits (4.75/5.0) on 20th day of storage. Edible coatings which act as a barrier for gaseous exchange reduces the availability of oxygen required for oxidation of ACC (1-Aminocyclopropane-1-carboxylic acid) during ethylene biosynthesis (Asrey et al., 2023). In this study, CMC 1% with effective gas barrier properties achieved a prominent decrease in EER. Similar outcomes were noted by Hazarika et al. (2017) in papaya.

Fruit surface and pulp color changes

One of the most essential variables in determining a papaya's ripening stage is its peel color: a dark green hue denotes a less mature stage, a light green one indicates a mature stage, and a yellowish orange hue signifies the completely ripe stage (Manenoi & Paull, 2005). Lower △E values indicate slower changes in peel and pulp color, preserving the green hue and extending storage life. Control fruits showed significantly higher ΔE values of fruit surface (108.52) and fruit pulp (71.68) on 20th day of cold storage, reflecting rapid ripening and shorter storage life. CMC 1% coated fruits maintained their freshness for 20 days in cold storage, showing delayed fruit surface color ΔE (87.45) and pulp color ΔE (62.6). Followed by chitosan 1%, which also supports improved storage under cold storage conditions by modestly controlling color change (Fig. 1c). This can be ascribed to the lower ripening rate and EER caused by coating treatments in conjunction with cold storage conditions, which delayed color change and preserved fruit freshness for extended periods of storage (Parven et al., 2020).

Fruit firmness

Fruit firmness is one of the major parameters deciding the shelf-life and consumer acceptability. Irrespective of the treatment, a declining trend of fruit firmness was observed with the advancement of storage (Fig. 1d). Softening of fruits is primarily due to the activity of pectinase and hydrolase enzymes that degrade cell wall during storage (Khaliq et al., 2015). However, fruits coated with CMC 1% maintained better fruit firmness

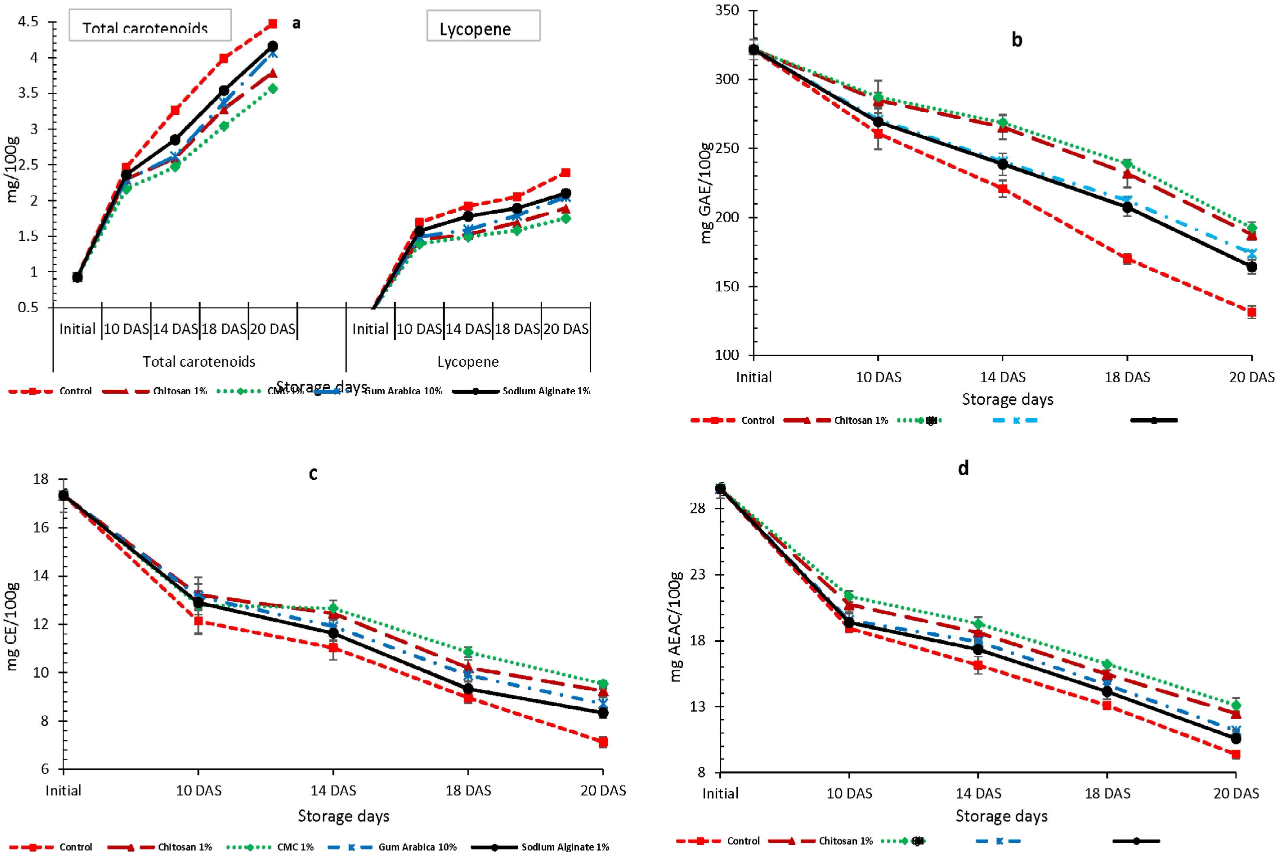

Fig. 3 : Edible coatings effect on (a) total carotenoids & lycopene, (b)total phenols, (c) total flavonoids, and (d) antioxidant (FRAP) activity of papaya fruits stored at 15°C (mean values are presented with SD)

(2.85 kg/cm^2) during storage while the control fruits had significantly lost firmness (1.97 kg/cm^2) within 20 days. Additionally, edible coatings retain greater fruit firmness by slowing down gaseous exchange, which lowers the activity of cell wall degrading enzymes. These findings are consistent with the findings of Hazarika et al. (2017) in papaya.

Reducing and total sugars

Reducing and total sugars are among the key factors that determine the taste and quality. As fruit ripens, the sugars increased in all the treatments initially and then decrease as they serve as a substrate for the respiration process during storage (Fig. 2a). Since CMC 1% coating is effective in reducing the RR, it helped in maintaining good amount of reducing (9.22%) and total sugars (10.22%) for longer duration *i.e.* 20 days under cold storage condition. While control fruits managed to retain a meager amount of reducing sugars (7.9%) and total sugars (9.07%) on 20th day of storage. Similar findings have been reported by Hazarika et al. (2017) during ambient storage of edible coated papaya.

Total Soluble Solids

Since sugars are a component of total soluble solids (TSS), their use in climacteric respiration causes reduction in TSS during storage (Menaka & Lekshmi, 2022). CMC 1% and Chitosan 1% were effective in maintaining significantly good amount of TSS (12.98 and 12.78 °Brix, respectively) at the end of cold storage compared to control and other treatments (Fig. 2b). Higher TSS content was observed in the CMC coated fruits as they had significantly lower RR. Similar results were reported in papaya (Raju et al., 2023) and goldenberries (Ballesteros et al., 2022).

Titratable acidity and Ascorbic acid

As the storage advances and sugar reserves deplete, the metabolism shifts towards utilization of organic acids as an alternative substrate for respiration process. Thus, organic acids content decrease with the advancement of storage which ultimately led to a decline in titratable acidity (Fig. 2c). But CMC 1% maintained a good amount of titratable acidity (0.25%) and ascorbic acid content (51.36 mg/100 g)

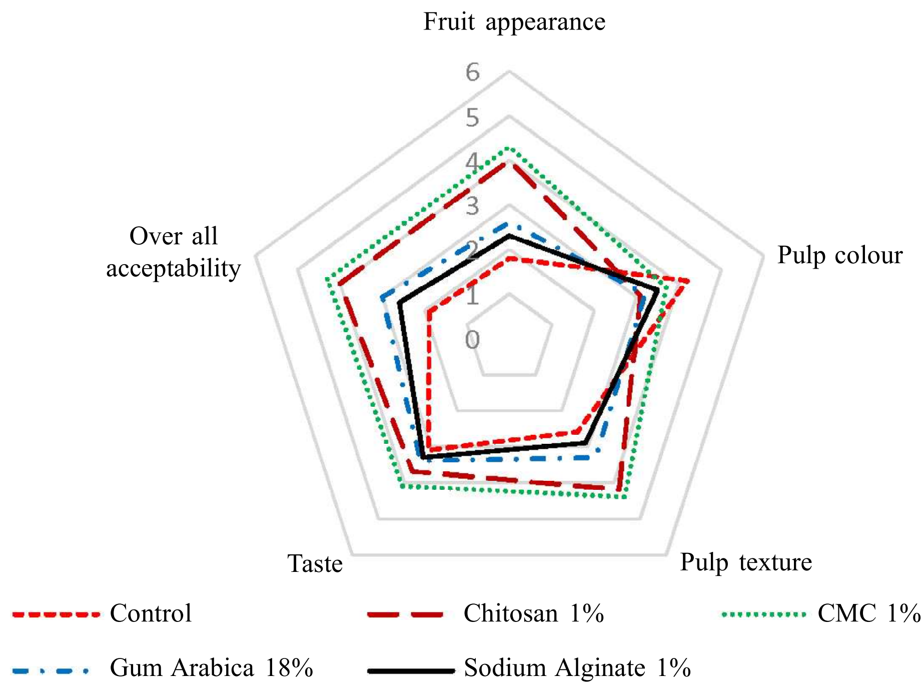

Fig. 4 : Sensory properties of edible coated and control papaya fruits on 20th day (18 days at 15°C + 2 days at RT)

up to 20 days of storage compared to control fruits which had significant loss of ascorbic acid (41.07 mg/100 g) and reduced titratable acidity (0.14%) at the end of storage. This variation in decreasing trend of ascorbic acid (Fig. 2d) might be due to different levels of oxidation in different coating treatments. During storage, activities of oxidizing enzymes like ascorbic acid oxidase, peroxidase, polyphenol oxidase and catalase might cause decrease in ascorbic acid content of fruits (Menaka & Lekshmi, 2022). Despite that, maintenance of more ascorbic acid content by CMC than other treatments might be due to its ability to reduce gaseous exchange, which in turn reduces the oxidation catalyzed by oxidizing enzymes (Tesfay & Magwaza, 2017).

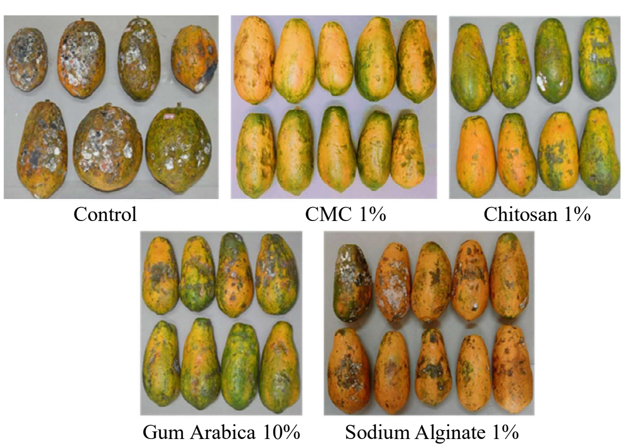

Fig. 5 : Edible coated and control papaya fruits on 20th day (18 days at 15°C + 2 days at RT)

Lycopene and total carotenoids

Papaya fruit ripening is characterized by degradation of chlorophyll and accumulation of lycopene and total carotenoids (Charoenchongsuk et al., 2018). Control fruits having higher ripening rate had higher total carotenoids (4.23 mg/100 g) and lycopene (2.29 mg/100 g) content on 20th day of cold storage. CMC 1% coating treatment which slows down the rate of ripening had slower accumulation of pigments over time (Fig. 2e), with the total carotenoids value of 3.71 mg/100 g and lycopene value of 1.81 mg/100 g after 20 days of storage. The endogenous ethylene is the major trigger responsible for the breakdown of chlorophyll and accumulation of carotenoids in the fruit pulp (Hazarika et al., 2017).

Total phenols and flavonoids

The secondary metabolites like flavonoids and phenols, which scavenge reactive oxygen species (ROS), electrophiles, and chelated metal ions, gradually decrease as a result of oxidation until papaya fruits reach the edible ripe stage (Prasad et al., 2024). Under cold storage, coating treatments helped in storage extension by preserving total phenols (Fig. 3a) and flavonoids (Fig. 3b) for the period of 20 days. CMC coating treatment showed better results by preserving good amount of total phenols (192.37 mg GAE/100 g) and flavonoids (9.53 mg/100g) till the end of storage indicating its significance over control and other treatments. It has also been reported in the experiment that CMC coating was effective in reducing fruit metabolic rate, especially fruit respiration and ethylene evolution over an extended period. Consequently, higher levels of phenols and flavonoids were preserved in the fruits (Prasad et al., 2024).

Antioxidant (FRAP) activity

Fruit quality is greatly preserved during storage by the antioxidant activity, which lowers oxidative stress and delays the breakdown of bioactive substances. In general, it decreases with the advancement of storage while fruits coated with 1% CMC retained a good FRAP value (13.08 mg AAE/100g) till 20 days of storage, indicating significant antioxidant activity. The low antioxidant activity of the control fruits (9.36 mg AAE/100g) towards the end of storage demonstrated the advantages of this coating treatment (Fig. 3c). This effect of preserving antioxidant activity by CMC is also due to controlled respiration and ethylene evolution in coated fruits (Xu et al., 2024).

Sensory properties

Among all the treatments, the CMC coated fruits exhibited better score for appearance (4.3), pulp texture (4.4), taste (4.1), and overall acceptability (4.3) on 20th day of storage followed by the chitosan coated fruits. The efficacy of treatments in improving sensory quality was demonstrated by the decreased acceptance of the control group and sodium alginate 1%, particularly in flavor and appearance during cold storage (Figs. 4 and 5). Similar results were reported in CMC coated goldenberries (Ballesteros et al., 2022).

CONCLUSION

Post-harvest handling of papaya fruit is extremely complex because of thin skin, chilling injury and microbial susceptibility. Compared to other coating treatments under cold storage, CMC 1% coating-maintained fruit freshness and quality till 20 days at 15^{o}C by significantly lowering the PLW by 43.6%, respiration by 23.7%, ethylene production by 33%, and ripening rate by 13.6%. The marketable fruit quality parameters assessed at the end of storage is highly desirable in the CMC 1% coating treatment. This investigation confirms that 1% CMC coating effectively doubles storage life without compromising quality, offering commercially viable strategy to minimize postharvest losses for the farmers/traders. Continued investigations with CMC coating and its combination with other preservation techniques to manage post-harvest losses in papaya will have profound implications for the global food security.

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