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RESEARCH ARTICLE

Eco-friendly edible coatings: Revolutionizing shelf-life extension for guava 'Allahabad Safeda'

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Abstract

Guava, a nutrient-rich but highly perishable fruit, has a limited shelf life, necessitating innovative solutions for preservation. This study investigated the efficacy of edible coatings in extending guava's storage life. Chitosan (0.5 %, 1 %, 1.5 %, 2 %), k-carrageenan (0.2 %, 0.4 %, 0.6 %, 0.8 %) and composite coatings of chitosan and k-carrageenan (0.5 %+0.2 %, 1 %+0.2 %, 1.5 %+0.2 %) were evaluated for their effects on guava stored at ambient temperatures over 15 days, following a completely randomized. Among the treatments, 1 % chitosan emerged as the most effective, minimizing reductions in physical attributes such as fruit length, width, firmness and pulp ratio, while significantly reducing physiological weight loss. Chitosan also excelled in preserving biochemical qualities. At various concentrations, it maintained the highest levels of total soluble solids (TSS), TSS-to-acid ratio, titratable acidity, pH and ascorbic acid content. Notably, the 0.5 % chitosan treatment optimized sugar profiles, showing the highest total sugar, reducing sugar and non-reducing sugar content. The findings highlight chitosan as a superior coating material for extending guava's shelf life while preserving its physical integrity and biochemical quality. Particularly, the 1 % chitosan treatment strikes an ideal balance, making it a promising, cost-effective solution for enhancing the marketability and post-harvest management of guava.

Keywords: chitosan; edible coating; guava; k-carrageenan; shelf life

Introduction

India ranks second globally in fruit production, trailing only China, with an estimated output of 107.24 million tonnes in 2021-2022, marking an increase of 4.76 million tonnes compared to 2020-2021. Notably, guava, a highly significant fruit, thrives on approximately 307000 hectares, yielding 4516 metric tonnes during this period. Despite horticultural crops utilizing just 13.1 % of the gross cropped area, they contribute 30.4 % to India's agricultural GDP (1). The horticulture sector overall adds about 33 % to the agricultural Gross Value Added (GVA). India leads global guava production, with Uttar Pradesh contributing 21.78 % of the country's total, followed by Punjab at 4.87 %, producing 219.85 tonnes, as per NHB data (2).

However, guava faces considerable post-harvest challenges, with the highest post-harvest loss among fruits in India, totalling 15.88 %. Storage losses account for 3.98 %, while packaging and transportation losses contribute 1.3 %. Effective solutions, including improved harvesting, storage, packaging and transportation, are crucial for mitigating these losses (3). Being a climacteric fruit, guava's shelf life is limited to just 3-4 days at room temperature, making it prone to rapid ripening, microbial spoilage and mechanical injury, which collectively reduce its marketability and economic returns (4). Edible coatings have emerged as an innovative and eco-friendly solution to address these challenges. These coatings act as a protective barrier, slowing the ripening process, minimizing water loss, regulating respiration and preventing microbial growth (5, 6). In addition to extending shelf life, they enhance the fruit's safety, appearance and sensory attributes while reducing packaging waste and maintaining structural integrity (7, 8).

Among edible coatings, chitosan and k-carrageenan stand out due to their unique properties. Chitosan, a biodegradable and biocompatible polysaccharide derived from shellfish, possesses antimicrobial and film-forming characteristics, effectively reducing water loss and bacterial contamination. K-carrageenan, sourced from red algae, is an excellent film-forming agent that inhibits weight loss and enhances freshness and biochemical properties (9, 10). Edible coatings also reduce packaging waste, protect against environmental damage and help preserve the aroma, taste and structural integrity of fruits and vegetables while extending shelf life (12, 13). Chitosan, comprising β-(1-4)-D-glucosamine and acetyl β-(1-4)-D-glucosamine, is derived from shellfish waste and is obtained through the alkaline deacetylation process (14).

These properties make chitosan prevent pre- and post-harvest diseases in fresh fruits through both water loss and respiration, thereby increasing the shelf life of the fruits. Chitosan coatings give a protective film against bacterial contamination and moisture loss, hence improving fruit storability (15). Besides, post-harvest treatment, chitosan is most utilized in pre-harvest treatment to conserve important properties, prolong shelf life and minimize the incidence of fungal rot once these fruits are put in storage post-harvest (16, 17). Kappa-carrageenan is a sulfated anionic polysaccharide sourced from red algae. It comprises copolymers of α-(1-3)-D-galactose and β-(1-4)-3,6-anhydro-D- or L-galactose. K-carrageenan's excellent film-forming properties make it suitable for various applications (18).

While individual coatings are effective, composite coatings of chitosan and k-carrageenan have demonstrated superior efficacy in improving the post-harvest quality of various fruits. This study evaluates the potential of these coatings, individually and in combination, to enhance guava's shelf life sustainably, without compromising its nutritional and sensory attributes. The findings underscore the environmental and economic advantages of these non-toxic, cost-effective solutions, aligning with modern, sustainable agricultural practices.

Materials and Methods

The study was conducted in the Horticulture Laboratory of the School of Agriculture at Lovely Professional University, Phagwara, Punjab, situated at 31˚1' N latitude and 75˚41' E longitude, with an elevation of 234 m above sea level. The region experiences a subtropical climate characterized by hot, dry summers and cold winters.

During the academic year 2021-2022, Phagwara exhibited significant seasonal temperature variations, with summer temperatures peaking at 45 °C between April and July and winter temperatures dipping below 5 °C from November to February. The experiment carried out from August to September, experienced relatively moderate conditions, with maximum and minimum temperatures averaging 35.57 °C and 25.90 °C, respectively. Morning relative humidity was recorded at 75.32 %, while evening humidity levels were slightly lower, at 64.29 %. These conditions provided a representative subtropical climate for conducting the experiment, ensuring relevance and applicability to similar agroclimatic zones.

Raw materials

Fruit samples of the guava variety "Allahabad Safeda," known for its mature green skin, uniform shape and medium to large size, were sourced from a well-maintained orchard in Kartarpur, Punjab, India (31.43° N, 75.49° E). To ensure uniformity and quality, only visually flawless fruits free from mechanical damage or blemishes were selected. The fruits were initially washed with distilled water to remove surface impurities and then sanitized using a sodium hypochlorite solution (150 mg/L concentration) to eliminate microbial contaminants, ensuring optimal pre-treatment hygiene (Control).

The experiment involved eleven distinct coating treatments; each was replicated three times. The treatments included different concentrations of chitosan (0.5 %, 1.0 %, 1.5 % and 2.0 %) sourced from Sigma-Aldrich Co., India and κ-carrageenan (0.2 %, 0.4 %, 0.6 % and 0.8 %) obtained from Foodchem International Corporation, China. In addition, composite coatings comprising chitosan and κ-carrageenan (0.5 % + 0.2 %, 1.0 % + 0.2 % and 1.5 % + 0.2 %) were also evaluated. An uncoated control group served as a baseline for comparison. Each fruit was meticulously coated to ensure even application, creating a protective barrier aimed at extending shelf life and preserving quality. The coated and control fruits were evaluated over a storage period using a range of physical and biochemical parameters. Physical traits assessed included fruit length, width, firmness, weight retention and disease incidence. Biochemical analyses measured total soluble solids (TSS), titratable acidity, TSS: acid ratio, pH, total sugars, reducing sugars, non-reducing sugars and ascorbic acid content were carried out following the protocols established by previous researchers (53-55). The metrics provided a comprehensive view of the effects of different coatings on the fruits' quality, shelf life and nutritional value.

Data collected during the study were subjected to rigorous statistical analysis using appropriate software tools (OPSTAT and Statistical Package for the Social Sciences (SPSS)) to ensure accuracy and reliability. The innovative combination of coatings and their systematic evaluation aimed to identify optimal formulations for enhancing the storage potential and marketability of guava fruit.

Results and Discussion

Length and width (mm)

The study evaluated the effects of various treatments on the length and width of guava fruits, revealing that 1 % chitosan coating exhibited the most effective results, with the least reduction in length (21.90 %) and width (22.03 %) compared to other treatments. Close behind was the 0.5 % chitosan treatment, whereas noncoated fruits experienced the most significant shrinkage, with length and width reductions soaring to 48.60 % and 58.39 %, respectively, as detailed in Table 1. These findings highlight the critical role of edible coatings in mitigating water loss, a primary driver of fruit shrinkage during storage. Furthermore, the fruit coated with K-carrageenan (0.6 %) also resulted in significantly higher fruit length and width reduction i.e. 37.14 % and 56.15 %, still the values were significantly superior in comparison to the non-coated fruit (control).

Water loss due to respiration and transpiration may form the principal cause of fruit shortening and narrowing, as the evaporation of moisture from the surface accelerates the dimensional decline. Notably, at ambient temperatures, prolonged storage leads to a gradual reduction in fruit dimensions, resulting in visible shrinkage. Similar trends have been reported in studies of pineapples coated with 1 % chitosan, which demonstrated minimal reductions in fruit length and width during storage (11, 19).

Chitosan's efficacy lies in its anti-senescent properties, which act as a shield against moisture loss and cellular degeneration. By curbing respiration rates and ethylene production, chitosan effectively delays senescence, maintaining the fruit's structural integrity and reducing shrinkage (20). Additionally, its ability to create a semi-permeable barrier on the fruit's surface restricts gas exchange and moisture evaporation, further preserving its dimensions (21). These results underscore the potential of chitosan-based edible coatings as a sustainable, cost-effective strategy to enhance the post -harvest quality of perishable fruits, offering a promising avenue for reducing post-harvest losses and extending marketable shelf life.

Table 1. Effect of different edible coating on length and width of Guava 'Allahabad safeda'

Treatments	Length (mm)			Width (mm)		
	Before coating (mm)	After coating (mm)	Per cent reduction (%)	Before coating (mm)	After coating (mm)	Percent reduction (%)
Chitosan (0.5 %)	4.85	3.75	22.32	5.00	3.83	23.21
Chitosan (1 %)	5.00	3.90	21.90	4.97	3.86	22.03
Chitosan (1.5 %)	4.53	3.32	26.81	5.24	3.11	40.38
Chitosan (2 %)	4.60	3.38	26.43	4.48	3.15	29.57
K-carrageenan (0.2 %)	4.42	3.22	27.10	4.98	2.94	40.83
K-carrageenan (0.4 %)	4.33	2.76	36.11	5.00	2.49	49.95
K –carrageenan (0.6 %)	4.24	2.66	37.14	5.56	2.43	56.16
K-carrageenan (0.8 %)	4.94	3.20	35.23	4.67	2.70	41.99
Chitosan (0.5 %) + K-carrageenan (0.2 %)	4.66	3.46	25.71	4.94	3.55	27.84
Chitosan (1 %) + K-carrageenan (0.2 %)	4.73	3.58	24.34	4.89	3.60	26.15
Chitosan (1.5 %) + K-carrageenan (0.2 %)	4.79	3.68	23.10	4.80	3.63	24.28
Control	4.09	2.10	48.60	5.30	2.20	58.39
Mean	4.60	3.25	29.56	4.98	3.12	36.73
CD (0.05)	0.28	0.20	5.95	0.42	0.20	7.32

Physiological loss in weight and firmness (N)

Physiological weight loss is an unavoidable phenomenon that affects all fruits after harvest, impacting their marketability and shelf life. In this study, guavas coated with 1 % chitosan exhibited significantly lower weight loss, retaining 93.27 % of their original weight by the end of storage, whereas uncoated fruits suffered a drastic 27.67 % loss (Table 2). The 0.5 % chitosan treatment was closely followed, with an 8.94 % reduction in weight. The superior performance of 1 % chitosan can be attributed to its ability to form a semi-permeable film, effectively reducing moisture loss while slowing down respiration and transpiration rates. Conversely, fruits coated with 0.6 % k-carrageenan showed the highest weight loss (27.01 %), followed by 0.4 % k-carrageenan (22.14 %), indicating its lower effectiveness in minimizing dehydration. Interestingly, the combined application of 1.5 % chitosan + 0.2 % k-carrageenan resulted in a notable reduction in weight loss (10.66 %), suggesting a synergistic effect that provided moderate protection. These findings reaffirm the effectiveness of chitosan-based coatings in delaying ripening, preserving moisture and enhancing overall fruit quality.

Firmness, a critical indicator of post-harvest fruit quality, is predominantly influenced by starch hydrolysis and the conversion of insoluble protopectins into soluble pectins. In the present study, guavas treated with 1 % chitosan retained 8.59 % firmness, experiencing only a 22.72 % reduction, the lowest among all treatments. This suggests that chitosan's anti-senescent properties played a pivotal role in minimizing cell degradation and structural breakdown. By limiting respiration and transpiration, the coating-maintained fruit integrity better than k-carrageenan. Parallel studies on strawberries treated with 1-1.5 % chitosan have reported similar improvements in firmness (22-T24). Interestingly, 2 % chitosan was found to provide the best firmness retention for guavas, closely followed by the 1 % chitosan treatment (25). These results underscore the remarkable potential of chitosan as a natural, eco-friendly post-harvest coating, effectively extending shelf life, preserving texture and minimizing fruit losses. By leveraging sustainable preservation techniques, chitosan offers a promising alternative to conventional synthetic coatings, aligning with the growing demand for green and biodegradable solutions in the fruit industry.

Disease incidence

Anthracnose, a critical post-harvest disease, significantly compromises the shelf life and quality of fruits, leading to considerable economic losses. The integration of natural antibacterial agents like edible coatings presents a sustainable solution to combat pathogenic organisms, minimize disease incidence and extend storage life (26, 27). In the present study, the guava variety 'Allahabad Safeda' was particularly vulnerable to anthracnose infection (Fig. 1). Remarkably, guavas coated with 1 % chitosan demonstrated delayed disease onset, with the first signs of anthracnose appearing only on the sixth day of storage, substantially later than other treatments. This extended the shelf life of the chitosan-coated guavas to 15 days, underscoring the coating's effectiveness.

Table 2. Effect of different edible coating on weight and firmness of Guava 'Allahabad safeda'

Treatments	Weight (gm)			Firmness (N)		
	Before coating (g)	After coating (g)	PLW (%)	Before coating	After coating	Percent reduction (%)
Chitosan (0.5 %)	132.93	121.00	8.94	11.13	8.44	23.84
Chitosan (1 %)	130.34	121.59	6.73	11.11	8.59	22.72
Chitosan (1.5 %)	124.94	101.55	18.71	11.90	7.33	38.41
Chitosan (2 %)	121.03	103.92	14.13	10.34	7.50	27.49
K-carrageenan (0.2 %)	124.56	99.95	19.73	10.88	6.63	38.96
K-carrageenan (0.4 %)	121.87	94.85	22.14	10.89	6.04	44.42
K –carrageenan (0.6 %)	128.32	93.62	27.01	10.99	5.92	46.01
K-carrageenan (0.8 %)	124.57	98.99	20.49	10.20	6.20	39.14
Chitosan (0.5 %) + K-carrageenan (0.2 %)	126.15	108.51	13.95	10.71	7.78	27.25
Chitosan (1 %) + K-carrageenan (0.2 %)	126.03	110.45	12.35	10.90	7.95	26.88
Chitosan (1.5 %) + K-carrageenan (0.2 %)	128.51	114.85	10.66	11.10	8.37	24.41
Control	119.33	86.29	27.67	7.80	4.13	46.98
Mean	125.71	104.63	16.87	10.66	7.07	33.87
CD (0.05)	3.93	4.81	3.96	0.90	0.93	9.05

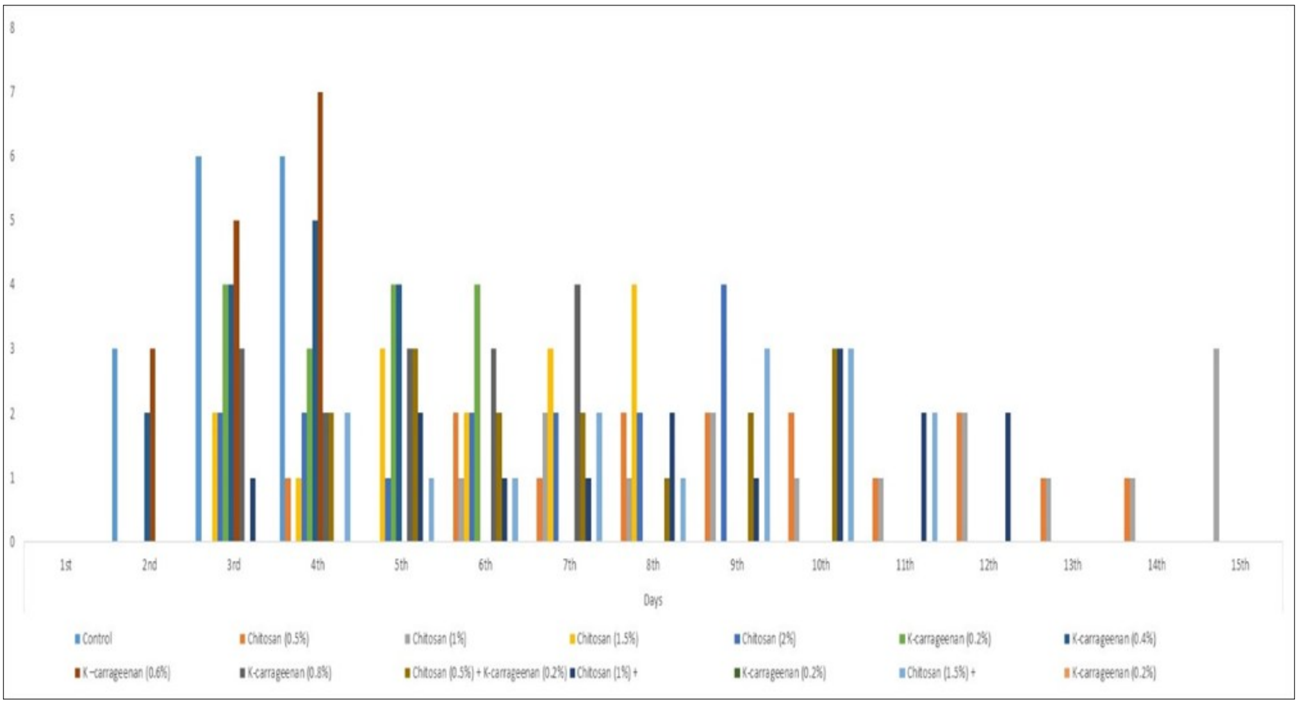

Fig. 1. Effect of edible coating on disease incidence of Allahabad safeda'.

The protective action of chitosan can be attributed to its ability to create a semi-permeable film around the fruit surface, which acts as a barrier against fungal pathogens by restricting their activity and growth (28). Research in other fruit crops, such as papaya, supports these findings, where 1 % chitosan treatment significantly inhibited the growth of anthracnose-causing fungi by disrupting their development cycle (29). Similarly, studies on the banana cultivar 'Embul' reported a substantial reduction in disease incidence and an extended shelf-life following chitosan application (28).

The delayed disease progression observed in the study highlights the potential of chitosan as a cost-effective, eco-friendly and efficient post-harvest treatment compared to all other treatments in the present study. By reducing the impact of anthracnose and extending fruit longevity, chitosan-based coatings improve marketability and contribute to sustainable post-harvest management practices, offering significant advantages to producers and consumers alike.

Total soluble solids (TSS), titratable acidity (TA), TSS: Acid ratio

TSS, a key indicator of fruit ripening and quality, were significantly influenced by storage duration and edible coating applications. As a climacteric fruit, guava naturally experiences an increase in TSS during ripening due to the enzymatic conversion of starch into simple sugars (30). The application of edible coatings in the present study further modulated this process, with 1 % chitosan-treated fruits exhibiting the highest TSS level (11.69 ˚B) closely followed by 0.5 % application of chitosan among all the treatments towards maturity with enhanced shelf life (Table 3). In contrast, control fruits recorded 11.81 ˚B towards maturity with significantly higher loss in physiological weight of the fruit. The enhanced TSS accumulation in coated guavas may be attributed to regulated enzymatic activity, which optimizes ripening while reducing excessive water loss and fruit softening. Hydrolysis of polysaccharides and the subsequent breakdown of complex organic molecules into simpler sugars further contributed to the observed increase; however, the coated fruits were still able to showcase a superior shelf life over the uncoated fruits (31, 32). Similar trends were also reported in sweet

Table 3. Effect of different edible coatings on TSS, acidity and TSS: Acid ratio of Guava 'Allahabad safeda

Treatments	TSS		Acidity		TSS: Acid ratio	
	Before coating	After coating	Before coating	After coating	Before coating	After coating
Chitosan (0.5 %)	9.54	11.38	0.73	0.52	14.14	21.83
Chitosan (1 %)	9.63	11.69	0.66	0.42	14.53	27.48
Chitosan (1.5 %)	9.16	10.50	0.95	0.85	9.66	12.57
Chitosan (2 %)	9.24	10.58	0.93	0.79	9.88	13.49
K-carrageenan (0.2 %)	9.97	10.30	0.84	0.65	10.78	15.90
K-carrageenan (0.4 %)	9.90	10.26	0.92	0.75	9.64	13.73
K –carrageenan (0.6 %)	9.80	10.46	0.88	0.70	10.09	13.77
K-carrageenan (0.8 %)	9.16	10.47	0.80	0.58	11.32	18.28
Chitosan (0.5 %) + K-carrageenan (0.2 %)	9.33	10.86	0.81	0.62	11.50	17.36
Chitosan (1 %) + K-carrageenan (0.2 %)	9.47	11.31	0.79	0.54	12.00	20.88
Chitosan (1.5 %) + K-carrageenan (0.2 %)	9.39	11.00	0.80	0.56	11.75	19.54
Control	9.43	11.81	0.70	0.40	13.69	21.53
Mean	9.24	10.54	0.81	0.61	11.58	18.03
CD (0.05)	0.29	0.47	0.18	0.11	2.97	3.24

cherries, where TSS levels increased from 17.11˚B to 22.49˚B with a 1 % chitosan treatment (33-35). Furthermore, the fruits coated with different concentrations of k-carrageenan also resulted in a significant increase in fruit TSS towards maturity; however, the fruit possessed a lesser shelf life as compared to the fruits coated with chitosan. Among all the k-carrageenan treatments the fruits coated with 0.6 % k-carrageenan resulted in higher fruit TSS (10.46 ºB) closely followed by the fruits coated with 0.2 % concentration (10.30 ºB).

Similarly, titratable acidity (TA), a crucial factor in determining fruit flavor and shelf stability, presented a progressive decline throughout the storage period. This reduction is likely driven by the respiratory metabolism of organic acids, which serve as primary substrates for energy production. Initially, organic acids undergo rapid oxidation and hydrolysis, but as respiration slows, acid breakdown decreases, leading to a decline in TA (36). In this study, 1.5 % chitosan-coated fruits maintained the highest TA (0.85 %), followed by 2 % chitosan (0.79 %), while the control group recorded the lowest TA (0.40 %). This trend aligns with findings in strawberries, where chitosan treatments preserved higher acidity levels during storage, contributing to prolonged freshness and delayed senescence (37). A similar decline was also reported in the fruits coated with different concentrations of k-carrageenan. It was observed that the fruits coated with 0.8 % concentration resulted in the lowest value of TA (0.58 %), whereas the fruits coated with 0.4 % resulted in the highest values for titratable acidity (0.75 %). Furthermore, the fruits coated with the combined application of chitosan and k-carrageenan also presented a significant decline in the titratable acidity towards maturity. However, the values were still significantly superior in comparison to the control (uncoated fruits).

The TSS: acid ratio, a balance between sweetness and acidity, exhibited a consistent upward trend from the initial to the final day of storage. The highest TSS: acid ratio (27.48 %) was recorded in 1 % chitosan-treated fruits, followed by 0.5 % chitosan (21.83 %), with 1.5 % chitosan showing the lowest ratio (12.57 %). This increase suggests that as storage progresses, the rise in TSS levels, coupled with the decline in TA, contributes to improved flavor development (38). Comparable results have been observed in mangoes, where chitosan-treated fruits exhibited higher TSS and TSS: acid ratios, reinforcing its role in maintaining fruit quality (39). Similarly, research on apples coated with 1 % chitosan demonstrated parallel trends in TSS enhancement and acid retention, supporting the effectiveness of chitosan in prolonging shelf life and maintaining fruit quality (40).

Therefore, among all the treatments, Chitosan (1 %) emerged as the most effective, striking an optimal balance between increasing Total Soluble Solids (TSS) and retaining acidity, thereby ensuring superior sensory and biochemical quality in guava. Meanwhile, k-carrageenan (0.2 %) and its combination with Chitosan (1 %) demonstrated notable efficacy in moderating TSS retention and maintaining acidity, showcasing their potential as viable alternatives. In stark contrast, the control group exhibited rapid deterioration, underscoring the indispensable role of edible coatings in prolonging guava's shelf life. The findings further established chitosan-based coatings as superior to k-carrageenan, offering enhanced preservation by slowing down ripening, reducing acidity loss and maintaining overall fruit quality. These results highlight the immense potential of chitosan as a natural, eco-friendly preservative, paving the way for sustainable post-harvest management strategies in the fruit industry.

Total sugar, reducing sugar, non-reducing sugar (%)

Total sugar content serves as a critical marker of fruit ripening, reflecting the metabolic transformations that occur during storage. In this study, a gradual decline in total sugar levels was observed across all treatments, with guavas coated in 0.5 % chitosan maintaining the highest sugar content (8.60 %), followed closely by the 1 % chitosan treatment (8.30 %). Conversely, the control group exhibited the most pronounced reduction, dropping to 6.59 % (Table 4). The ability of edible coatings to preserve sugar levels can be attributed to their protective barrier, which minimizes moisture loss, restricts oxygen diffusion and curbs sugar oxidation and degradation, ultimately preventing premature fermentation (40, 41). A similar pattern has been previously reported in guavas, where total sugar levels progressively declined towards the end of the storage period (42).

The findings further revealed that guavas treated with 0.5 % chitosan retained the highest levels of reducing (4.53 %) and non-reducing sugars (4.06 %), followed closely by those coated with 1 % chitosan. In contrast, the control fruits displayed the lowest values for reducing (3.76 %) and non-reducing sugars (2.82 %), reinforcing the

Table 4. Effect of different edible coatings on total sugar, reducing sugar and non-reducing sugar of Guava 'Allahabad safeda'

Treatments	Total sugar		Reducing sugar		Non reducing	
	Before coating	After coating	Before coating	After coating	Before coating	After coating
Chitosan (0.5 %)	9.10	8.60	4.90	4.53	4.20	4.06
Chitosan (1 %)	8.85	8.30	4.85	4.45	4.00	3.84
Chitosan (1.5 %)	8.40	7.70	4.62	4.14	3.78	3.56
Chitosan (2 %)	8.50	7.82	4.68	4.21	3.81	3.60
K-carrageenan (0.2 %)	8.20	7.39	4.55	3.97	3.65	3.41
K-carrageenan (0.4 %)	8.16	7.16	4.53	3.89	3.63	3.27
K –carrageenan (0.6 %)	8.00	6.92	4.46	3.80	3.54	3.11
K-carrageenan (0.8 %)	8.37	7.57	4.60	4.03	3.77	3.54
Chitosan (0.5 %) + K-carrageenan (0.2 %)	8.60	7.95	4.74	4.29	3.85	3.65
Chitosan (1 %) + K-carrageenan (0.2 %)	8.79	8.20	4.80	4.40	3.98	3.80
Chitosan (1.5 %) +	8.68	8.06	4.77	4.34	3.91	3.72
Control	7.72	6.59	4.44	3.76	3.28	2.82
Mean	8.44	7.69	4.66	4.15	3.79	3.53
CD (0.05)	0.34	0.23	0.18	0.32	0.39	0.40

rapid metabolic depletion that occurs in unprotected fruits. Reducing sugar levels play a crucial role in fruit senescence, as they serve as primary substrates for respiration and energy metabolism. Over time, their depletion accelerates ripening and quality deterioration (43). However, edible coatings act as metabolic modulators by slowing respiration rates and delaying sugar conversion, thereby extending the fruit's shelf life and maintaining its biochemical integrity (44). Interestingly, while this study observed an overall reduction in sugar content, contrasting research has reported a steady increase in total, reducing and non-reducing sugars throughout storage (45). This suggests that the impact of edible coatings on sugar metabolism may vary depending on formulation, storage conditions and fruit physiology, highlighting the need for further investigation into optimized preservation strategies.

While chitosan-based treatments exhibited strong efficacy, k-carrageenan at 0.2 % demonstrated notable potential in maintaining total, reducing and non-reducing sugars (Table 4). Fruits treated with 0.2 % k-carrageenan retained considerable sugar levels post-storage, offering a protective barrier against metabolic degradation and delaying ripening. Moreover, the combination of 1 % chitosan with 0.2 % k-carrageenan further enhanced sugar preservation, suggesting a complementary interaction between the two biopolymers. This synergistic effect helped reduce sugar loss while maintaining fruit integrity over the storage period. Compared to the control group, which experienced a sharp decline in sugar content (total sugar reduced to 6.59 % and non-reducing sugar to 2.82 %), k-carrageenan-based treatments significantly mitigated enzymatic breakdown, preventing rapid deterioration. While 1 % chitosan remained the most effective in preserving sugar content, k-carrageenan provided a viable alternative, particularly when used in combination. This study highlights the potential of k-carrageenan as an eco-friendly, effective post-harvest treatment, demonstrating its ability to enhance guava shelf life while maintaining biochemical quality.

Ascorbic acid (mg/100 g) and pH

The study comprehensively assessed the impact of different edible coatings on ascorbic acid retention and pH stability in guava during storage. The results highlighted chitosan-based treatments as the most effective in preserving ascorbic acid levels, followed by k-carrageenan and their combined applications. In contrast, the control group exhibited the most rapid decline. Among all treatments, guavas coated with 1 % chitosan maintained the highest ascorbic acid content (135.29 mg/100 g), closely followed by the blend of 1 % chitosan with 0.2 % k-carrageenan (131.01 mg/100 g) (Table 5). These coatings effectively minimized oxidative degradation, thereby safeguarding the fruit's nutritional quality (46). Other chitosan treatments, including 0.5 %, 1.5 % and 2 %, also exhibited superior retention compared to k-carrageenan alone.

Similarly, K-carrageenan at 0.2 % and 0.4 % also demonstrated moderate ascorbic acid preservation (118.85 mg/100 g and 116.69 mg/100 g, respectively), while higher concentrations (0.6 % and 0.8 %) resulted in comparatively lower retention. This suggests that while k-carrageenan contributed to ascorbic acid stabilization, its efficacy peaked at lower concentrations. The study further revealed variations in guava pH across treatments. Fruits coated with 1 % chitosan exhibited the highest pH (5.90), indicating its ability to slow acidity loss and delay ripening. The combination of 1 % chitosan with 0.2 % k-carrageenan also maintained pH stability (5.60), suggesting a synergistic effect between these coatings in prolonging fruit freshness. Conversely, the control group exhibited the lowest pH (4.83), indicating accelerated degradation and heightened acidity.

The superior performance of chitosan-based coatings in preserving ascorbic acid and pH can be attributed to their low oxygen permeability, which restricts enzymatic oxidation and limits ascorbic acid breakdown (47). Additionally, the slightly acidic nature of chitosan may function as an antioxidant, further mitigating ascorbic acid loss (48). The enzymatic conversion of ascorbic acid to dehydroascorbic acid also contributed to the observed decline, reinforcing the role of edible coatings in slowing this process (49). These findings align with previous research demonstrating the effectiveness of chitosan in maintaining ascorbic acid levels in guava over extended storage periods (49). Moreover, the observed increase in pH during storage is likely due to the metabolic transformation of organic acids into sugars, a natural consequence of fruit respiration (50). Enzymatic activity and the gradual depletion of organic acids further contribute to this trend (51). The consistency of these findings with previous studies on tomatoes and strawberries underscores the ability of chitosan-based coatings to modulate fruit physiology, reduce post-harvest losses and extend shelf life (52, 53). This study establishes that 1 % chitosan is the most effective edible coating for maintaining guava's nutritional integrity and delaying ripening, while k-carrageenan and its combinations provide additional benefits. The integration of these coatings presents a natural, sustainable approach to post-harvest fruit preservation, offering promising applications for the fresh produce industry.

Table 5. Effect of different edible coatings on ascorbic acid and pH of Guava 'Allahabad safeda'

Treatments	Ascorbic acid (mg/100gm)		pH	
	Before Coating	After Coating	Before Coating	After Coating
Chitosan (0.5 %)	185.11	132.64	5.63	5.66
Chitosan (1 %)	193.15	135.29	5.88	5.90
Chitosan (1.5 %)	164.89	120.92	5.22	5.33
Chitosan (2 %)	168.50	121.80	5.30	5.49
K-carrageenan (0.2 %)	156.86	118.85	5.13	5.16
K-carrageenan (0.4 %)	152.72	116.69	5.05	5.13
K –carrageenan (0.6 %)	145.89	115.62	4.89	4.96
K-carrageenan (0.8 %)	161.11	119.58	5.18	5.23
Chitosan (0.5 %) + K-carrageenan (0.2 %)	170.26	122.73	5.38	5.53
Chitosan (1 %) + K-carrageenan (0.2 %)	181.14	131.01	5.56	5.60
Chitosan (1.5 %) + K-carrageenan (0.2 %)	177.41	129.04	5.42	5.56
Control	139.99	70.66	4.78	4.83
Mean	166.42	119.57	5.29	5.36
CD (0.05)	14.16	16.71	0.44	0.45

Conclusion

The present study highlights the significant potential of chitosan and k-carrageenan-based edible coatings in preserving the post-harvest quality of guava, effectively enhancing its shelf life and nutritional integrity. Among all treatments, 1 % chitosan emerged as the most effective, maintaining optimal fruit firmness, minimizing weight loss, delaying disease incidence and preserving biochemical attributes such as total soluble solids, acidity and ascorbic acid content. This superior performance can be attributed to chitosan's ability to form a semi-permeable barrier, restricting respiration, transpiration and microbial proliferation, thereby extending guava's marketability. K-carrageenan, particularly at 0.2 %, also demonstrated notable efficacy, moderating sugar retention and delaying acidity loss. However, its effectiveness was maximized when combined with chitosan, suggesting a synergistic effect in maintaining fruit freshness. The chitosan-k-carrageenan composite coatings (1 % + 0.2 %) provided an enhanced protective effect, reinforcing the viability of these natural polymers as eco-friendly, biodegradable alternatives to conventional chemical preservatives.

The findings underscore the transformative role of edible coatings in the fresh produce industry, addressing key challenges related to post-harvest losses, food safety and consumer demand for sustainable preservation methods. By integrating chitosan and k-carrageenan coatings into commercial post-harvest management, producers can significantly reduce fruit wastage, optimize storage conditions and offer high-quality guava with improved nutritional, sensory and economic value. As global trends shift towards green, sustainable food preservation technologies, the application of natural biopolymer coatings like chitosan and k-carrageenan stands as a pioneering solution for reducing post-harvest losses while ensuring food security and sustainability. Future research should explore their scalability across different fruit varieties, investigate molecular interactions at the biochemical level and optimize coating formulations for commercial adoption. By embracing these innovative preservation strategies, the agricultural and food industries can revolutionize post-harvest management, ensuring fresher, healthier and longer-lasting produce for global markets.

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Authors' contributions

KJS conceived and designed the research study. SB contributed to experimental planning, data collection and the drafting of the primary manuscript. VJ assisted in data interpretation, critical revision of the manuscript, and overall supervision of the work. AK supported statistical analysis and validation of experimental results. VB contributed to laboratory experimentation and prepared figures and tables. SV assisted in sample processing, literature review and data organization. RK contributed to the methodological framework and provided technical support during experimentation. ST assisted in manuscript editing, proofreading and final formatting. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

The authors affirm that the present study was carried out in accordance with ethical guidelines and institutional rules. No human participants or animals took part in this research. All data were obtained through standard experimental methods, and there are no ethical conflicts of interest related to this work. The authors also declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

Conflict of interest: The authors declare that they have no known financial, professional, or personal conflicts of interest that could have influenced the research, authorship, or publication of this manuscript.

Ethical issues: None

References

1. Tiwari A, Afroz SB, Kumar V. Market vulnerabilities and potential of horticulture crops in India: With special reference to top crops. Indian Journal of Agricultural Marketing. 2021;35(3):1-20.
2. National Horticulture Board. Model project reports. 2022.
3. NABCONS. Study report of post-harvest losses. 2022.
4. Chen N, Wei W, Yang Y, Chen L, Shan W, Chen J, et al. Postharvest physiology and handling of guava fruit. Foods. 2024;13(5):805. https://doi.org/10.3390/foods13050805
5. Shanta SS, Ahmed T, Jubayer MF, Sharma M, Sridhar K, Hoque MM, et al. Effect of taro corm mucilage and black seed oil as edible coatings on the shelf-life and quality of fresh guava. Agronomy. 2023;13(2):538. https://doi.org/10.3390/agronomy13020538
6. Wu J, Zhang L, Fan K. Recent advances in polysaccharide-based edible coatings for preservation of fruits and vegetables: A review. Critical Reviews in Food Science and Nutrition. 2024;64(12):3823-38. https://doi.org/10.1080/10408398.2022.2136136
7. Shaifali M, Bakshi M. Shelf-life enhancement of guava (*Psidium guajava* L.) fruit using novel coating materials. The Pharma Innovation Journal. 2021;10:792-7.
8. Parmar BK, Mohite AS, Pathan DI, Desai AS, Wasave SM. The use of herbs and spices in fish preservation at chilled temperature storage: opportunities and challenges. International Journal of Food Science & Technology. 2022.
9. Nair MS, Saxena A, Kaur C. Effect of chitosan and alginate-based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). Food Chemistry. 2018;240:245-52. https://doi.org/10.1016/j.foodchem.2017.07.122
10. Kumar L, Ramakanth D, Akhila K, Gaikwad KK. Edible films and coatings for food packaging applications: A review. Environmental Chemistry Letters. 2022;1-26. https://doi.org/10.1007/s10311-021-01339-z
11. Jurić M, Bandić LM, Carullo D, Jurić S. Technological advancements in edible coatings: Emerging trends and applications in sustainable food preservation. Food Bioscience. 2024:103835. https://doi.org/10.1016/j.fbio.2024.103835
12. Sharma HP, Chaudhary V, Kumar M. Importance of edible coating on fruits and vegetables: A review. Journal of Pharmacognosy and Phytochemistry. 2019;8(3):4104-10.
13. Ghidelli C, Pérez-Gago MB. Recent advances in modified atmosphere packaging and edible coatings to maintain the quality of fresh-cut fruits and vegetables. Critical Reviews in Food Science and Nutrition. 2018;58(4):662-79. https://doi.org/10.1080/10408398.2016.1211087

14. Elsabee MZ, Abdou ES. Chitosan-based edible films and coatings: A review. Materials Science and Engineering: C. 2013;33(4):1819-41. https://doi.org/10.1016/j.msec.2013.01.010

15. Shiekh RA, Malik MA, Al-Thabaiti SA, Shiekh MA. Chitosan is a novel edible coating for fresh fruits. Food Science and Technology Research. 2013;19(2):139-55. https://doi.org/10.3136/fstr.19.139

16. Giacalone G, Chiabrando V. Effect of preharvest and postharvest application of chitosan coating on storage quality of nectarines. In: VIII International Peach Symposium. 2013;1084:675-80. https://doi.org/10.17660/ActaHortic.2015.1084.90

17. Reddy MB, Belkacemi K, Corcuff R, Castaigne F, Arul J. Effect of pre-harvest chitosan sprays on post-harvest infection by *Botrytis cinerea* and quality of strawberry fruit. Postharvest Biology and Technology. 2000;20(1):39-51. https://doi.org/10.1016/S0925-5214(00)00108-3

18. Li L, Ni R, Shao Y, Mao S. Carrageenan and its applications in drug delivery. Carbohydrate Polymers. 2014;103:1-1. https://doi.org/10.1016/j.carbpol.2013.12.008

19. Hazbavi E, Khoshtaghaza MH, Mostaan A, Banakar A. Effect of storage duration on some physical properties of date palm (cv. Stamaran). Journal of the Saudi Society of Agricultural Sciences. 2015;14(2):140-6. https://doi.org/10.1016/j.jssas.2013.10.001

20. Mandal D, Takey B, Lalhruaitluangi N. Influence of essential oils and chitosan on quality attributes and shelf life of pineapple cv. Giant Kew at ambient storage. Journal of Postharvest Technology. 2022;10(4):124-34.

21. Hosseini MS, Zahedi SM, Abadía J, Karimi M. Effects of postharvest treatments with chitosan and putrescine to maintain quality and extend shelf-life of two banana cultivars. Food Science & Nutrition. 2018;6(5):1328-37. https://doi.org/10.1002/fsn3.662

22. El Ghaouth A, Arul J, Ponnampalam R, Boulet M. Chitosan coating effect on storability and quality of fresh strawberries. Journal of Food Science. 1991;56(6):1618-20. https://doi.org/10.1111/j.1365-2621.1991.tb08655.x

23. Krishna KR, Rao DS. Effect of chitosan coating on the physiochemical characteristics of guava (*Psidium guajava* L.) fruits during storage at room temperature. Indian Journal of Science and Technology. 2014;7(5):554. https://doi.org/10.17485/ijst/2014/v7i5.4

24. Maqbool M, Ali A, Ramachandran S, Smith DR, Alderson PG. Control of postharvest anthracnose of banana using a new edible composite coating. Crop Protection. 2010;29(10):1136-41. https://doi.org/10.1016/j.cropro.2010.06.005

25. No HK, Park NY, Lee SH, Meyers SP. Antibacterial activity of chitosan and chitosan oligomers with different molecular weights. International Journal of Food Microbiology. 2002;74(1-2):65-72. https://doi.org/10.1016/S0168-1605(01)00717-6

26. Jinasena D, Pathirathna P, Wickramarachchi S, Marasinghe E. Use of chitosan to control anthracnose on Embul banana. International Conference on Asia Agriculture and Animal. 2011;13:56-60.

27. Hewajulige IG, Sivakumar D, Sultanbawa Y, Wilson Wijeratnam RS, Wijesundera RL. Effect of chitosan coating on the control of anthracnose and overall quality retention of papaya (*Carica papaya* L.) during storage. Ist International Symposium on Papaya. 2005;740:245-50. https://doi.org/10.17660/ActaHortic.2007.740.29

28. Yousaf AA, Abbasi KS, Ibrahim MS, Sohail A, Faiz M, Khadim M. Storage stability assessment of guava (*Psidium guajava* L.) cv. Gola in response to different packaging materials. Sustainable Food Technology. 2024;2(1):210-21. https://doi.org/10.1039/D3FB00113J

29. Radi M, Firouzi E, Akhavan H, Amiri S. Effect of gelatin‐based edible coatings incorporated with *Aloe vera* and black and green tea extracts on the shelf life of fresh‐cut oranges. Journal of Food Quality. 2017;2017:9764650. https://doi.org/10.1155/2017/9764650

30. Hernandez-Munoz P, Almenar E, Del Valle V, Velez D, Gavara R. Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria* × *ananassa*) quality during refrigerated storage. Food Chemistry. 2008;110(2):428-35. https://doi.org/10.1016/j.foodchem.2008.02.020

31. Zeb S, Sajid M, Shah ST, Ali M, Ali S, Nawaz Z, et al. Influence of post-harvest application of chitosan on physico-chemical changes of apple fruit during storage. Pure and Applied Biology. 2020;9(4):2554-62. https://doi.org/10.19045/bspab.2020.90271

32. Abdipour M, Malekhossini PS, Hosseinifarahi M, Radi M. Integration of UV irradiation and chitosan coating: A powerful treatment for maintaining the postharvest quality of sweet cherry fruit. Scientia Horticulturae. 2020;264:109197. https://doi.org/10.1016/j.scienta.2020.109197

33. Gupta OP, Singh BP, Gupta AK. Studies on the shelf life of different guava cultivars. Haryana Agricultural University Journal of Research. 1979;9(3):247-50.

34. Gol NB, Patel PR, Rao TR. Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. Postharvest Biology and Technology. 2013;85:185-95. https://doi.org/10.1016/j.postharvbio.2013.06.008

35. Shahid MN, Abbasi NA. Effect of bee wax coatings on physiological changes in fruits of sweet orange cv. Blood Red. Sarhad Journal of Agriculture. 2011;27(3):385-94.

36. Mandal D, Takey B, Lalhruaitluangi N. Influence of essential oils and chitosan on quality attributes and shelf life of pineapple cv. Giant Kew at ambient storage. Journal of Postharvest Technology. 2022;10(4):124-34.

37. Sharma B, Nigam S, Verma A, Garg M, Mittal A, Sadhu SD. A biogenic approach to develop guava-derived edible copper and zinc oxide nanocoating to extend shelf life and efficiency for food preservation. Journal of Polymers and the Environment. 2024;32(1):331-44. https://doi.org/10.1007/s10924-023-02972-1

38. Vyas PB, Gol NB, Rao TR. Postharvest quality maintenance of papaya fruit using polysaccharide-based edible coatings. International Journal of Fruit Science. 2014;14(1):81-94. https://doi.org/10.1080/15538362.2013.801753

39. Shaifali M, Bakshi M. Shelf-life enhancement of guava (*Psidium guajava* L.) fruit using novel coating materials. The Pharma Innovation Journal. 2021;10:792-7.

40. Dave RK, Ramana Rao TV, Nandane AS. Improvement of post-harvest quality of pear fruit with optimized composite edible coating formulations. Journal of Food Science and Technology. 2017;54:3917-27. https://doi.org/10.1007/s13197-017-2850-y

41. Zhou Y, Hu L, Chen Y, Liao L, Li R, Wang H, et al. The combined effect of ascorbic acid and chitosan coating on postharvest quality and cell wall metabolism of papaya fruits. LWT. 2022;171:114134. https://doi.org/10.1016/j.lwt.2022.114134

42. Abbasi KS, Anjum N, Sammi S, Masud T, Ali S. Effect of coatings and packaging material on the keeping quality of mangoes (*Mangifera indica* L.) stored at low temperature. Pakistan Journal of Nutrition. 2011;10(2):129-38. https://doi.org/10.3923/pjn.2011.129.138

43. Dang QF, Yan JQ, Li Y, Cheng XJ, Liu CS, Chen XG. Chitosan acetate as an active coating material and its effects on the storage of *Prunus avium* L. Journal of Food Science. 2010;75(2):S125-31. https://doi.org/10.1111/j.1750-3841.2009.01483.x

44. Ayranci E, Tunc S. The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.). Food Chemistry. 2004;87(3):339-42. https://doi.org/10.1016/j.foodchem.2003.12.003

45. Singh N, Georget DM, Belton PS, Barker SA. Physical properties of zein films containing salicylic acid and acetylsalicylic acid. Journal of Cereal Science. 2010;52(2):282-7. https://doi.org/10.1016/j.jcs.2010.06.008

46. Kumar JY, Singh V, Johar V. The effect of edible coating materials to enhance storage life of guava (*Psidium guajava* L.) cv. L-49. Pharma Innovation Jr. Hort. 2022;11(6):522-5.

47. Kazimi R, Saxena D. Application of *Aloe vera* gel on shelf-life of grape (*Vitis vinifera* L. var. Shindokhani). Editorial Board. 133.

48. Khodaei D, Hamidi-Esfahani Z, Rahmati E. Effect of edible coatings on the shelf-life of fresh strawberries: A comparative study using TOPSIS–Shannon entropy method. NFS Journal. 2021;23:17-23. https://doi.org/10.1016/j.nfs.2021.02.003

49. Athmaselvi KA, Sumitha P, Revathy BJ. Development of *Aloe vera*-based edible coating for tomato. International Agrophysics. 2013;27(4). https://doi.org/10.2478/intag-2013-0006

50. AOAC. Associate of Official Analytical Chemists, Official Methods of Analysis. 1965.

51. Rangana S. Manual of analysis of fruit and vegetable products. 1979.

52. Khare SR, Adhikary K, Bhati D, Pandey D, Singh V. Influence of bio-edible and nano-enriched coatings on the enhancement of shelf life of guava (*Psidium guajava* L.) cv. Allahabad Safeda. Plant Archives. 2024;24(2):1177-86. https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.167

53. Singh P, Sharma R, Verma S. Role of edible coatings and nanomaterials in improving postharvest quality and storability of tropical fruits. Journal of Food Biochemistry. 2024;48(2):e14723.

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