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RESEARCH ARTICLE

Effect of lipid-polysaccharide edible coatings on enhancing shelf life and quality of guava (Arka Kiran)

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Abstract

The physicochemical properties of guava (Arka Kiran) fruits were examined in relation to pre- and post-harvest treatments, both individually and in combination, using various edible compounds, including hexanal, chitosan and salicylic acid. The fruits were treated with different concentrations of hexanal (2%), chitosan (1%) and salicylic acid (500 ppm) and assessed for various physico-chemical parameters. In the storage study, guava fruits treated with these edible compounds were stored under both ambient conditions (30°C ± 1° C) and cold storage conditions (10 ± 2°C). The fruits treated with 2% hexanal demonstrated the most significant improvements in quality-related parameters under cold storage and ambient conditions. The combination of pre-harvest spray and post-harvest treatments using 2% hexanal in cold storage significantly delayed physiological weight loss (24.55%), preserved total soluble solids (10.25 °Brix) and maintained ascorbic acid content (135.05µg) by the 18th day of the storage period. Furthermore, pre-and post-harvest treatment with chitosan under cold storage conditions significantly enhanced the retention of antioxidant activity and phenolic content in guava fruit. Overall, the treatment with 2% hexanal proved to be the most effective in regulating physicochemical changes and improving the storage quality of guava fruits.

Keywords

Arka Kiran; pre-harvest; post-harvest; storage; shelf life; quality

Introduction

Guava (*Psidium guajava* L.) belongs to the Myrtaceae family and is India's fourth most important crop. Known for its high vitamin and nutritional content, it is often referred to as the "poor man's apple" and the "apple of the tropics" (1). Guava pulp contains more vitamin C than citric fruits and has a higher concentration of vitamins A and B_1. The red-fleshed variety, Arka Kiran, has a relatively short shelf life and is rich in lycopene (2). Guava is a climacteric fruit with high levels of transpiration and respiration, exhibiting physiological characteristics similar to those of bananas. According to (3), the post-harvest shelf life of guava is limited to 3-4 days at 25 ± 2 °C because of its climacteric ripening process. However, this shelf life can be extended to six days when

harvested at the mature-green stage. The Central Institute of Post Harvest Engineering & Technology (CIPHET) reports that guava experiences the highest post-harvest losses, reaching 15.88%, with approximately 4% of the fruit deteriorating during storage (4).

Guavas are susceptible to chilling injury when stored at temperatures below 6°C, resulting in internal damage, nutrient loss, and decreased resistance to disease, which negatively affect their overall quality. Although refrigeration may offer a short shelf life extension, guavas generally struggle to maintain their quality for more than one week at room temperature, rendering standard cold storage methods ineffective (5). An alternative to address the challenges of cold storage for guava is using edible coatings, which effectively preserve fruit quality, extend shelf life and reduce postharvest losses. This approach represents a promising alternative to conventional storage methods and underscores the need for innovative preservation techniques like edible coatings to enhance shelf life and improve storage conditions (6). Edible coatings are applied as thin, transparent layers that significantly enhance the shelf life of fruits by incorporating natural additives. These coatings strengthen the fruit's epidermis against microbial decay, mechanical damage, water loss, and color changes while often providing a glossy appearance(7). Chitosan coatings, derived from chitin, reduce fungal decay and moisture loss by forming a semi-permeable barrier, making them particularly effective for fruits like strawberries. Whey protein coatings help prevent weight loss and browning in fresh-cut fruits such as apples by acting as a barrier against moisture and microbes. Gelatin, known for its film-forming properties, aids moisture retention and pathogen protection, especially in tropical fruits. Pectin coatings, useful for citrus fruits, improve texture and reduce respiration rates, while starch-based coatings slow ripening by limiting gas exchange. Additionally, natural wax coatings derived from plants help maintain the firmness and freshness of fruits like apples and pears during extended storage (8). These coatings effectively mitigate moisture loss, microbial spoilage and enzymatic browning, making them a promising solution for preserving the quality and extending the freshness of tropical fruits like guava.

Edible coating compounds demonstrate strong adhesive properties, drying quickly and retaining structural stability and functionality even after prolonged storage. They must remain flexible to adapt to morphological changes, such as mechanical damage or fruit shrinkage (9). Edible coatings, made of polysaccharides, proteins, lipids, or their combination, vary in effectiveness depending on composition and concentration (10). These coatings serve as barriers to water vapor, oxygen, carbon dioxide and lipid transfer within food systems, thereby enhancing preservation (11). Edible coatings reduce transpiration by providing an extra layer over the stomata, thereby minimizing weight loss. One of the key advantages of edible coatings is their ability to reduce physiological weight loss, as demonstrated in studies on various fruits and vegetables (12). Additionally, their effectiveness in minimizing microbial spoilage, moisture loss and enzymatic browning underscores their role in extending shelf life and maintaining produce quality.

Biomaterials, including polysaccharides, proteins, and lipids, have played a critical role in the advancement of food preservation, especially via the development of edible coatings. Among lipid-based edible coatings, hexanal-based options are notably effective, offering antimicrobial properties, delaying ripening and enhancing fruit quality. By inhibiting microbial growth and spoilage, hexanal extends shelf life, maintains firmness and reduces decay (13). Its designation as Generally Recognized as Safe (GRAS) by the U.S. Food and Drug Administration (FDA) underscores its safety and distinguishes it from other coatings. Although higher concentrations may impact flavor, hexanal's sensory profile can benefit specific products, such as dairy and nut-based foods (14). As a naturally occurring plant aldehyde, hexanal is a biotic stress defense and provides strong antioxidant and antimicrobial benefits, making it an effective and safe choice for edible coatings.

Chitosan, widely regarded in the food preservation industry for its robust antimicrobial activity, is also GRAS-certified by the U.S. FDA (15) (16). Known for extending the shelf life of perishable fruits, chitosan is a versatile, biodegradable and eco-friendly alternative to synthetic coatings (17). With its excellent properties and strong consumer acceptance, chitosan remains a leading choice among hydrocolloid edible coatings. Salicylic acid is another effective ingredient in edible coatings, known for delaying ripening, extending shelf life and preserving nutritional quality. Its cost-effectiveness, biodegradability and biocompatibility add to its appeal in food preservation. Research shows that salicylic acid coatings reduce decay and preserve antioxidant properties, protecting produce from oxidative stress (18). Its proven effectiveness, alongside benefits over other materials, like chitosan, make salicylic acid a top choice for improving the quality and longevity of perishable goods (19). Applying pre-harvest sprays significantly boosts fruit quality before storage by enhancing resistance to diseases and pests, which complements the protective effects of edible coatings. Examining these treatments highlights their impact on the inherent properties of the fruit, thereby optimizing postharvest management. Additionally, the synergy between pre-harvest and post-harvest treatments enhances the effectiveness of edible coatings; pre-harvest applications prepare fruits to better utilize the coatings, leading to longer shelf life and reduced spoilage (20). This research both evaluate the efficacy of hexanal, chitosan and salicylic acid in extending guava varieties' shelf life through the pre-harvest spray and post-harvest dip treatment under ambient and cold storage conditions. By leveraging the distinct properties of these biomaterials, the study aims to present a comprehensive approach to reducing post-harvest losses and maintaining guava fruits' freshness.

Materials and Methods

Sample collection

The experiment was conducted in Ayakudi, located in the Dindigul district, at 10° 44' N latitude and 77° 55' E longitude. The site experienced maximum and minimum temperatures of 39.5°C and 27.5°C, respectively, during the 2023-2024. The

experimental setup followed a Factorial Completely Randomized Design (FCRD) with twenty distinct treatments across two seasons, each replicated twice with 20 fruits per treatment unit. High-quality varieties like Arka Kiran, weighing 200-220 grams, were selected for their yield potential and marketability. Optimal maturity for this variety was identified between 103 and 120 days post-flowering, as immature or overripe fruits could compromise quality and increase losses. The favorable climate and soil of Ayakudi Palani in Tamil Nadu supported guava cultivation, enhancing fruit quality for both domestic and international markets. To ensure a comprehensive evaluation, the study employed three specific food-grade compounds (refer to Table 1) to assess their effects fully.

Chemical Preparations

The study utilized three food-grade chemicals: hexanal formulation, chitosan and salicylic acid, each prepared to ensure optimal solubility and efficacy. Due to the inherent immiscibility of hexanal with water, solubility was achieved by adding Tween 20 and ethanol, thereby enhancing its application potential(21).

Chitosan stock solutions were prepared using high-quality chitosan (Sigma-ID 448869-250G; degree of deacetylation ≥75, MW: 50-190 k Da). A 1% (w/v) solution was created by accurately weighing 10 g of chitosan and diluting it to 500 ml with distilled water in a volumetric flask. To aid in dissolution, 3 ml of glacial acetic acid was added, and the mixture was heated in a water bath for 15 minutes. Once fully dissolved, the solution was cooled to room temperature, making it stable and ready for application.

Salicylic acid solutions (6 liters at a concentration of 500 ppm) were freshly prepared using high-purity salicylic acid (Sigma Aldrich, Madrid). To improve effectiveness and ensure uniform application, 1 mL L^{-1} Tween-20, a non-ionic detergent, was added. These carefully prepared solutions aimed to maximize the effectiveness of hexanal, chitosan, and salicylic acid in extending the shelf life and improving the quality of guava fruits under varying storage conditions.

Guava fruits treatments

For the pre-harvest spray application, 32 guava trees at the flowering stage were randomly selected and tagged in a farmer's field. Various solutions of hexanal, chitosan, salicylic acid and a control (plain water) were sprayed 20 days before harvest. Both pre-and post-harvest treatment strategies were carefully chosen based on extensive research assessing their impact on the quality and shelf life of various crops. Studies indicate that pre-harvest mineral fertilization significantly enhances sugars, ascorbic acid, and polyphenols levels in fruits-key attributes that contribute to market appeal and nutritional quality (22).

The solutions were sprayed on the fruits until they began to drip, and the fruits were left on the trees until they reached the mature green stage. The treated fruits were then harvested for post-harvest analysis. Initially, pre-harvest treated fruits were kept separate; afterward, half of these fruits also underwent post-harvest treatments, as shown in Fig. 1. For the post-harvest dip, uniformly mature green fruits were selected and immersed in the same treatment solutions for 1 minute. The treated guavas were then stored under ambient and cold storage conditions to monitor and compare the effects of the different treatments. These coated fruits underwent comprehensive biochemical analysis at three-day intervals, continuing until the 18th day of storage.

Physiological loss in weight (%)

Each fruit's weight was measured and recorded at the beginning of storage using an electronic balance (Model: Opal, Manufacturer: Well worth Electronics). After that, fruit weights were measured at regular intervals of three days.

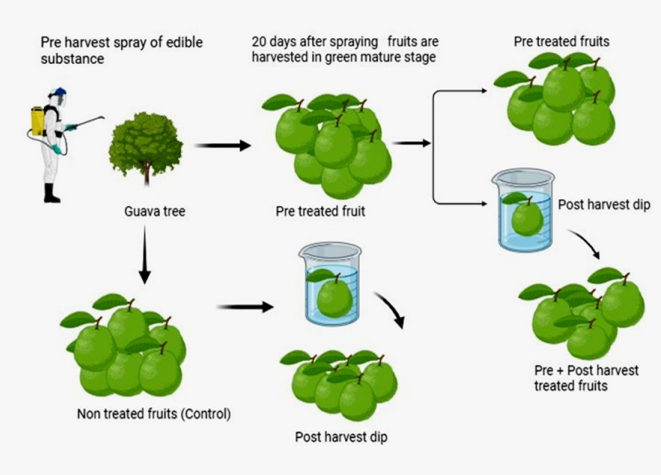

Fig. 1. Pictorial representation of pre-and post-harvest treatment in guava fruits

Table1. Treatment details for pre- and post-harvest treatment of guava

Factor A (Food grade chemicals)	Factor B (Storage Condition)	Treatment
C_1 - 2% hexanal **C_2** - 1 % Chitosan **C_3** - 500 ppm salicylic acid	**S_1** - Ambient condition (30°C ±°1C) **S_2**-Refrigerated condition (10°C±2°C)	**T_1** - Control **T_2** - Pre harvest spray of 2% hexanal **T_3** - Pre harvest spray of 1 % chitosan **T_4** - Pre harvest spray of 500 ppm salicylic acid **T_5** - Post harvest dip of 2% hexanal **T_6** - Post harvest dip of 1 % chitosan **T_7** - Post harvest dip of 500 ppm salicylic acid **T_8** - Pre + Post harvest dip of 2% hexanal **T_9** - Pre + Post harvest dip of 1 % chitosan **T_{10}** - Pre + Post harvest dip of 500 ppm salicylic acid

Total soluble solids (T.S.S)

A digital refractometer (Model: PAL 3, Manufacturer: Atago Ltd., Japan) was used to measure the total soluble solids (TSS) of the pulped guava fruits, with a range of 0% to 32%. The values were converted to the percentage TSS of guava fruits. Measurements, recorded in degrees Brix (°Bx), were taken at room temperature (average temperature: 28°C).

Titratable acidity (%)

The visual titration method was slightly modified to determine the acid content of guava pulp. 5g of guava pulp was crushed with distilled water using a mortar and pestle, filtered through Whatman No. 4 paper and diluted to 25 ml. A 10 ml aliquot of this filtrate was mixed with 10 ml of distilled water and a few drops of phenolphthalein indicator. The mixture was then titrated with 0.1N NaOH until a pink color appeared, marking the endpoint.

Total phenol

The Folin-Ciocalteu assay was slightly modified to assess the total phenol content in guava pulp. One gram of guava pulp was crushed with 80% methanol, then centrifuged at 10,000 rpm and 27°C with the supernatant used for the assay. A standard curve was established using gallic acid. In a test tube, 0.2 ml of Folin-Ciocalteu reagent (1N), 3.25 ml of distilled water, 0.5 ml of the methanol extract, and 1 ml of sodium carbonate (20%) were mixed. The mixture was incubated for 30 minutes at room temperature, and the resulting yellowish color was measured at 700 nm using a Thermo Scientific Genesys 180 UV-visible spectrophotometer.

Ascorbic acid (mg/100 g of pulp)

A total of 0.5 grams of guava pulp were homogenized with 10 ml of 4% oxalic acid and allowed to settle. A 5 ml aliquot of the supernatant was then diluted to 10 ml with 4% oxalic acid and titrated with 2, 6-dichlorophenol indophenol dye until a light pink color persisted for 30 seconds. A standard solution was prepared by dissolving 100 mg of ascorbic acid in 4% oxalic acid and diluting 10 ml to 100 ml, resulting in a standard ascorbic acid concentration of 0.1 mg/ml. This standard was titrated similarly to determine the standard titration value.

Total antioxidant

Antioxidant activity was assessed using the DPPH radical scavenging method. Five hundred milligrams of fruit pulp were macerated in 10 ml of methanol and then centrifuged at 4,000 rpm for 15 minutes. The resulting supernatant was diluted with methanol to estimate antioxidant activity. Absorbance was measured at 517 nm using a spectrophotometer, with methanol mixed with 0.5 ml of DPPH solution serving as the blank. The percentage of DPPH scavenging was then calculated using the appropriate formula.

Results and Discussion

Shelf life of guava

Fruit absorption rates are influenced by the type of coatings used and the storage conditions, which affect water and gas absorption, both essential for maintaining freshness. Coatings can alter fruit metabolism and absorption efficiency; some are specifically designed to reduce permeability, decreasing respiration while allowing for necessary gas exchange. Environmental factors, such as temperature and humidity, also play a significant role in fruit behavior; high humidity can enhance moisture absorption, whereas low humidity may lead to desiccation. Hexanal improves postharvest quality by reducing membrane disintegration, inhibiting enzyme activity, delaying ripening and preserving firmness. The interplay of coatings, storage conditions, and hexanal collectively enhances the preservation and quality of fruits (23).

The effects of various post-harvest treatments on guava shelf life are illustrated in Fig. 2. The most extended shelf life of 18.5 days was achieved with treatment T8S2, which involved pre- and post-harvest hexanal treatments under cold storage. In contrast, the shortest shelf life of 7 days was observed in the control group (T1S1) stored at ambient conditions. Hexanal and chitosan treatments significantly extended guava storage life, with hexanal demonstrating particularly effective results. Differences in shelf life among treatments may be attributed to varying fruit absorption rates. However, modifying internal atmospheres with edible coatings can sometimes result in low oxygen levels and anaerobic fermentation (24). Additionally, chitosan has proven effective in reducing weight loss in fruits such as strawberries (25).

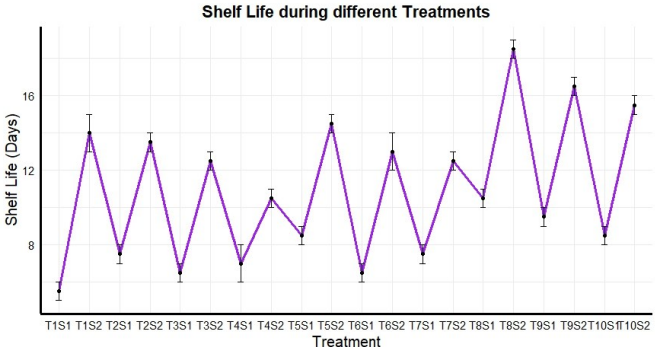

Fig.2. Effect of the edible compound on the shelf life of guava fruits in different storage conditions (Two-season pooled mean)

Physiological loss in weight

The physiological loss in weight (PLW), a critical indicator of guava fruit shelf life and quality, increased steadily throughout storage, as depicted in Table 2. Fruits treated with a 2% hexanal of pre + post-harvest treatment and stored under cold conditions exhibited the least physiological loss in weight, followed by those treated with a combination of chitosan and salicylic acid under the same conditions. The lowest weight loss was observed in fruits treated with 1% chitosan before and after harvest, followed by those treated with 500 ppm salicylic acid and stored at ambient temperature.

Respiration in fruits leads to weight loss and reduced quality as stored carbohydrates are metabolized, resulting in moisture and sugar depletion. This loss is accelerated by transpiration, which involves the evaporation of water from the fruit, ultimately impacting shelf life. Chitosan coatings help mitigate weight loss by forming a semi-permeable barrier that limits moisture migration and slows respiration

Table 2. Effect of edible compound on physiological losses in weight of guava fruits (Two-season pooled mean)

Treatments	Physiological loss in weight (%)					
	3rd day	6th day	9th day	12th day	15th day	18th day
$T_1 S_1$	8.35	11.35	*	*	*	*
$T_1 S_2$	8	11	13.65	16.6	19.3	22.4
$T_2 S_1$	6.95	9.7	11.9	*	*	*
$T_2 S_2$	6.85	9.9	12.05	16.4	19.05	22.65
$T_3 S_1$	6.65	9.8	12	*	*	*
$T_3 S_2$	6.7	5.17	12.25	16.8	18.75	23.45
$T_4 S_1$	7.3	9.7	12.35	*	*	*
$T_4 S_2$	7.15	9.8	12.6	15.4	18.15	21.9
$T_5 S_1$	7.1	9.6	12.7	*	*	*
$T_5 S_2$	7.05	9.7	12.05	16.35	18.4	21.55
$T_6 S_1$	7.1	9.5	12.5	*	*	*
$T_6 S_2$	7.15	9.4	12.2	14.4	18.25	23.35
$T_7 S_1$	7.15	8.3	11.7	*	*	*
$T_7 S_2$	6.85	8.75	10.7	15.4	17.85	22
$T_8 S_1$	6.35	9.35	11.5	*	*	*
$T_8 S_2$	5.85	8.5	10.65	14.25	16.15	20.65
$T_9 S_1$	5.85	7.4	11.4	*	*	*
$T_9 S_2$	6.7	9.7	12.55	16.85	18.15	24.55
$T_{10} S_1$	7.35	10.3	12	*	*	*
$T_{10} S_2$	6.15	10	12.4	15.45	16.3	21.4

Factors	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)
Factor (P)	0.307	0.642	0.975	2.034	0.345	0.72	0.153	0.319	0.251	0.525	0.691	1.442
Factor (S)	0.137	0.287	0.436	0.909	0.154	0.322	0.068	0.143	0.112	0.234	0.309	0.645
Factor (PS)	0.435	0.908	1.379	2.877	0.488	1.019	0.216	0.452	0.356	0.742	0.978	2.04

* Product Spoilage (data was not recorded)

Data are pooled mean of two replications (n=2)

rates. Studies have shown that these coatings significantly reduce respiration and weight loss in fruits such as strawberries and plums by enhancing antioxidant activity and inhibiting enzymes that accelerate ripening (26).

In summary, respiration contributes to weight loss, while chitosan coatings preserve fruit quality during storage (27). The reduced weight loss in chitosan-treated guavas aligns with findings in bananas reported by (28) and has also been observed in strawberries (29). Furthermore, tomatoes treated with Enhanced Freshness Formulation (EFF, 2 mM) as a post-harvest dip showed improved color, firmness and higher ascorbic acid content after 21 days of storage (30).

Total soluble solids

Total soluble solids (TSS) are crucial indicators of fruit quality, reflecting sugar content and sweetness, which influence consumer preference and market value. High TSS levels correlate with better flavor and nutritional value, while fluctuations during storage can signal potential spoilage. Initially, TSS may increase as fruits ripen, but they typically decline due to respiration and sugar depletion. Treated fruits can maintain taste and texture longer than untreated ones. Therefore, managing storage conditions, including temperature, humidity and coatings, is vital for preserving TSS and ensuring fruit quality throughout storage (31).

The impact of edible coatings and storage conditions on guava's total soluble solids (TSS) content was significant throughout storage, as depicted in Table 3. Guavas stored under refrigeration remained in good condition for up to 18 days, while those at ambient temperature lasted only 9 days. The lowest TSS change (10.25 °Bx on day 18) was observed in the T_8S_2 treatment (a pre- and post-harvest dip of 2% hexanal + cold storage). Under ambient conditions, the minimal TSS change (9.6 °Bx on day 6) was seen in T_8S_1 (a pre- and post-harvest dip of 2% hexanal). TSS increased gradually at low temperatures compared to ambient storage, likely due to the hydrolysis of polysaccharides and pectic substances into simpler sugars like glucose, fructose and sucrose, enhancing sweetness (32).

The combined effects of edible coatings and storage duration also significantly influenced TSS. In guavas treated with EFF (0.015% hexanal) and 0.02% hexanal, TSS decreased over 35 days, while control fruits showed an initial increase followed by a sharp decline after 14 days studied by (33).

Titratable acidity

A gradual decline in acidity was observed across all treatments during storage, likely due to acid metabolism, as shown in Table 4. The highest acidity (0.305) was found in fruits treated with T_9 (Pre + Post 1% chitosan + cold storage), while the lowest acidity (0.18) was found in fruits treated with T9 (pre- and post-harvest 1% chitosan + cold storage), while the lowest acidity (0.18) was recorded in the control group (distilled water dip). Among the treatments, 2% hexanal was also effective in maintaining higher acidity during cold storage. The retention of acidity in chitosan-treated fruits may be attributed to reduced hydrolysis. Hexanal formulations (1.5% and 2.0%) effectively slowed the degradation of titratable acidity during storage. In contrast, untreated control fruits exhibited a rapid decline in acidity over 45 days, linked to increased metabolic activity (34).

Table 3. Effect of the edible compound on Total Soluble Solids of guava fruits (Two-season pooled mean)

Treatments	Total Soluble Solids (TSS)					
	Storage Periods (Days)					
	3rd day	6th day	9th day	12th day	15th day	18th day
$T_1 S_1$	9.95	11.315	*	*	*	*
$T_1 S_2$	9.95	11.225	11.355	11.49	11.965	12.09
$T_2 S_1$	9.88	10.4	10.58	*	*	0
$T_2 S_2$	9.465	10.25	10.655	10.85	11.44	11.465
$T_3 S_1$	9.815	10.925	11.365	*	*	*
$T_3 S_2$	9.665	10.97	10.99	11.35	11.34	11.495
$T_4 S_1$	10.01	10.77	10.87	*	*	*
$T_4 S_2$	10.12	10.76	10.825	10.795	10.94	11.525
$T_5 S_1$	9.695	10.22	10.41	*	*	*
$T_5 S_2$	9.785	10.175	10.3	10.465	10.565	10.685
$T_6 S_1$	10.12	10.27	10.42	*	*	*
$T_6 S_2$	9.8	10.22	10.34	10.385	10.485	10.565
$T_7 S_1$	9.495	10.55	10.895	*	*	*
$T_7 S_2$	9.67	10.535	10.785	11.045	11.16	11.27
$T_8 S_1$	9.38	9.555	9.615	*	*	*
$T_8 S_2$	9.37	9.48	9.525	9.925	10.045	10.25
$T_9 S_1$	9.495	9.85	9.875	*	*	*
$T_9 S_2$	9.435	9.66	9.785	10.025	10.22	10.355
$T_{10} S_1$	9.59	9.96	9.96	*	*	*
$T_{10} S_2$	9.415	9.615	9.935	10.185	10.27	10.375

Factors	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)
Factor (P)	0.165	0.344	0.056	0.117	0.107	0.224	0.037	0.077	0.005	0.011	0.012	0.026
Factor (S)	0.073	0.154	0.025	0.052	0.048	0.1	0.016	0.034	0.002	0.005	0.005	0.011
Factor (PS)	0.233	0.487	0.079	0.165	0.152	0.317	0.052	0.109	0.007	0.016	0.018	0.037

* Product Spoilage (data was not recorded)

Data are pooled mean of two replications (n=2)

Table 4. Effect of the edible compound on Titratable acidity of guava fruits (Two-season pooled mean)

Treatments	Titratable Acidity					
	Storage Periods (Days)					
	3rd	6th	9th	12th	15th	18th
$T_1 S_1$	0.325	0.24	*	*	*	*
$T_1 S_2$	0.335	0.285	0.225	0.195	0.195	0.18
$T_2 S_1$	0.345	0.265	0.235	*	*	*
$T_2 S_2$	0.36	0.245	0.285	0.265	0.245	0.225
$T_3 S_1$	0.34	0.25	0.245	*	*	*
$T_3 S_2$	0.32	0.28	0.235	0.215	0.205	0.2
$T_4 S_1$	0.32	0.27	0.255	*	*	*
$T_4 S_2$	0.335	0.295	0.265	0.225	0.215	0.225
$T_5 S_1$	0.345	0.27	0.235	*	*	*
$T_5 S_2$	0.365	0.275	0.22	0.225	0.215	0.22
$T_6 S_1$	0.39	0.345	0.325	*	*	*
$T_6 S_2$	0.37	0.365	0.32	0.21	0.2	0.205
$T_7 S_1$	0.395	0.325	0.305	*	*	*
$T_7 S_2$	0.4	0.315	0.315	0.3	0.285	0.265
$T_8 S_1$	0.415	0.355	0.35	*	*	*
$T_8 S_2$	0.385	0.345	0.33	0.305	0.275	0.275
$T_9 S_1$	0.385	0.32	0.32	*	*	*
$T_9 S_2$	0.43	0.38	0.365	0.335	0.3	0.305
$T_{10} S_1$	0.375	0.325	0.305	*	*	*
$T_{10} S_2$	0.365	0.34	0.31	0.29	0.28	0.255

Factors	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)
Factor (P)	0.014	0.03	0.015	0.032	0.009	0.018	0.006	0.014	0.005	0.012	0.006	0.014
Factor (S)	0.006	0.013	0.007	0.014	0.004	0.008	0.003	0.006	0.002	0.005	0.003	0.006
Factor (PS)	0.02	0.043	0.022	0.046	0.012	0.026	0.009	0.02	0.008	0.017	0.009	0.02

*Product Spoilage (data was not recorded)

Data are pooled mean of two replications (n=2)

Ascorbic acid

The vitamin C content in guava fruits varied between 189.3 and 95.85 mg/100g across different edible coatings and storage conditions, as shown in Table 5. The highest retention of vitamin C was observed in treatment T_8S_2 (pre- and post-harvest dip of 2% hexanal + cold storage), which maintained ascorbic acid levels of 189.3 mg/100g on the first day and decreased to 135.05 mg/100g by the 18th day. This treatment significantly outperformed the control, indicating that the combination of hexanal and cold storage effectively minimized ascorbic acid loss, an essential antioxidant. The decline in ascorbic acid content over the storage period was notable across all treatments, with more rapid losses observed at ambient temperatures. Ascorbic acid (vitamin C) is primarily synthesized in fruits through the L-galactose pathway, with contributions from other pathways like L-glucose and D-galacturonic acid. During ripening, galactose is converted to ascorbic acid, which is crucial for fruit development. In contrast, organic acids like citric and malic acids are transformed into sugars, affecting flavor and vitamin C levels. Key enzymes, including L-galactose dehydrogenase, are vital in determining the final vitamin C concentration, which varies among species and during ripening, as acids are converted into sugars (35). This decrease in vitamin C content is consistent with previous findings in hexanal-treated guava (36). It can be attributed to ascorbic acid oxidase, which converts ascorbic acid into 2-dehydroascorbic acid (37).

Total antioxidant

Total antioxidant activity, which reflects the overall capacity to counteract oxidative stress, progressively decreased during storage and ranged from 4.86 to 2.21 mg Vit C eq g^{-1} FW, as depicted in Fig. 3. Both - and post-harvest treatments with 1% chitosan effectively slowed this decline, with the highest retention of antioxidant activity observed in fruits treated with 500ppm salicylic acid, followed by those treated with 2% hexanal. The antioxidant properties of chitosan are likely due to its capacity to bind metal ions at enzyme active sites, therefore blocking oxidative enzymes (38). These findings are consistent with similar studies conducted on grapes (39). Variations in antioxidant activity can be influenced by factors such as the fruit's inherent properties, extraction methods, solutions and specific antioxidant compounds. (40) reported antioxidant activities of 7,884.33 µg g^{-1} for yellow guava, 3,617 µg g^{-1} for red guava and 20,324.82 µg g^{-1} for general guava antioxidant levels across various Myrtaceae species. Furthermore, the antimicrobial properties of hexanal have been studied in both real and model systems against various spoilage microorganisms (41).

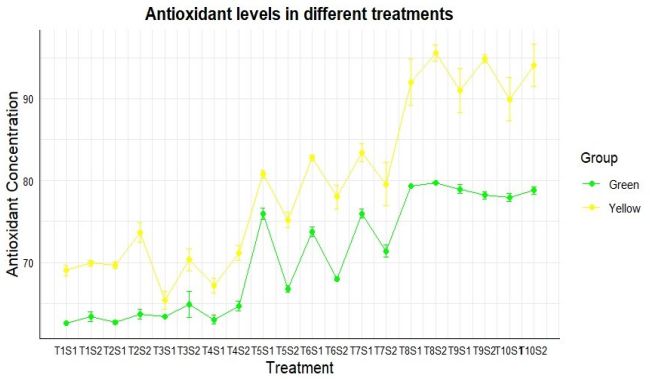

Fig.3. Effect of the edible compound on Total Antioxidant of guava fruits in different storage conditions (Two-season pooled mean)

Table 5. Effect of the edible compound on Ascorbic acid of guava fruits (Two-season pooled mean)

Treatments	Ascorbic acid					
	Storage Periods (Days)					
	3rd	6th	9th	12th	15th	18th
T_1S_1	9.95	11.315	*	*	*	*
T_1S_2	9.95	11.225	11.355	11.49	11.965	12.09
T_2S_1	9.88	10.4	10.58	*	*	*
T_2S_2	9.465	10.25	10.655	10.85	11.44	11.465
T_3S_1	9.815	10.925	11.365	*	*	*
T_3S_2	9.665	10.97	10.99	11.35	11.34	11.495
T_4S_1	10.01	10.77	10.87	*	*	*
T_4S_2	10.12	10.76	10.825	10.795	10.94	11.525
T_5S_1	9.695	10.22	10.41	*	*	*
T_5S_2	9.785	10.175	10.3	10.465	10.565	10.685
T_6S_1	10.12	10.27	10.42	*	*	*
T_6S_2	9.8	10.22	10.34	10.385	10.485	10.565
T_7S_1	9.495	10.55	10.895	*	*	*
T_7S_2	9.67	10.535	10.785	11.045	11.16	11.27
T_8S_1	9.38	9.555	9.615	*	*	*
T_8S_2	9.37	9.48	9.525	9.925	10.045	10.25
T_9S_1	9.495	9.85	9.875	*	*	*
T_9S_2	9.435	9.66	9.785	10.025	10.22	10.355
$T_{10}S_1$	9.59	9.96	9.96	*	*	*
$T_{10}S_2$	9.415	9.615	9.935	10.185	10.27	10.375

Factors	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)	SE (d)	CD (P=0.05)
Factor (P)	0.675	1.409	1.206	2.515	1.079	2.252	0.818	1.706	0.557	1.163	0.554	1.157
Factor (S)	0.302	0.63	0.539	1.125	0.482	1.007	0.365	0.763	0.249	0.52	0.248	0.517
Factor (PS)	0.955	1.993	1.705	3.558	1.526	3.184	1.156	2.413	0.788	1.644	0.784	1.636

* Product Spoilage (data was not recorded)

Data are pooled mean of two replications (n=2)

Total phenol

The phenolic content in guava fruits progressively declined during storage, ranging from 52 to 20.9 mg/g across different coatings under both ambient and cold conditions, as shown in Fig. 4. Treatments with 1% chitosan applied both pre-and post-harvest accelerated this reduction, with untreated fruits showing the most substantial decrease. According to (42), phenolic compounds typically diminish as fruits transition from ripe to overripe stages. In this study, guavas coated with 65 g/L solid lipid nanoparticles (SLN) exhibited only a minor decrease in total phenolic content (TPC) and these changes were not statistically significant ($p \leq 0.05$), suggesting that fruit ripening was delayed under the tested conditions.

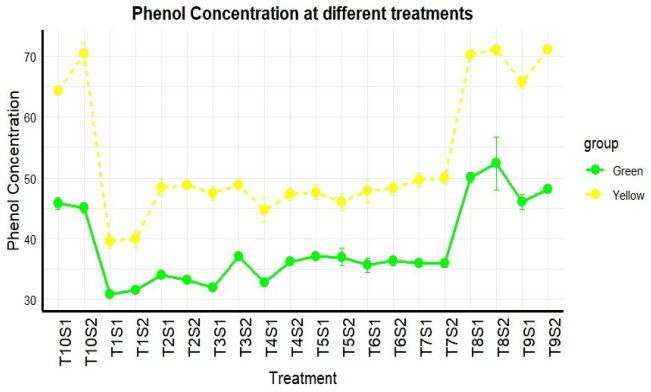

Fig. 4. Effect of the edible compound on total phenol of guava fruits in different storage conditions (Two-season pooled mean)

Conclusion

Hexanal and chitosan treatments significantly enhance guava quality during storage and transport, which is critical for effective supply chain management. By extending shelf life, these treatments support flexible inventory control, enhance market responsiveness and reduce food waste by slowing the ripening and spoilage processes. They help retain fruit firmness and nutrient levels, meeting consumer demand for high-quality produce. Additionally, employing hexanal displays a dedication to sustainability, improving company reputation and creating consumer loyalty. These treatments reduce physiological loss in weight (PLW), preserve total soluble solids (TSS) and sustain higher phenolic content and antioxidant activity throughout storage. Cold storage extends guava's shelf life to 18 days, compared to just 9 days under ambient conditions, underscoring the effectiveness of edible coatings in reducing post-harvest losses and enhancing marketability. With rising demand for premium fruits, hexanal -treated guava can command higher prices as consumer's value quality and extended freshness. Hexanal's regulatory approval as a safe edible coating further encourages producers to adopt this technology, positioning it as a valuable advancement in the fruit industry.

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Authors' contributions

P. J contributed to conceptualizing the review, methodology design, and overall supervision. K.R. V played a significant role in writing the original draft and editing the manuscript. A. N conducted the literature search, organized the data and wrote sections of the original draft. V. J contributed to the data visualization and formatting of the manuscript. K. G played a key role in writing parts of the original draft and in the review and editing process. J. S contributed to the formal analysis and validation of the collected data, participated in writing the manuscript and ensured the integrity of the review process. All authors reviewed and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this manuscript, the authors used ChatGPT to assist with paraphrasing content. After using this tool, the authors reviewed and edited the content as required and take full responsibility for the publication's content.

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