

Article

Improving postharvest shelf life of guava using edible natural extract coatings from Swarupkathi, Pirojpur district, Bangladesh

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Abstract: Guava (*Psidium guajava* L.) is a highly perishable tropical fruit that undergoes rapid postharvest deterioration, leading to significant losses in quality and market value. This study aimed to evaluate the effectiveness of natural plant extracts—ginger (*Zingiber officinale*), moringa (*Moringa oleifera*), and garlic (*Allium sativum*)—in maintaining the postharvest quality and extending the shelf life of guava fruits. Freshly harvested guavas were treated with aqueous extracts of these plants, while untreated fruits served as controls. All fruits were stored under ambient conditions for eight days, and changes in weight loss, firmness, total soluble solids (TSS), titratable acidity (TA), pH, vitamin C content, moisture, dry matter, and overall shelf life were analyzed using inferential statistical methods. Results showed that all fruits experienced a gradual loss of weight and firmness, but the extent varied among treatments. Ginger-treated fruits exhibited the least weight loss and highest firmness retention, followed by moringa and garlic, while control fruits deteriorated most rapidly. TSS increased over time in all samples, whereas TA and vitamin C declined, with ginger-treated fruits retaining higher acidity and vitamin C levels. A slight increase in pH and dry matter, and a corresponding decrease in moisture, were observed across all treatments. The estimated shelf life was longest in ginger-treated fruits (11.67 days), followed by moringa (10.67 days), garlic (8.67 days), and control (7.67 days). These findings indicate that ginger and moringa extracts can slow ripening, maintain nutritional quality, and provide practical, eco-friendly options for improving guava storage, reducing postharvest losses, and enhancing market value. The study provides practical guidance for farmers and the fruit industry to use ginger and moringa extracts as natural, cost-effective methods to enhance guava shelf life and marketability.

Keywords: guava preservation; fruit firmness; biochemical changes; natural coatings; storage stability

1. Introduction

Guava (*Psidium guajava* L.), a member of the Myrtaceae family, is one of the most widely cultivated and consumed tropical fruits in Bangladesh. Its popularity arises from its affordability, nutritional richness, and diverse health-promoting properties (Kumar *et al.*, 2021). Guava is an excellent source of vitamin C, pectin, and essential minerals such as potassium, manganese, magnesium, and phosphorus. The fruit typically contains significant amount of moisture, acidity, sugar, total soluble solids (TSS), and vitamin C (Tanveer, 2022). Guava seeds are also consumed for their high fiber and omega fatty acid content (Meena *et al.*, 2021). Due to its

nutritional value, taste, and affordability, guava plays a vital role in food security and nutrition, particularly among low-income populations in Bangladesh.

Despite its economic and nutritional significance, guava suffers from considerable post-harvest losses, mainly due to its highly perishable nature. Studies have reported losses up to 40% resulting from mechanical injury, poor handling, and lack of proper storage facilities (Chen *et al.*, 2024). Being a climacteric fruit, guava produces high levels of ethylene, which accelerate ripening, softening, and spoilage (Azam *et al.*, 2021). Consequently, its short shelf life reduces marketability and profitability, posing a serious challenge for growers, traders, and consumers. To provide fresh, high-quality guava throughout the year, effective post-harvest management practices are essential to maintain physicochemical and sensory quality while minimizing nutrient degradation (Rehman *et al.*, 2020; Zaidi *et al.*, 2023).

Numerous post-harvest treatments have been investigated to minimize spoilage and extend shelf life. These include edible coatings, gamma irradiation, calcium chloride, ascorbic acid, 1-methylcyclopropene (1-MCP), controlled atmosphere storage, and low-temperature storage (Shabir *et al.*, 2020; Ribeiro *et al.*, 2020; Moreira *et al.*, 2022; Kahar *et al.*, 2024; Zhang, 2024). Among these, edible coatings have recently gained significant attention as a simple, safe, and effective method for fruit preservation. Such coatings act as semi-permeable barriers that regulate moisture and gas exchange, slow down respiration, reduce microbial activity, and maintain fruit firmness and color (El-Gioushy *et al.*, 2022; Sharma *et al.*, 2023). They also offer an environmentally friendly alternative to chemical preservatives and are compatible with consumer preferences for natural products. However, identifying the most suitable natural coating or extract for guava remains an ongoing research need (Kohli *et al.*, 2024; Lekshmi *et al.*, 2025).

In Bangladesh, limited information is available on the use of natural edible coatings or plant extracts to extend the shelf life of guava, and the widely cultivated Swarupkathi variety is particularly prone to rapid softening and spoilage under ambient conditions due to the lack of cold-chain facilities and proper postharvest management. This study was designed to address this challenge by investigating whether natural extracts from ginger, moringa, and garlic—hypothesized to reduce moisture loss, delay softening, and maintain key biochemical attributes—can effectively prolong the storage life of guava fruits. The central research question guiding the work is: How do ginger, moringa, and garlic extracts influence the physicochemical properties and overall shelf life of Swarupkathi guava compared with untreated fruits? This study was conducted to evaluate the effects of ginger, moringa, and garlic extracts on the postharvest physicochemical properties and shelf life of Swarupkathi guava under ambient storage conditions. By generating evidence on the effectiveness of affordable, residue-free, and sustainable preservation methods, the study contributes knowledge that can support improved postharvest handling practices and enhance the stability and market quality of guava within local supply chains.

2. Materials and Methods

2.1. Ethical approval

No ethical approval was required to conduct the study.

2.2. Sample collection, experimental site, and climate

Guava samples were collected from Swarupkathi, Pirojpur, Bangladesh, a prominent guava-producing region renowned for its high-quality Swarupkathi variety. The experiment was carried out in the postharvest laboratory of the Department of Horticulture, Patuakhali Science and Technology University, from 28 August to 7 September 2025. Laboratory temperature and relative humidity were monitored daily at 10:00 am and 5:00 pm using a digital thermometer, with an average temperature of 27.4 °C and relative humidity ranging from 60 to 65% throughout the study period (Figure 1).

2.3. Experimental materials and design

The Swarupkathi variety of guava was used as the experimental material. Commercially mature fruits of uniform size and shape were harvested from a farmer's field in Swarupkathi, Pirojpur district, Bangladesh, and immediately transferred to the postharvest laboratory. Upon arrival, the fruits were cured, and their skins were gently cleaned using a soft cloth and water to remove any surface impurities. The experiments consist of four treatments viz., T0 = control; T1 = moringa (7%); T1 = ginger (25%); T1 = garlic (25%).

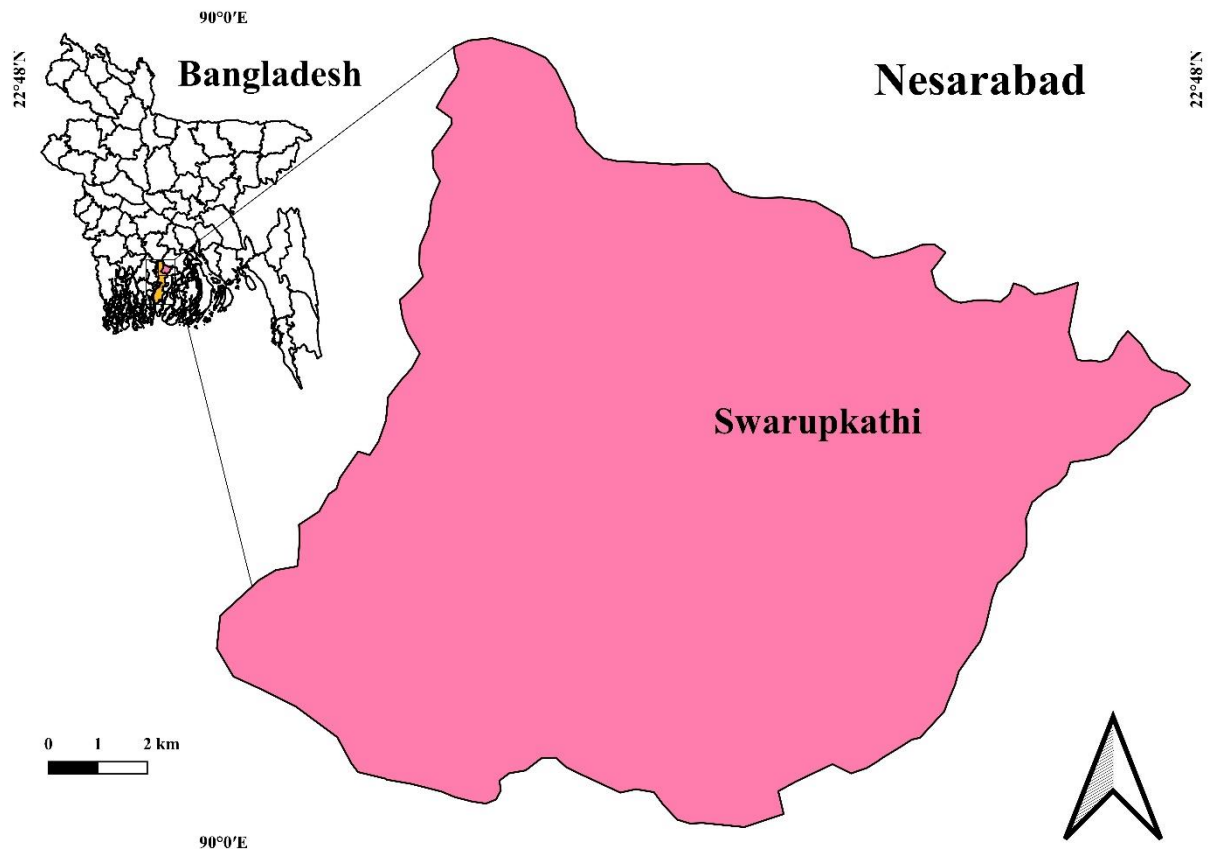


Figure 1. Map showing the guava collection site at Swarupkathi, Pirojpur, Bangladesh.

Table 1. Treatments applied to Swarupkathi guava fruits for postharvest quality evaluation.

Treatment code	Treatment description	Concentration
T0	Control	0
T1	Moringa	7%
T1	Ginger	25%
T1	Garlic	25%

2.4. Experimental method

A total of 120 fresh guava fruits were used in the experiment, with ten fruits allocated to each treatment. The selected fruits were individually dipped into their respective solutions for 2 minutes, allowed to air-dry for 10 minutes, and then placed on brown paper for observation at $22 \pm 2^\circ\text{C}$ and 70–85% relative humidity. Throughout the storage period, the fruits were carefully monitored daily, while data on physicochemical changes were recorded at 2, 4, 6, and 8 days after storage (DAS) to assess the effects of different edible coatings. The experiment was conducted using a completely randomized design (CRD) with three replications. Within each replication, the postharvest-treated fruits were randomly assigned, with ten fruits per treatment combination arranged under ambient conditions.

2.5. Chemical washing and coating application

The harvested guava fruits were first washed to remove dirt and debris and then disinfected in a 1% sodium hypochlorite (NaOCl) solution, prepared by mixing 100 mL of 5% NaOCl in 10 L of distilled water, for 2–3 minutes. The fruits were subsequently rinsed with distilled water to remove any residual chlorine before further treatment. The 7% moringa solution was prepared by dissolving 140 g of dried moringa leaf powder in 2 L of distilled water (equivalent to 7 g per 100 mL), followed by thorough stirring and filtration to obtain a uniform solution. For the ginger and garlic solutions, fresh ginger rhizomes and garlic cloves were washed, peeled, and ground into a fine paste. Each paste (500 g) was mixed with 2 L of distilled water to prepare 25% (w/v) solutions. The mixtures were homogenized and filtered through muslin cloth to obtain clear extracts suitable for fruit coating.

2.6. Measurement of firmness and water loss

Fruit firmness was measured using a digital penetrometer (model: GY-4, Zhejiang Top Instrument Co., China) equipped with a 5 mm diameter stainless-steel probe. The probe penetrated the fruit pulp to a depth of 5 mm from two opposite sides of each fruit. Both the pre-test and post-test speeds were set at 1 mm s⁻¹ to ensure consistent measurements. Firmness was defined as the maximum force required to rupture the fruit tissue and was expressed in Newtons (N). Fruit weight loss was monitored periodically during storage. Each fruit was weighed at the beginning (initial/fresh weight) and at the end of the storage interval (final weight) using a digital balance with 0.01 g accuracy. The percentage of weight loss was calculated following Supa *et al.* (2023) using the formula,

$$\text{Weight loss (\%)} = \frac{IW - FW}{IW} \times 100$$

Where, IW is the initial (fresh) weight and FW is the final weight in grams. This parameter served as an indicator of water loss and overall postharvest deterioration.

2.7. Titratable acidity (TA) and pH measurement

The TA of guava fruits was determined following the standard method described by Ranganna (1986). The juice obtained for TA analysis was subsequently used to measure the pulp pH. pH was measured using a digital pH meter equipped with a glass electrode (GLP 21, Crison, Barcelona, Spain). The instrument was calibrated prior to each use with standard buffer solutions at pH 4.0 and 7.0 to ensure measurement accuracy. Together, TA and pH analyses provided complementary information on the fruit's acidity, which is important for assessing flavor, quality, and storage stability.

2.8. Shelf-life evaluation

Shelf life of guava fruits, as influenced by different treatments, was determined by counting the number of days required for the fruits to reach full ripeness while retaining optimal marketable and eating quality, following the method of Bhooriya *et al.* (2019).

2.9. Determination of vitamin C (ascorbic acid) content

Vitamin C content in guava pulp was quantified using the dye titration method as described by Supa *et al.* (2023). This method is based on the reduction of 2,6-dichlorophenol indophenol (DCPIP) dye by ascorbic acid in an acidic medium, leading to decolorization. The reaction is specific for ascorbic acid within a pH range of 1.0–3.5.

For each estimation, a measured volume of guava extract was titrated with the standard DCPIP solution until a light pink endpoint persisted for at least 15 seconds. The ascorbic acid content was calculated and expressed in mg per 100 g of fresh fruit weight using the formula,

$$\text{Vitamin C (mg/100 g)} = \frac{T \times D \times V_1}{V_2 \times W} \times 100$$

Where, T = titre value (mL), D = dye factor, V₁ = volume made up (mL), V₂ = volume of extract used for titration (mL), and W = weight of the sample (g)

2.10. Measuring total soluble solids (TSS)

The TSS in guava pulp were measured using a digital refractometer (model: BOE 32345, BOECO, Germany) following the method described by Winkler and Knoche (2018). The filtrate remaining from the titratable acidity determination was used for this analysis. Prior to measurement, the refractometer was calibrated with distilled water to ensure a 0% baseline. One to two drops of the juice filtrate were placed on the prism surface of the refractometer, and the % TSS value was recorded. Results were expressed in °Brix, providing an estimate of the soluble sugar concentration and other dissolved solids that contribute to the fruit's sweetness and overall flavor quality.

2.11. Statistical analysis

Descriptive statistics, including mean, standard deviation (SD), and standard error (SE), were computed for all measured physicochemical and qualitative parameters of guava. Data were checked for normality and homogeneity of variances before analysis. A split-split plot design was applied, with plant extract treatments (ginger, moringa, garlic, control) as main plots, storage duration as sub-plots, and measured quality parameters as sub-sub-plots. One-way ANOVA was used to test for significant differences among treatments, and Tukey's HSD test was applied for mean separation when ANOVA indicated significance (*P* < 0.05). Analyses were performed using IBM SPSS Statistics version 27, and all tests were two-tailed at a 5% significance level.

3. Results

3.1. Weight loss and moisture content dynamics

All guava samples showed a steady increase in weight loss during storage, with statistically significant differences among treatments on all sampling days ($F = 261.454\text{--}847.39$, $P < 0.001$). On day 2, weight loss was highest in the control fruits ($1.81 \pm 0.05\%$), followed by garlic ($1.43 \pm 0.03\%$), moringa ($1.30 \pm 0.02\%$), and ginger ($1.10 \pm 0.02\%$). This pattern persisted through day 8, when the control fruits again exhibited the greatest loss ($6.98 \pm 0.13\%$) and ginger-treated fruits the least ($4.08 \pm 0.03\%$). Overall, ginger consistently minimized postharvest water loss across all storage intervals. Moisture content declined gradually in all treatments, mirroring the increase in weight loss. Differences among treatments were significant up to day 6 ($F = 27.30\text{--}17.0$, $P < 0.05$), but not on day 8 ($F = 1.75$, $P = 0.23$). On day 2, moringa-treated fruits had the highest moisture content ($79.60 \pm 0.10\%$), followed by ginger ($79.30 \pm 0.10\%$), control ($79.10 \pm 0.10\%$), and garlic ($78.97 \pm 0.06\%$). By day 8, moisture levels had decreased across all treatments, with moringa maintaining the highest value ($77.37 \pm 0.67\%$) and garlic the lowest ($76.23 \pm 1.42\%$) (Table 2).

Table 2. Differences in treatments among different parameters of Guava.

Parameter	Treatment	Day 2	Day 4	Day 6	Day 8
Weight loss (%)	Control	1.81 ± 0.05^d	3.22 ± 0.10^d	5.08 ± 0.13^d	6.98 ± 0.13^d
	Moringa	1.30 ± 0.02^b	2.51 ± 0.04^b	3.70 ± 0.05^b	4.95 ± 0.05^b
	Ginger	1.10 ± 0.02^a	2.28 ± 0.03^a	3.18 ± 0.08^a	4.08 ± 0.03^a
	Garlic	1.43 ± 0.03^c	2.80 ± 0.05^c	4.10 ± 0.05^c	5.70 ± 0.05^c
	Total	1.41 ± 0.27	2.70 ± 0.37	4.02 ± 0.73	5.43 ± 1.12
	Test statistics	261.45	128.97	290.92	847.39
	P value	<0.001	<0.001	<0.001	<0.001
Firmness (N)	Control	2.28 ± 0.03^a	1.91 ± 0.04^a	1.5 ± 0.02^a	1.08 ± 0.03^a
	Moringa	2.60 ± 0.02^c	2.25 ± 0.05^c	1.92 ± 0.03^c	1.58 ± 0.03^c
	Ginger	2.70 ± 0.02^d	2.40 ± 0.02^d	2.02 ± 0.03^d	1.70 ± 0.02^d
	Garlic	2.50 ± 0.02^b	2.14 ± 0.04^b	1.78 ± 0.03^b	1.38 ± 0.03^b
	Total	2.52 ± 0.17	2.18 ± 0.19	1.81 ± 0.21	1.43 ± 0.25
	Test statistics	214.71	87.41	270.43	386.22
	P value	<0.001	<0.001	<0.001	<0.001
Total soluble solids (^o Brix)	Control	11.50 ± 0.10^b	12.10 ± 0.10^b	12.80 ± 0.10^c	13.40 ± 0.10^d
	Moringa	11.40 ± 0.10^b	11.90 ± 0.10^b	12.40 ± 0.10^b	13.00 ± 0.10^b
	Ginger	11.33 ± 0.06^a	11.60 ± 0.10^a	12.10 ± 0.10^a	12.50 ± 0.10^a
	Garlic	11.60 ± 0.10^c	12.20 ± 0.10^c	12.80 ± 0.10^c	13.20 ± 0.10^c
	Total	11.46 ± 0.13	11.95 ± 0.25	12.53 ± 0.32	13.03 ± 0.36
	Test statistics	4.90	21	34.75	44.75
	P value	0.032	<0.001	<0.001	<0.001
Titratable acidity (%)	Control	10.20 ± 0.10^b	9.30 ± 0.10^b	8.10 ± 0.10^a	6.66 ± 0.13^b
	Moringa	10.50 ± 0.10^c	9.80 ± 0.10^c	9.00 ± 0.10^c	8.20 ± 0.10^c
	Ginger	10.60 ± 0.10^d	10.00 ± 0.10^d	9.20 ± 0.10^b	8.50 ± 0.10^d
	Garlic	10.10 ± 0.10^a	9.00 ± 0.10^a	8.10 ± 0.10^d	5.20 ± 3.55^a
	Total	10.35 ± 0.23	9.53 ± 0.42	8.60 ± 0.53	7.14 ± 2.05
	Test statistics	17.0	62.75	102	2.21
	P value	0.001	<0.001	<0.001	0.165
Dry matter content (%)	Control	20.57 ± 0.49^a	21.50 ± 0.10^a	22.00 ± 0.10^a	22.80 ± 0.10^a
	Moringa	21.20 ± 0.10^b	21.80 ± 0.10^b	22.50 ± 0.10^b	23.10 ± 0.10^d
	Ginger	21.40 ± 0.10^c	21.90 ± 0.10^c	22.50 ± 0.10^c	23.00 ± 0.10^c
	Garlic	21.03 ± 0.06^d	21.60 ± 0.10^d	22.20 ± 0.10^d	22.87 ± 0.06^b
	Total	21.05 ± 0.39	21.70 ± 0.19	22.30 ± 0.24	22.94 ± 0.14
	Test statistics	5.68	10	18	6.5
	P value	0.022	0.004	0.001	0.015
Moisture content (%)	Control	79.10 ± 0.10^b	78.50 ± 0.10^b	77.90 ± 0.10^b	77.20 ± 0.10^b
	Moringa	79.60 ± 0.10^d	79.00 ± 0.10^c	78.30 ± 0.10^c	77.37 ± 0.67^d
	Ginger	79.30 ± 0.10^c	78.80 ± 0.10^d	78.20 ± 0.10^d	77.60 ± 0.10^c
	Garlic	78.97 ± 0.06^a	78.40 ± 0.10^a	77.80 ± 0.10^a	76.23 ± 1.42^a
	Total	79.24 ± 0.26	78.68 ± 0.26	78.05 ± 0.23	77.10 ± 0.87
	Test statistics	27.3	22.75	17	1.75
	P value	<0.001	<0.001	0.001	0.234

Table 2. Contd.

Parameter	Treatment	Day 2	Day 4	Day 6	Day 8
pH	Control	4.55 ± 0.01 ^d	4.61 ± 0.01 ^d	4.70 ± 0.01 ^d	4.80 ± 0.01 ^d
	Moringa	4.52 ± 0.01 ^b	4.56 ± 0.01 ^b	4.60 ± 0.01 ^b	4.65 ± 0.01 ^b
	Ginger	4.51 ± 0.01 ^a	4.54 ± 0.01 ^a	4.58 ± 0.01 ^a	4.62 ± 0.01 ^a
	Garlic	4.53 ± 0.01 ^c	4.58 ± 0.01 ^c	4.65 ± 0.01 ^c	4.72 ± 0.01 ^c
	Total	4.53 ± 0.02	4.57 ± 0.03	4.63 ± 0.05	4.70 ± 0.07
	Test statistics	8.75	26.75	86.75	192.75
	P value	0.007	<0.001	<0.001	<0.001
Vitamin C (mg/100FW)	Control	6.90 ± 0.10 ^a	6.20 ± 0.10 ^a	5.40 ± 0.10 ^a	4.60 ± 0.10 ^a
	Moringa	7.30 ± 0.10 ^c	6.90 ± 0.10 ^c	6.50 ± 0.10 ^c	6.10 ± 0.10 ^c
	Ginger	7.40 ± 0.10 ^d	7.10 ± 0.10 ^d	6.80 ± 0.10 ^d	6.50 ± 0.10 ^d
	Garlic	7.10 ± 0.10 ^b	6.70 ± 0.10 ^b	6.20 ± 0.10 ^b	5.60 ± 0.10 ^b
	Total	7.18 ± 0.22	6.73 ± 0.36	6.22 ± 0.55	5.70 ± 0.75
	Test statistics	14.75	44.75	108.75	202
	P value	0.001	<0.001	<0.001	<0.001
Shelf life (days)	Control	7.67 ± 0.58 ^b			
	Moringa	10.67 ± 0.58 ^c			
	Ginger	11.67 ± 0.58 ^d			
	Garlic	8.67 ± 0.58 ^a			
	Total	9.67 ± 1.72			
	Test statistics	30			
	P value	<0.001			

Values presented as Mean ± SD; P value less than 0.05 indicates statistically significant differences. Superscripts (^a, ^b, ^c, ^d) show significant differences between treatments; the same letter means no significant difference. Tucker-Lewis post-hoc test was applied.

3.2. Changes in fruit firmness

Fruit firmness declined progressively across all treatments during storage, with statistically significant differences observed at each sampling point ($F = 87.41\text{--}386.22$, $P < 0.001$). On day 2, ginger-treated fruits exhibited the greatest firmness (2.70 ± 0.02 N), followed by moringa (2.60 ± 0.02 N), garlic (2.50 ± 0.02 N), and the control (2.28 ± 0.03 N). By day 8, firmness had decreased in all groups, yet ginger-treated fruits retained the highest value (1.70 ± 0.02 N), whereas control fruits showed the lowest (1.08 ± 0.03 N). This consistent reduction in softening among treated fruits highlights the effectiveness of plant extracts in delaying textural deterioration during storage (Table 2).

3.3. Total Soluble Solids (TSS) dynamics

TSS (°Brix) increased progressively in all treatments as storage advanced, with significant differences observed among groups throughout the study period ($F = 4.9\text{--}44.75$, $P < 0.05$). On day 2, TSS values ranged from 11.33 ± 0.06 °Brix in ginger-treated fruits to 11.60 ± 0.10 °Brix in garlic-treated fruits. By day 8, TSS rose to 12.5 ± 0.10 °Brix in ginger, 13.0 ± 0.10 °Brix in moringa, 13.2 ± 0.10 °Brix in garlic, and 13.4 ± 0.10 °Brix in control fruits. This steady increase across treatments reflects ongoing metabolic conversion of starches into soluble sugars during ripening (Table 2).

3.4. Titratable acidity (TA) and pH changes

The TA declined steadily in all treatments as storage progressed, with statistically significant differences observed up to day 6 ($F = 17.0\text{--}102.0$, $P < 0.05$). By day 8, however, TA differences were no longer significant ($F = 2.205$, $P = 0.165$). On day 2, TA ranged from $10.10 \pm 0.10\%$ in garlic-treated fruits to $10.60 \pm 0.10\%$ in ginger-treated fruits. By day 8, acidity decreased to $8.50 \pm 0.10\%$ in ginger, $8.20 \pm 0.10\%$ in moringa, $6.66 \pm 0.13\%$ in the control, and $5.20 \pm 3.55\%$ in garlic-treated fruits. In contrast, pH increased progressively during storage, with significant treatment effects at all sampling points ($F = 8.75\text{--}192.75$, $P < 0.001$). At day 2, pH values ranged from 4.51 ± 0.01 (ginger) to 4.55 ± 0.01 (control). By day 8, they rose to 4.62 ± 0.01 and 4.80 ± 0.01 , respectively. Ginger-treated fruits consistently maintained the lowest pH throughout the storage period, followed by moringa, garlic, and the control (Table 2).

3.5. Dry matter, vitamin C retention, and shelf life

Dry matter content increased steadily throughout storage, with significant differences among treatments on all sampling days ($F = 5.68\text{--}18.0$, $P < 0.05$). On day 2, values ranged from $20.57 \pm 0.49\%$ in the control to $21.40 \pm 0.10\%$ in ginger-treated fruits. By day 8, dry matter increased further to $22.80 \pm 0.10\%$ in control, $23.10 \pm 0.10\%$ in moringa, $23.00 \pm 0.10\%$ in ginger, and $22.87 \pm 0.06\%$ in garlic-treated fruits. Vitamin C content declined progressively during storage, showing highly significant treatment effects at all-time points ($F = 14.75\text{--}202.0$, $P < 0.001$). On day 2, vitamin C ranged from 6.90 ± 0.10 mg/100 g FW in the control to 7.4 ± 0.1 mg/100 g FW in ginger-treated fruits. By day 8, levels decreased to 4.60 ± 0.10 mg/100 g FW in control, 5.60 ± 0.10 in garlic, 6.10 ± 0.10 in moringa, and 6.50 ± 0.10 in ginger-treated fruits. The slower degradation in treated fruits highlights the protective effects of the plant extracts. Shelf life also differed significantly among treatments ($F = 30.0$, $P < 0.001$). Ginger-treated fruits exhibited the longest shelf life (11.67 ± 0.58 days), followed by moringa (10.67 ± 0.58 days), garlic (8.67 ± 0.58 days), and the control (7.67 ± 0.58 days) (Table 2).

4. Discussion

4.1. Weight loss and moisture content dynamics

Weight loss increased progressively across storage days for all treatments, as typically observed in fruits stored under ambient or semi-controlled conditions (Hanani *et al.*, 2023). The study results revealed significant differences among treatments ($P < .001$ for all storage intervals). Control fruits exhibited the highest percentage of weight loss throughout storage, while ginger-treated fruits consistently recorded the lowest values (from $1.10 \pm 0.02\%$ at day 2 to $4.08 \pm 0.03\%$ at day 8). Moringa and garlic treatments showed intermediate reductions, suggesting partial efficacy in minimizing transpiration or internal water migration. These results indicate that the treatments acted as semi-permeable coatings or created micro-barrier effects that reduced vapor diffusion. The superior performance of the ginger treatment suggests enhanced regulation of water exchange, possibly through reduced cuticular permeability or delayed metabolic dehydration. Weight loss in fruits is primarily driven by transpiration and respiration, both of which contribute to tissue water depletion and subsequent turgor loss (Hanani *et al.*, 2023). As turgor pressure declines, softening accelerates, and overall fruit quality deteriorates (Roy *et al.*, 2023). Therefore, treatments that restrict weight loss play a critical role in maintaining structural integrity and firmness. Previous studies have reported similar outcomes; for example, Labib *et al.* (2025) found that coated guavas experienced reduced weight loss and better quality retention. Likewise, essential oils and natural plant extracts have been shown to reduce weight loss by forming a thin, semi-permeable barrier around fruits (Othman *et al.*, 2017). The present findings are consistent with these observations, indicating that ginger, moringa, and garlic may act as bioactive coatings that slow water loss during storage.

4.2. Changes in fruit firmness

Firmness decreased progressively in all treatments during storage, consistent with the expected softening caused by enzymatic degradation of cell wall materials and loss of turgor pressure. However, the rate of decline varied significantly among treatments ($P < 0.001$ for all days). Fruits treated with ginger retained the highest firmness (2.70 ± 0.02 N at day 2, decreasing to 1.70 ± 0.02 N at day 8), followed by those treated with moringa and garlic, while control fruits softened most rapidly. The higher firmness retention in treated fruits suggests that these treatments helped maintain cell wall integrity and membrane stability, possibly by inhibiting softening enzymes such as pectinase or reducing oxidative stress. Although calcium-based treatments are known to strengthen cell walls through pectin crosslinking, the bioactive compounds in ginger and moringa may have produced a comparable stabilizing effect. The relationship between water retention and firmness is notable: fruits that lost less water maintained higher turgor and mechanical resistance (Roy *et al.*, 2023). Therefore, the superior firmness observed in ginger-treated fruits likely reflects a dual effect—limiting water loss and slowing enzymatic softening.

4.3. Total Soluble Solids (TSS) dynamics

The TSS increased significantly across all treatments ($P < 0.05$ to $P < 0.001$), indicating a rise in the concentration of soluble sugars and metabolites due to water loss and starch hydrolysis. The control fruits showed the highest TSS increase, rising from 11.50 ± 0.10 °Brix on day 2 to 13.40 ± 0.10 °Brix on day 8, while the ginger and moringa treatments exhibited slower increases. This suggests that these treatments delayed physiological ripening and moderated metabolic activity. The moderation of TSS accumulation likely reflects reduced respiration and a delayed conversion of complex carbohydrates into simple sugars. A rapid rise in TSS can lead to flavor imbalance and premature senescence; therefore, the slower rate observed in treated fruits

indicates a desirable effect on quality retention (Labib *et al.*, 2025). Similar findings were reported in coated guavas, which showed a slower increase in TSS compared to uncoated controls (prolonging the shelf life of fresh-cut guava).

4.4. Titratable acidity (TA) and pH changes

The TA decreased across all treatments during storage, consistent with the utilization of organic acids in respiration and metabolic reactions. Ginger-treated fruits retained significantly higher acidity levels than the other treatments up to day 6 ($P < 0.001$), indicating slower acid degradation. By day 8, the differences among treatments were not statistically significant ($P = 0.165$), likely due to the high variability observed in the garlic treatment. Maintaining higher acidity levels helps preserve flavor balance and inhibits microbial spoilage. The greater acid retention observed in ginger-treated fruits suggests a slower metabolic consumption of organic acids. In contrast, the sharper decline in the garlic treatment, accompanied by a higher standard deviation, reflects less stability in acid metabolism. A gradual increase in pH was observed during storage across all treatments, inversely corresponding to the decline in acidity. The higher pH values in control fruits further indicate a faster depletion of organic acids (Zaidi *et al.*, 2023). The significant differences in pH values among treatments demonstrate that the treatments effectively influenced the acid–base balance of stored guava fruits.

4.5. Dry matter, vitamin C retention, and shelf life

Dry matter content increased significantly over storage in all treatments ($P < 0.05$ – 0.001), reflecting concentration of solids as moisture declined. Ginger-treated fruits consistently showed the highest dry matter content ($23.00 \pm 0.10\%$ on day 8), while control fruits displayed the lowest. This pattern aligns closely with weight loss and moisture trends. Moisture content decreased progressively; the control and garlic treatments lost water most rapidly, while moringa and ginger treatments exhibited superior moisture retention. Vitamin C (ascorbic acid) content declined over time, but ginger- and moringa-treated fruits retained significantly higher levels compared to control and garlic treatments. This indicates that the treatments reduced oxidative degradation of ascorbic acid, possibly due to antioxidant activity or reduced oxidative stress (Ranganna, 1986; Azam *et al.*, 2021). The better vitamin C preservation in these treatments underscores their potential to maintain nutritional and biochemical stability. Shelf-life assessment, based on the number of days to acceptable ripeness, revealed that ginger treatment significantly extended shelf life (11.67 ± 0.58 days), followed by moringa (10.67 ± 0.58 days), garlic (8.67 ± 0.58 days), and control (7.67 ± 0.58 days). This hierarchy mirrors the overall trends observed in weight loss, firmness, acidity, and vitamin C retention. Overall, the result demonstrates that ginger treatment was most effective in maintaining the physicochemical quality and extending the postharvest shelf life of guava. The combined effects of reduced weight loss, delayed softening, improved acidity retention, and enhanced vitamin C stability indicate that bioactive compounds in ginger exerted a synergistic influence on slowing senescence and prolonging storability (Zaidi *et al.*, 2023).

The study demonstrates that ginger, moringa, and garlic treatments effectively influence key postharvest quality attributes of guava, including weight loss, firmness, TSS, acidity, vitamin C, and pH. Its strengths include a comprehensive assessment of multiple quality indicators under controlled storage conditions and the use of natural, eco-friendly treatments. However, the short storage duration, absence of mechanistic measurements (e.g., respiration, ethylene, enzyme activity, microbial load), lack of sensory evaluation, and unoptimized treatment dosages limit broader interpretation. These gaps highlight the need for longer-term, mechanistic, and consumer-focused studies to strengthen and expand these findings.

5. Conclusions

The study demonstrates that natural plant extracts can effectively improve the postharvest quality and shelf life of guava, with ginger extract being the most effective in reducing weight loss, maintaining firmness, preserving acidity and vitamin C, and slowing ripening. Moringa and garlic extracts provided moderate benefits, supporting their use as natural alternatives for fruit preservation. These findings highlight the potential of edible coatings for sustainable, chemical-free postharvest management. Further research is needed to elucidate the underlying biochemical mechanisms, optimize formulations, and explore combined or sequential applications to enhance the shelf life and nutritional quality of guava and other tropical fruits.

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Data availability

The data supporting the findings of this study are available upon request from the corresponding author.

Conflict of interest

None to declare.

Authors' contribution

Shekh Tanjina Islam Dola: conceptualization, investigation, methodology design, data collection, statistical analysis, interpretation, manuscript preparation, software application, validation, visualization, and overall supervision of the study, as well as the writing, reviewing, and final editing of the manuscript. The author has read and approved the final manuscript.

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