ISSN: 2347-467X, Vol. 14, No. (2) 2026, Pg. 974-986

Current Research in Nutrition and Food Science

www.foodandnutritionjournal.org

Influence of Carboxymethyl Cellulose Coating on Colour Index, Biochemical and Sensory Characteristics of Minimally Processed Bamboo Shoots

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Abstract

Bamboo shoots are traditionally consumed as a staple food by indigenous tribal communities of Arunachal Pradesh in Northeast India, where they are eaten fresh, dried, or as fermented products. Among these, tribes such as the Adi and their Galo sub-group, as well as other ethnic groups in districts like East Siang and West Siang, widely incorporate bamboo shoots into local dishes, reflecting their deep cultural and dietary significance. However, bamboo shoots are highly perishable due to their high moisture content and a rapid increase in enzymatic activity, which leads to discoloration and lignification. Therefore, the effect of edible coatings in combination with browning inhibitors on various physicochemical attributes of minimally processed bamboo shoots was assessed. The control and coated samples were analysed for colour, weight loss, browning index, total soluble solids, titratable acidity, ascorbic acid, total phenolic content, antioxidant activity and sensory attributes. The results showed that the minimum physiological loss in weight (PLW) was observed in samples treated with combination of carboxymethyl cellulose (CMC 1%) and ascorbic acid (AA 1%) (4.26%), while the lowest browning index (BI) was also recorded in the same treatment (27.50). The highest antioxidant activity was noted in the CMC 1% + AA 1% treated samples (7.88 μmol Trolox g^{-1}). In conclusion, CMC coating combined with browning inhibitors may serve as an effective preservation method to enhance the shelf life of minimally processed bamboo shoots by inhibiting enzymatic activity.

Article History
Received: 15 October 2025
Accepted: 19th june 2026

Keywords
Antioxidants;
Browning;
Carboxymethyl cellulose;
Colour;
Minimally processed.

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Doi: http://dx.doi.org/10.12944/CRNFSJ.14.2.18

Introduction

Bamboo is a woody-stemmed perennial grass species with a long life span, strong stems, and high renewability. It predominantly occurs in tropical, subtropical, temperate, moist deciduous, and semi-evergreen climatic conditions.[1] Bamboo shoots are a highly nutritious and widely consumed vegetable among various communities in North Eastern India. They have great potential as a food source and are consumed in four forms: fresh, processed, dried, and canned.[2] Minimally processed bamboo shoots are recognised as an excellent source of bioactive compound including essential carbohydrates, minerals, fibers and vitamins.[3] Their naturally low levels of sugar and fat make them an ideal component of a balanced diet, contributing to both nutritional value and potential health benefits.[4] The delicate nature of bamboo shoots makes them vulnerable to lignification and loss of flavour,[5] which accelerates the deterioration of their sensory and nutritional quality post-harvest.[6,7] In addition to being a storehouse of nutrients, they also contain significant antioxidants and therapeutic compounds that may help inhibit the development of metabolic diseases.[8]

Carboxymethyl cellulose (CMC), a chemically modified derivative of cellulose, is a white, odourless, and tasteless compound that is considered non-toxic.[9] CMC based edible coating have been evaluated on Table grapes,[9] Aonla,[10] Kinnow mandarins,[11] Mango[12] Banana[13] and Pakchoi[14] under different storage condition. Therefore, CMC was selected as the coating matrix because of its established barrier and film-forming behaviour, and ascorbic acid was selected as a safe and effective anti-browning antioxidant to strengthen the coating system against oxidative discoloration in fresh-cut tissues.[15-17]

Minimally processed bamboo shoots exhibit a very limited shelf life, along with cell wall thickening and tissue discoloration associated with browning and abnormal hardening, which result in quality deterioration during postharvest processing.[18] Bamboo shoots have a distinct flavour that can be significantly influenced by microbial activity and storage conditions. Enzymatic browning happens when enzymes like polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), and peroxidase (POD) help oxidize phenolic compounds.[19-21] Delaying enzymatic browning and lignification can preserve shoot quality and increase shelf life.[22] Applying edible coatings like carboxymethyl cellulose, either by itself or with anti-browning agents, can effectively reduce enzymatic activity. Therefore, preventing browning is a primary challenge in maintaining the quality of minimally processed bamboo shoots.

In this study, the physicochemical and sensory quality characteristics of bamboo shoots were evaluated under refrigerated storage conditions. The findings of this study could offer important insights into the storage of minimally processed bamboo shoots, aiming to extend their shelf life and increase their market value. Thus, the objective of this study was to evaluate the impact of CMC, either alone or in combination with anti-browning agents on maintaining the postharvest quality of minimally processed bamboo shoots under refrigerated storage conditions.

Materials and Methods

Sampling and Preparation of Bamboo Shoots for Analysis

Fresh bamboo shoots were collected from the Siang market nearby airport Pasighat, Arunachal Pradesh, and quickly brought to the PHM Laboratory at the CHF, CAU (I), Pasighat, Arunachal Pradesh. All chemicals used in the study were purchased from Merck & HiMedia.

Preparing Samples and Creating Coating Formulations

Fresh edible bamboo shoots were surface-sterilized with 200 µL/L NaOCl and stored at 4 ± 2 °C to cool. After that, the shoots were peeled and sliced by hand with a scalpel (Plate.1). To make the coating solution, 1% CMC powder was dissolved in hot water at 75 °C and stirred until clear. As the solution cooled to ambient temperature, 1% ascorbic acid was added to the edible coating.[15-17]

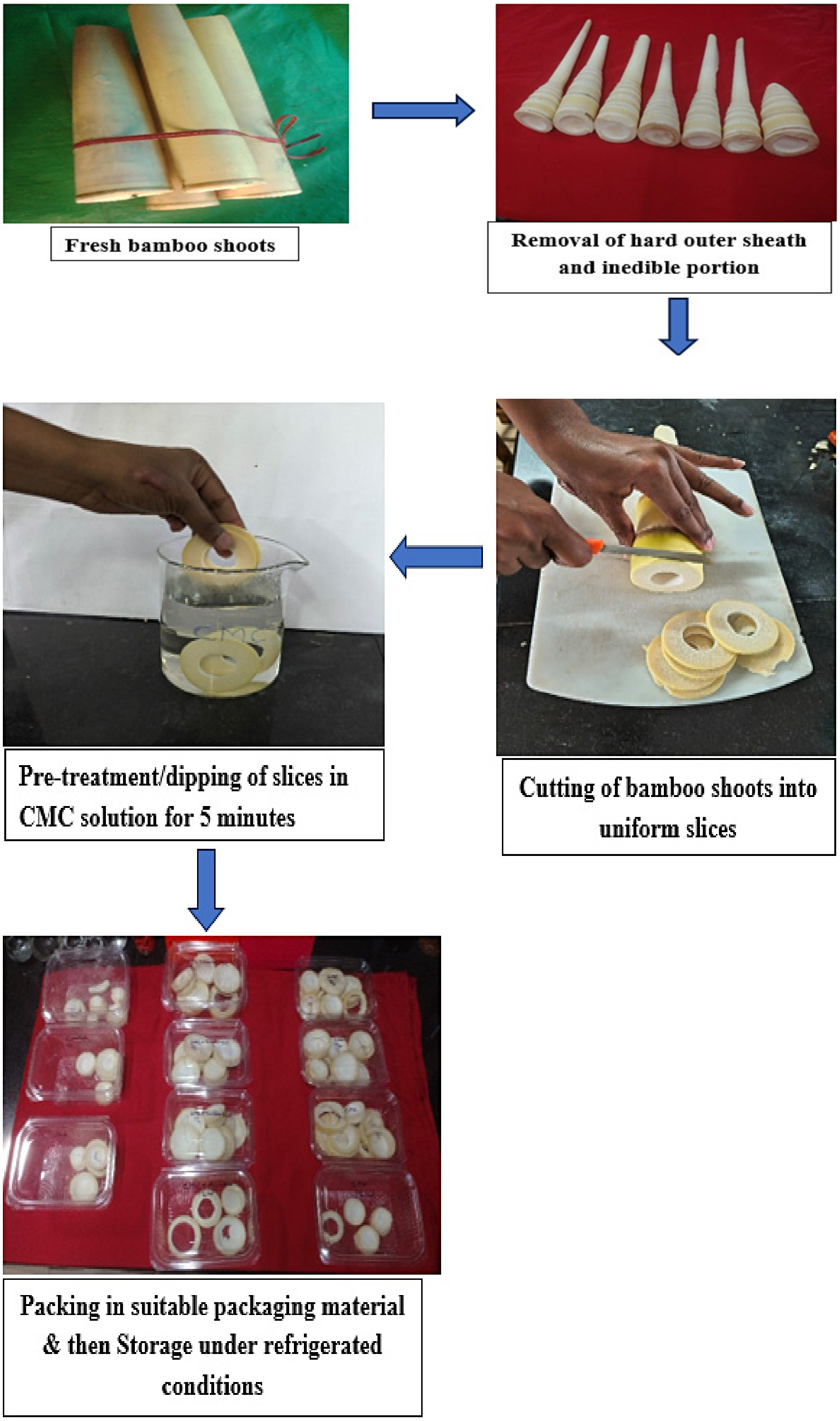

Plate. 1: Schematic illustration of the preparation of carboxymethyl cellulose (CMC) coating formulations and application of CMC coatings on bamboo shoots by the dip-coating method.

Postharvest Treatments and Storage of Minimally Processed Bamboo Shoots

Bamboo shoot slices were immersed for 5 minutes in various coating formulations: distilled water (T_1, control), 1% carboxymethyl cellulose (T_2), and a combination of 1% carboxymethyl cellulose with 1% ascorbic acid (T_3). After coating, the slices were air-dried at room temperature for 30 minutes. After treatment, 12 to 15 bamboo shoot slices were put into polyethylene terephthalate (PET) punnets, each with a snap-on lid. The samples were stored at 5 ± 2 °C for 6 days. We recorded colour attributes (L* and BI), weight loss, and biochemical parameters every two days (Plate. 2).

Assessment of Physiological Loss in Weight, Colour Attributes and Browning Index

Physiological loss in weight (PLW) of minimally processed bamboo shoots was determined by measuring the weight of the slices during the 6-day storage period and comparing it to their initial weight, using a precision electronic balance (Model CY 223C, ACZET Pvt. Ltd., India). PLW was expressed as a percentage loss relative to the initial weight.[23] We measured colour changes in bamboo slices stored in the refrigerator with a colour analyzer. Before taking measurements, we calibrated the device with standard white and black tiles. We then calculated the Browning Index (BI), which shows how much browning has occurred in processed foods, using the methodology followed by kumar *et al* 2018b).

Estimation of Total Soluble Solids (TSS), Titratable Acidity (TA), and Ascorbic Acid (AA) content

Total soluble solids (TSS) in bamboo shoot samples were measured using a digital refractometer (Milwaukee Instruments, Inc., USA), and the results were expressed as a percentage. Titratable acidity (TA) was determined according to the method described by Kumar *et al*. (2024).[24] Ascorbic acid content was determined using the 2,6-dichlorophenolindophenol titration method. One gram of fresh bamboo shoot sample was homogenized with 3% metaphosphoric acid solution and filtered. The clear supernatant was titrated against the standardized dye until a light pink colour persisted, indicating the endpoint. The ascorbic acid content was expressed as mg per 100 g fresh weight (FW).[25]

Assessment of Total Phenolic Content and Antioxidant Activity

The total phenolic content (TPC) was determined according to the method developed by Singleton and Rossi. (1965).[26] One gram of bamboo shoot sample was homogenized with 80% methanol and centrifuged at 10,000 rpm for 20 minutes at 4 °C. Subsequently, 100 µL of the supernatant was collected, diluted with 3 mL of distilled water, Next, Fallowed by addition of 0.5 mL of Folin–Ciocalteu reagent (FCR). Afterward, 3 minutes addition of 2 mL of Na_2CO_3 and the mixture was mixed well. Absorbance was measured at 760 nm with a spectrophotometer, and results were given as mg gallic acid equivalent (GAE) per 100 g fresh weight. The antioxidant activity of bamboo shoot slices was measured using the method from Apak *et al*. (2004).[27] Results were reported as µmol Trolox equivalent per gram (µmol Trolox g^{-1}).

Sensory Evaluation

Sensory evaluation of minimally processed bamboo shoot samples was conducted following the method opted by Kumar *et al*., (2024).[24] The sensory scores of minimally processed bamboo shoots were evaluated based on colour, texture, aroma, taste, and overall acceptability. A panel of semi-trained experts provided feedback scores using a five-point hedonic score, where 1 ware indicated 'very poor' and 5 were indicated 'excellent'.

Statistical Analysis

All analyses of the bamboo shoot samples were performed, and results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was conducted to identify significant differences ($p < 0.05$) among the treatment means. Subsequently, Duncan's Multiple Range Test (DMRT) was applied to separate the means.

Results

Physiological Loss in Weight (PLW)

Moisture loss significantly influences the quality of fresh-cut products. Minimally processed bamboo shoots are particularly vulnerable to weight loss resulting from evaporation and increased metabolic activity. Throughout the six-day refrigeration period, all samples exhibited a significant increase in weight loss (Fig. 1a). The control sample showed the highest PLW at 5.2%, while the samples coated with CMC 1% and AA 1% had the lowest value at 4.26%.

Weight loss increased progressively throughout the storage period (Fig. 3a).

Colour and Browning Index

There were statistically significant differences ($p < 0.05$) in the L*, a*, and b* colour values. This shows that hydrocolloid coatings helped keep the colour and reduce discoloration (Fig. 1b, c, and d). Among the treatments, the highest L* value was observed in the CMC 1% + AA 1% treated samples control bamboo shoot slices (71.20), while the lowest was recorded in control bamboo shoot slices (69.17) after 6 days of storage. The minimum a* value was recorded in the control sample (3.11), whereas the maximum was observed in the CMC 1% treatment (4.60). The control sample had the highest b* value at 15.45. The lowest value, 13.80, was found in the CMC 1% + AA 1% treatment. Among the treatments, the highest browning index (BI) was recorded in the control (28.73), while the lowest was observed in CMC 1% + AA 1% treated samples (27.50) (Fig. 1e).

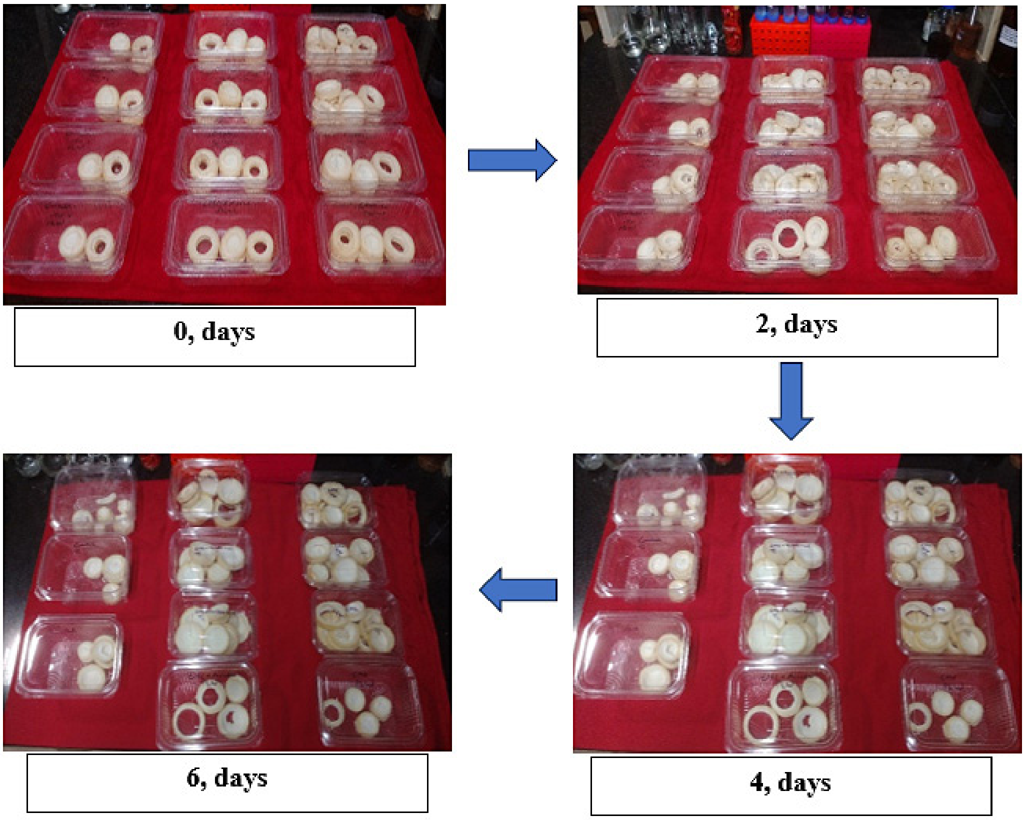

Plate. 2: Images illustrating the effect of edible coatings on the appearance of bamboo shoot slices during refrigerated storage.

Row 1 represents the uncoated control, Row 2 represents bamboo shoots coated with CMC 1% + Ascorbic Acid 1%, and Row 3 represents bamboo shoots coated with CMC 1%. The images depict visual changes occurring during storage under refrigerated conditions.

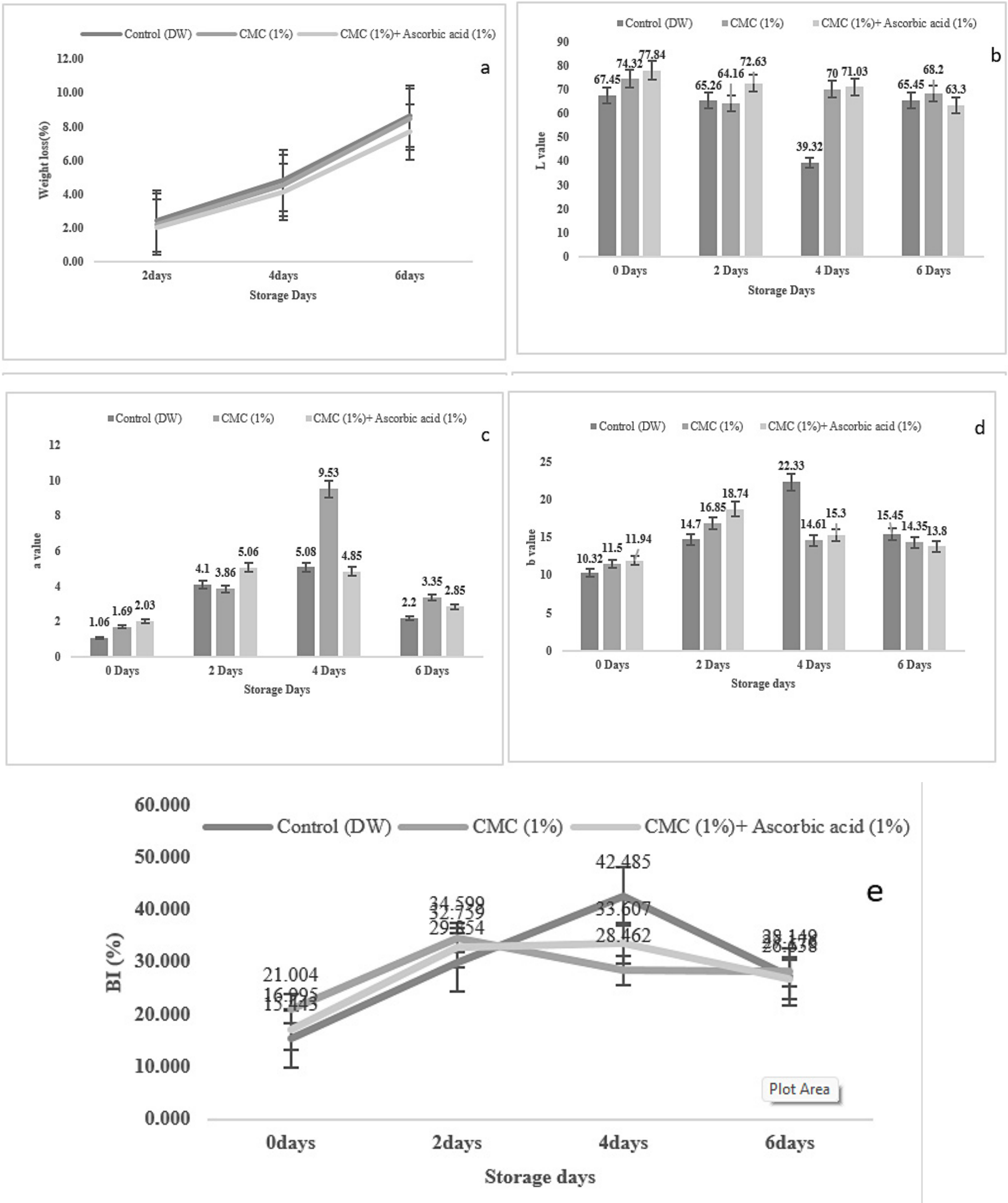

Fig. 1: Effect of CMC and anti-browning inhibitor on physiological loss in weight (PLW) (a), colour values (L, a and b) (b, c and d) and browning index (e) of minimally processed bamboo shoots during refrigerated storage

Total Soluble Solids and Titratable Acidity

Table 1a illustrate the changes in (TSS) in treated and control bamboo shoot slices during 6 days of storage. The highest TSS content was recorded in the CMC 1% + AA 1% treated samples (5.50%), while the lowest was observed in the control samples (4.40%). Table 1b indicated the changes in titratable acidity (TA) of both coated and uncoated bamboo shoot slices increased during the storage period. The maximum TA was recorded in the treated samples (1.0%), while the minimum was observed in the uncoated sample (0.88%).

Table 1a: Impact of CMC and anti-browning agents on total soluble solids (%) of minimally processed bamboo shoots during refrigerated storage condition

Treatment	Total soluble solids (%)				
	Storage interval (day)				
	0	2	4	6	Mean
Control	5.9 ± 0.06[a]	3.50 ± 0.035[c]	3.90 ± 0.039[c]	4.50 ± 0.045[b]	4.40 ± 0.51[b]
CMC (1%)	5.9 ± 0.06[a]	3.80 ± 0.038[b]	4.90 ± 0.049[b]	4.70 ± 0.047[b]	4.80 ± 0.48[b]
CMC (1%) + Ascorbic Acid (1%)	5.9 ± 0.06[a]	4.80 ± 0.048[a]	6.10 ± 0.061[a]	5.20 ± 0.052[a]	5.50 ± 0.01[a]
Mean	5.90	4.03	4.96	4.80	

Mean values in the same column followed by identical letters indicates no significant differences at ($p \leq 0.05$), as determined by DMRT.

Table 1b: Impact of CMC and anti-browning agents on titratable acidity (%) of minimally processed bamboo shoots during refrigerated storage condition

Treatment	Titratable acidity (%)				
	Storage interval (day)				
	0	2	4	6	Mean
Control	0.47 ±0.002[a]	0.96 ± 0.009[b]	0.96 ± 0.009[a]	1.11 ± 0.077[a]	0.88 ± 0.04[a]
CMC (1%)	0.47 ± 0.005[a]	1.44 ± 0.014[a]	0.96 ± 0.009[a]	1.12 ± 0.101[a]	1.00 ± 0.04[a]
CMC (1%) + Ascorbic Acid (1%)	0.48 ± 0.002[a]	0.96 ± 0.009[b]	1.14 ± 0.011[a]	1.12 ± 0.005[a]	1.00 ± 0.08[a]
Mean	0.47	1.12	1.12	1.12	

Mean values in the same column followed by identical letters indicates no significant differences at ($p \leq 0.05$), as determined by DMRT.

Ascorbic Acid Content and Total Phenolic Content (TPC)

Table 2a shows changes in ascorbic acid content over 6 days of refrigerated storage. The CMC 1% + AA 1% treatment had the highest ascorbic acid content (8.75 mg/100 g), while the control samples had the lowest (6.12 mg/100 g). Table 2b shows an increase in total phenolic content (TPC) in both treated and control bamboo shoot samples during 6 days of refrigerated storage. The highest TPC was recorded in the CMC 1% + AA 1% treatment (282.2 mg/100 g), while the lowest was observed in the CMC 1% samples (259.7 ± 0.97) after 6 days of storage.

Table 2a: Influence of CMC and anti-browning agents on ascorbic acid (mg 100 g-1) in minimally processed bamboo shoots under refrigerated storage conditions

Treatment	Ascorbic acid (mg 100 g-1)				
	Storage interval (day)				
	0	2	4	6	Mean
Control	7.00 ± 0.07[b]	7.00 ± 0.07[b]	3.50 ± 0.03[b]	7.00 ±0.10[b]	6.12 ± 0.04[c]
CMC (1%)	10.50 ± 0.10[b]	7.00 ± 0.07[b]	7.00 ± 0.07[b]	7.00 ± 0.07[b]	7.87 ± 0.02[b]
CMC (1%) + Ascorbic Acid (1%)	7.00 ± 0.07[b]	10.50 ± 0.10[b]	7.00 ± 0.07[b]	10.50 ± 0.10[b]	8.75 ± 0.02[a]
Mean	8.16	8.16	5.83	8.16	

Mean values in the same column followed by identical letters indicates no significant differences at ($p \leq 0.05$), as determined by DMRT.

Table 2b: Influence of CMC and anti-browning agents on total phenol content (mg 100 g-1) in minimally processed bamboo shoots under refrigerated storage conditions

Treatment	Total phenol content (mg 100 g-1)				
	Storage interval (day)				
	0	2	4	6	Mean
Control	135.00 ± 1.30[b]	180 ± 1.80[a]	299.60 ± 2.99[b]	453 ± 4.59[b]	266.9 ± 1.68[b]
CMC (1%)	125.50 ± 1.20[c]	170 ± 1.70[c]	294 ± 2.94[b]	449.5 ± 4.49[b]	259.7 ± 0.97[c]
CMC (1%) + Ascorbic Acid (1%)	180 ± 1.80[a]	190 ± 1.90[a]	300 ± 3.00[a]	459 ± 4.59[a]	282.2 ± 0.84[a]
Mean	146.80	180	297.80	453.80	

Mean values in the same column followed by identical letters indicates no significant differences at ($p \leq 0.05$), as determined by DMRT.

Table 3: Effect of carboxymethyl cellulose and anti-browning agents on antioxidant activity (µmol Trolox g-1FW) of minimally processed bamboo shoots during refrigerated storage condition

Treatment	Antioxidant activity (µmol Trolox g-1 FW)				
	Storage interval (day)				
	0	2	4	6	Mean
Control	10.75 ± 0.10[c]	2.45 ± 0.02[c]	5.75 ± 0.05[c]	5.55 ± 0.05[a]	6.13 ± 0.04[c]
CMC (1%)	11.25 ± 0.11[b]	7.65 ± 0.07[b]	6.25 ± 0.06[b]	3.92 ± 0.03[c]	7.27 ± 0.02[b]
CMC (1%) + Ascorbic Acid (1%)	11.55 ± 0.11[a]	8.85 ± 0.08[a]	6.62 ± 0.06[a]	4.50 ± 0.04[b]	7.88 ± 0.02[a]
Mean	11.18	6.31	6.20	4.62	

Mean values in the same column followed by identical letters indicates no significant differences at ($p \leq 0.05$), as determined by DMRT.

Antioxidant Activity

Table 3 shows that antioxidant activity in both treated and control samples decreased throughout the storage period. The highest antioxidant activity was recorded in the CMC 1% + AA 1% treatment (7.88 ± 0.02 μmol Trolox g^{-1}), while the lowest was observed in the uncoated sample (6.13 ± 0.04 μmol Trolox g^{-1}).

Sensory Evaluation

The mean scores of various organoleptic traits of minimally processed bamboo shoots are presented in Fig. 2. Assessment of sensory score was used 5-point hedonic scale. The texture, colour, aroma, taste, and overall acceptability were assessed. By the end of the storage period, minimally processed bamboo shoots treated with carboxymethyl cellulose (CMC) in combination with anti-browning agents exhibited superior retention of sensory quality compared to control samples.

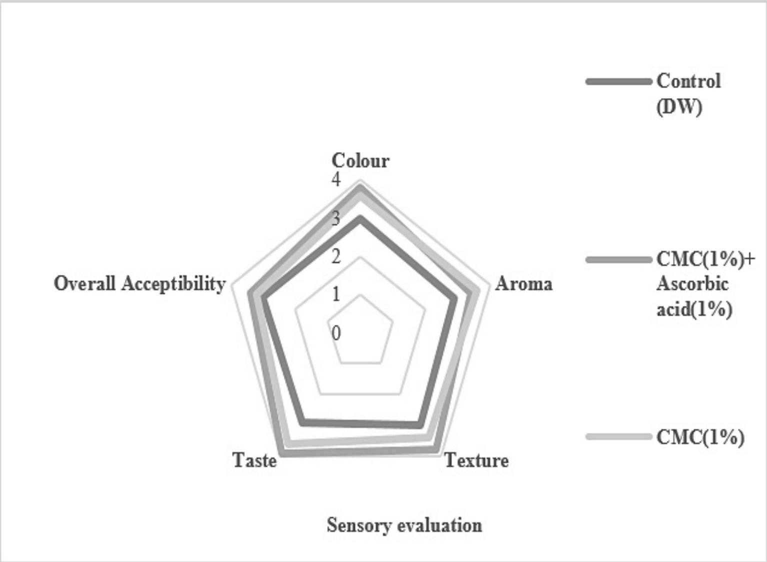

Fig. 2: Impact of CMC and anti-browning inhibitor on sensory evaluation of minimally processed bamboo shoots during refrigerated storage.

Discussion

The PLW in CMC (1%) + ascorbic acid (1%) treated bamboo shoot samples can be attributed to the formation of a semi-permeable coating layer that limits water vapour diffusion and oxygen exchange, thereby reducing respiration-associated substrate degradation. Ascorbic acid further moderates wound-induced oxidative metabolism, collectively reduces water loss and metabolic activity even under refrigerated storage.[15,16,17] Similarly, Pongprasert *et al*. (2007)[28] reported that weight loss was greatest in the control sample and lowest in both PVC- and vacuum-treated bamboo shoot slices. The finding of Zheng *et al*. (2022)[29] also reported that treatment with oxalic acid inhibited weight loss in bamboo shoots during storage. The finding of Kumar *et al*. (2018a) indicated that utilizing CMC, whether independently or in conjunction with anti-browning substances, reduced weight loss in fresh-cut apple slices during storage. This effect was attributed to the coating's low permeability to water vapor. These results are consistent with the findings of Singhal *et al*. (2013),[8] Li *et al*. (2019).[31] Colour is an important quality attribute that influences consumer preference. Browning results from mechanical damage that activates polyphenol oxidase (PPO), which catalyses the oxidation and subsequent polymerization of phenolic compounds, leading to the formation of brown pigments.[32-34] However, PPO activity is not the sole factor responsible for browning, as tissue discoloration may also be influenced by enzymes associated with senescence.[35] Pongprasert *et al*. (2007) found that using PVC and vacuum packaging helped reduce browning in bamboo shoots. The findings of Chinganbam *et al*. (2026)[36] also reported control sample had slower degradation of TSS and treated with CMC highest retention of TSS. According to the findings of Chinganbam *et al*. (2026)[36] The lower titratable acidity observed in the control group compared to the coated samples indicates that the CMC coating delayed the ripening process by forming a transparent layer around the fruits. Sharma *et al*. (2018)[37] found that the decline in ascorbic acid content in pineapple is due to oxidative degradation. Kumar *et al*. (2018b)[38] found that adding anti-browning agents to carboxymethyl cellulose (CMC) coatings effectively preserved the sensory qualities of fresh-cut apples during storage. Ballesteros *et al*. (2022)[39] reported that the acidity value more stable for CMC treated goldenberries then for uncoated goldenberries. Ballesteros *et al*. (2022)[39] observed significant changes in ascorbic acid content in goldenberries coated with CMC. This finding aligns with Abdullah *et al*. (2023),[40] who reported that coated strawberries had higher TSS than uncoated strawberries. The finding of Baswal *et al*. (2021)[41] reported that CMC coated 'Kinnow' mandarin fruit exhibited highest antioxidant activity as compared to uncoated mandarin. Earlier, the findings of Zheng *et al*. (2022)[29] treated bamboo shoots with oxalic acid and reported an increase in TPC along with a reduction in disease incidence during cold storage. Elevated phenolic levels have been shown to suppress browning enzyme activity, thereby preserving whiteness and minimizing discoloration in minimally processed pineapple cubes, consistent with findings by Kumar *et al*. (2018a).[30] Carboxymethyl cellulose (CMC) alone demonstrated efficacy in mitigating the decline of total phenolic content; however, its synergistic application with ascorbic acid proved more effective in preserving phenolic stability in pineapple cubes,[16,17] observed that antioxidants, including ascorbic acid, act as reducing agents capable of modulating the degradation of phenolic compounds by limiting their oxidative conversion. Kumar *et al*. (2018a)[30] found that applying an edible coating to fresh-cut apple slices significantly increased antioxidant activity compared to the control, suggesting better retention of bioactive compounds due to the coating's protective barrier.

Conclusion

Our study found that applying a carboxymethyl cellulose (CMC) coating with 1% ascorbic acid reduced weight loss and maintained colour integrity in minimally processed bamboo shoots during refrigerated storage. Samples treated with 1% CMC and 1% ascorbic acid demonstrated an extended shelf life of up to 6 days under refrigerated conditions (5 ± 2 °C), surpassing that of the control. Therefore, It can be inferred that CMC coating formulations that are combined with anti-browning agents have the potential to significantly extend the postharvest storage life and maintain the nutritional and sensory quality of minimally processed bamboo shoots. Future research should focus on the direct quantification of browning related enzymes and metabolic profiling to further elucidate the mechanistic basis of edible coating–mediated regulation of post-harvest metabolism and post-harvest quality retention in minimally processed bamboo shoots.

Acknowledgement

The authors are grateful to the Department of Post-Harvest Management, College of Horticulture and Forestry, Central Agricultural University (Imphal), Pasighat, Arunachal Pradesh, India, for providing the necessary laboratory and instrumental facilities to carry out this research.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflicts of Interest

The authors do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

Informed consent was obtained from all participants.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to reproduce material from other sources

Not Applicable

Author Contributions

- **Shubham Maurya:** Data Analysis, Methodology, Data Collection, Writing- Original Draft.
- **Pushpendra Kumar:** Conceptualization, Validation, Writing- Review & Editing.
- **Siddharth Madhukar Lokhande:** Review & Editing.
- **Gireesh Chand:** Review & Editing.
- **Okenmang Jamoh:** Review & Editing.
- **Gaidinglungliu Gonmei:** Review & Editing.
- **Monika Verma:** Review & Editing.

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