Quality Assurance and Safety of Crops & Foods, 2025; 17(2): 75–85

Impact of different botanical extracts on the postharvest biochemical attributes and shelf life of mango (*Mangifera indica* L.)

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Academic Editor: Balasubramanian Balamuralikrishnan, PhD., Department of Food Science and Biotechnology, College of Life Science, Sejong University, Seoul, Korea

Received: 1 January 2025; Accepted: 29 January 2025; Published: 1 April 2025

ORIGINAL ARTICLE

Abstract

This study aimed to reduce the use of agrochemicals after harvest of mango for increasing shelf life, particularly of the Amrapali variety, by using locally available plant extracts. Seven botanical extracts, namely, T0: Control, T1: Stink vine leaf, T2: Garlic clove, T3: Lemon leaf, T4: Custard apple leaf, T5: *Aloe vera* leaf, and T6: Neem leaf extracts were used for coating treatments. Unblemished, mature mangoes were kept on brown paper at ambient conditions after being immersed in extract solutions for 5 min. Three-day intervals following the day of storage were used to record data at 0, 3, 6, and 9 days after storage (DAS). It was observed that physiochemical characteristics and shelf life of mangos were greatly influenced by coating of botanical extracts (CBE). Within 3 days of storage, traits related to ripening and biochemical markers were changed, but these changes were significantly slower as compared to untreated fruits. By negating the activity of ethylene and other enzymes, coating is thought to establish a physical barrier that eventually lessens biochemical alterations. Among the coating treatments, T1, T5, and T6 exhibited superior performance in reducing physio-biochemical changes and increasing the shelf life of mango.

Keywords: Botanical extracts; postharvest biochemical changes; shelf life; mango

Introduction

Postharvest loss of mango is a great concern in developing countries, including Bangladesh. Farmers produce huge amounts of mango each year, but a significant amount is wasted because of poor postharvest handling, transportation, and storage systems. Hassan (2010) reported that after harvest, a significant percentage of fruits and vegetables were lost—from 23.6 to 43.5%. In Bangladesh, mangoes are among the most widely traded fruits. In recent years, the area and production of this fruit have increased significantly. According to Bangladesh

Bureau of Statistics (BBS) (2022), the total area and production of mango are 121,075 ha and 1207446 MT, respectively. Mango has a climacteric pattern of respiration. Therefore, it is usually harvested when it is fully green, and ripening occurs while it is being transported and stored. Mangoes contain high amounts of moisture and nutrients, which makes them highly perishable and susceptible to several postharvest diseases (Haggag, 2010). Moreover, a very short postharvest shelf life and rapid ripening process are also responsible for the substantial loss of these fruits. The primary goal of the developing nations like Bangladesh is lowering the postharvest degradation of fresh fruits and vegetables. A large number of synthetic agrochemicals are being used for the management of postharvest fruits and vegetable losses. Ethylene is the main controlling factor in the maturation of climacteric fruits, such as mangos. This naturally generated growth regulator for plants affects fruit growth, maturation, and lifespan in storage in several ways (Barry *et al.*, 2000). A significant factor in the climacteric fruit ripening process is ethylene (Alexander and Grierson, 2002; Barry *et al.*, 2000; Klee, 2002). A number of postharvest treatments, such as ethylene inhibitors (1-MCP), plant growth regulators (GA_3), ethylene scavengers (KMnO4), and different coating materials been used over the years to preserve the quality and extension of shelf life of fruits (Pandey *et al.*, 2017; Parvin *et al.*, 2023). In addition to the above chemicals, various fungicides, like mancozeb, carbendazim, benomyl, and thiabendazole, are being applied to prevent postharvest diseases (Lee *et al.*, 2009) and extend the shelf life of fruits (Gupta and Jain, 2014). All these chemicals are hazardous to health. Therefore, it is necessarily important to identify some eco-friendly and sustainable substitutes for postharvest management of fruits which are safe, non-toxic, and environmentally friendly.

Different botanical extracts can be utilized as postharvest coating agents to reduce postharvest spoilage and enhance the shelf quality of fruits. Recently, interest in plant extracts has grown among the scientists because of their antifungal and antibacterial activities (Lee *et al.*, 2007; Santas *et al.*, 2010). Numerous investigations have demonstrated the potential of certain secondary metabolites produced by plants, such as volatile chemicals and essential oils, to function as biocides against postharvest infections (Deferera *et al.*, 2000). A good number of investigations have already been carried out to assess the antibacterial efficacy of different extracts of medicinal plants against plant fungi. According to reports, they are crucial for preventing plant diseases caused by fungi (Raji and Raveendran, 2013). Hafiz *et al.* (2018) investigated the physio-microbial activity of mango under conditions of nonchemical preservation. They reported that edible oil could be a useful postharvest coating agent for reducing the postharvest loss of mango cv. Amrapali. Rayhan *et al.* (2023) claimed that shelf life of banana can be extended about a week by the application of turmeric powder coating during storage. In another report, Khaliq *et al.* (2019) noticed that *Aloe vera* gel coating along with garlic oil can be used as an effective biofungicide for controlling anthracnose diseases of the banana fruit. Shelf life and postharvest quality of tomato can be enhanced by applying neem leaf powder (Hosea *et al.*, 2017). Jodhani and Nataraj (2021) reported that *Aloe* gel and lemon peel extract coating are effective alternatives to improve shelf life and reduce the postharvest loss of banana.

Rapid physiological weight loss because of water loss from fruits as well as ethylene synthesis enhances the ripening process of fruits, which reduces the storage life of fruits. Any physical barrier or coating substance could limit water loss from the fruit surface and inhibit chlorophyll degradation as well as ethylene synthesis. Moreover, the control of fungal infections by using any plant extract could be a way to extend the longevity of fruits and minimize the postharvest loss. Using different botanical extracts may be a beneficial substitute for the use of synthetic fungicides for managing postharvest fruit loss, thereby prolonging the longevity of fruit storage. The aim of this study was to ascertain whether applying certain locally accessible plant leaf extracts as coating materials throughout the fruit storage process may minimize decrease after harvest and increase the shelf life of mango cv. Amrapali.

Materials and Methods

The research was conducted from June to July 2022 at the postgraduate laboratory of the Department of Horticulture, Bangladesh Agricultural University, Mymensingh. Leaf extracts of the following plants were used for controlling postharvest spoilage and improving the storage life of fruits: leaf extract of stink vine (*Paederia foetida*), garlic clove (*Allium sativum* L.), lemon (*Citrus limon* L. Osbeck), custard apple (*Annona squamosa*), *Aloe vera* (*Aloe vera* L. Burm.), and neem (*Azadirachta indica*). Leaves of selected plants and garlic cloves were collected from the Bangladesh Agricultural University Germplasm Center (BAU-GPC). The extraction and formulation of plant leaf extracts of the selected plants were performed following standard protocols available in the literature. In brief, 500 g each of fresh mature leaves of stink vine, garlic cloves, lemon leaves, custard apple leaves, and neem leaves were crushed separately using an electric blender. Thereafter, the extract was filtrated by a double layered muslin cloth. Gel from *Aloe vera* leaves was scraped out using a spoon followed by filtrate using a double layered muslin cloth. After that, 400 mL extract was added to 600 mL distilled water in a glass beaker (1 L), and the solution was stirred up using a glass rod to mix it properly. About four to five drops of Tween 20 was added with all botanical extract solution as the surfactant. The solution was prepared a day ahead of the experiment. The titratable acidity (TA), ascorbic acid (AA), and pH and dry matter (DM) contents of the extract solutions were determined, and the results are TA: 0.13%, 0.21%/, 0.08%, 0.02%, 0.02%, and 0.06%; AA: 19.68, 19.41, 26.24, 13.12, 13.12, and 242.72 mg/100 g fresh weight; pH: 4.45, 6.08, 6.18, 5.68, 7.07, and 4.88; and DM: 6.68%, 16.66%, 3.73%, 3.77%, 2.85%, and 5.15% of stink vine, garlic clove, lemon, custard apple, and neem leaves, respectively. Mango cv. Amrapali was collected from BAU-GPC at the fully mature stage. Unblemished, uniform, mature green mango of the selected variety was collected on the same day of harvesting. Thereafter, the fruits were washed in running tap water, followed by air drying. Fruits were submerged in the leaf extract mixture for 5 min. Fruits that had been air-dried were placed on brown paper sheets in the laboratory at ambient condition (25–28°C temperature). Laboratory analyses of different physio-biochemical changes in fruits were performed at the postgraduate laboratory of the Department of Horticulture, Central Laboratory of BAU, and the Laboratory of Agricultural Chemistry, BAU. Seven treatments of botanical extracts were assigned following a completely randomized design with three replications. Ten fruits were used in each treatment and replicates thrice. The following parameters were measured during the entire experimental period.

Physiological weight loss of fruits

The weight loss of fruits under different treatments was measured at 3-day intervals by using a digital balance and expressed in percentage.

Fruit texture/firmness

Fruit firmness was determined at 3-day intervals by using a digital fruit firmness tester (Model GY-3, China) and expressed in Newton (N). Fruit firmness was measured according to the method described by Padda *et al.* (2011). In brief, fruit firmness was measured from the equatorial position of the fruits from different treatments. A small part of the skin at the measured location was removed before penetrating the probe of the instrument. Thereafter, the probe was pressed through the fruit flesh and the force (N) required to penetrate up to the marked position of the instrument was recorded.

Determination of moisture content

Fifty grams of fruit pulp was sampled from treated and untreated fruits at 3-day intervals. The pieces were kept in aluminum foil and oven-dried at 70°C until their weights were consistent. The moisture content of fruit pulp was calculated using the following formula according to AOAC (2000):

$$\%\ \text{moisture content} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Fruit pH

Fruit pH was measured according to the method described by Jayaraman (1981). An electric pH meter was used to determine fruit pH. Before use, the electrode of the pH meter was calibrated by buffer solution (pH 4 and pH 7). A pH meter was used to measure the pulp of the homogenate made from 10 g of fresh pulp that had been homogenized in 10 mL of distilled and deionized water (pH 7.0).

Determination of total soluble solids (TSS)

TSS of the fruit sample was determined by using the NR 151 Digital Refractometer. An extract of mango fruit juice from the fruit pulp was kept on the prism of the refractometer, and the value was recorded from the direct reading of the instrument. The temperature was adjusted using the temperature correction table.

Determination of AA (vitamin C) content

The AA level was calculated using Plummer's (1971) approach. In a blender, approximately 5 g of fresh fruit and 70 mL of solution containing 6% metaphosphoric acid were combined and emulsified for 2 min. After blending and sieving the mixture, a 5-min, 2,000 ppm centrifugation was performed. A 100 mL volumetric flask containing 6% metaphosphoric acid was filled with the homogenized supernatant. The aliquot, containing 5 mL, was titrated using a commonly used 2,6-dichloroindophenol dye solution which serves as an indicator in redox titrations because of its ability to undergo a distinct color change when reduced in a conical flask. The following formula was utilized to determine the samples' AA content:

$$\text{Ascorbic acid content}\ \left(\text{mg}/100\ \text{g}\right) = \frac{\text{Titer} \times \text{Dye factor} \times \text{Volume made up}}{\text{Volume of extract} \times \text{Weight of sample}} \times 100$$

Determination of TA

TA of mango was determined following the method described by Ranganna (1979). The reagents listed below were used to calculate the TA: standard NaOH (0.1 N) solution containing 1% phenolphthalein. Five milliliters of solution was taken in a conical flask. After adding a couple of drops of the phenolphthalein indicator, the flask was agitated vigorously. After that, a burette containing 0.1 N NaOH solution was used to titrate the solution immediately until a persistent pink hue emerged. The percentage of TA and the quantity of NaOH solution required for the titration were calculated using the following formula:

$$\text{Percent titratable acidity } (\%) = \frac{\text{Titer} \times \text{ Normality of NaOH} \times \text{Volume made up} \times \text{ Equivalent weight}}{\text{Volume of extract} \times \text{Weight of sample} \times 1{,}000} \times 100$$

Determination of total sugar content

The enthrone method was employed to determine the total sugar content of fruit samples calorimetrically (Jayaraman, 1981). After pipetting one milliliter of pulp extract into each test tube, 4 mL of enthrone reagent was added and stirred well. The blue-green solution's absorbance was calculated using a colorimeter at 620 nm. 0.1, 0.2, 0.4, 0.6, 0.8, or 1.0 mL of standard glucose solution were introduced to different test tubes that contained 0, 10, 20, 40, 60, 80, or 10 mg of glucose each. The volume was then increased to 1 mL with distilled water. At 620 nm, the absorbance was measured using a blank consisting of 1 mL of water and 4 mL of enthrone reagent. A glucose reference curve was employed to ascertain the total quantity of sugar in the extract. Ultimately, to find the percentage of total sugar, the following formula was utilized:

$$\text{Total sugar } (\%) = \frac{\text{Amount of sugar obtained}}{\text{Weight of sample}} \times 100$$

Determination of shelf life

The shelf life of mango refers to the duration up to which the fruit remains marketable and edible. To count the days, all the treated and untreated fruits were observed regularly and the duration under different treatments was recorded at ambient (25–28˚C) temperature with 75–85% of relative humidity.

Sensory evaluation of fruits treated with botanical extracts during storage

Sensory evaluation is important for determining the acceptability of plant extracts as coating materials. Therefore, an organoleptic test of the treated fruits was conducted by a panel of male and female students, teachers, and staff. Fruit texture, taste, and flavor were evaluated using a rating scale. The rating scales used were texture (1: very soft, 2: moderately soft, 3: soft), taste (1: bitter, 2: sour, 3: sweet), and flavor (1: bad, 2: good, 3: very good).

Statistical analysis

To ascertain the relevance of the differences between the approaches, statistical analysis was performed on the data collected for physiochemical characteristics. The statistical package MSTATC was used to evaluate the gathered data. ANOVA was used to examine the differences in physicochemical characteristics. The significance of the difference in treatment means was compared by the least significant difference (LSD) test at 5% and 1% probability levels.

Results

Physiological weight loss (PWL)

The PWL was rapid in the control treatment, and the value changed from 0 to 20.28% by the 9th day of storage. Fruits coated with leaf extracts showed a slower tendency for PWL, and T1 (Stink vine leaf extract) exhibited the slowest change in PWL, with the value changing from 0 to 10.36% by the 12th day of storage (Table 1). On the 9th day after storage, the order of the PWL of fruits under the various coating applications was T0>T3>T4>T6>T5>T3>T2>T1.

Fruit firmness

The initial fruit firmness ranged from 5.40 to 6.50. Fruit firmness rapidly declined under control conditions, and the value changed from 5.40 to 0.6 within 6 days after storage (DAS), while coating-treated fruits showed a gradual declining trend during the storage period (Table 2).

Moisture content

In the case of control fruits, the moisture content decreased at a faster pace during storage in contrast to the fruits that were covered by various coating treatments. The fruits coated with botanical extract slowly kept losing moisture up to the 9th day of storage, but this reduction was accelerated from the 9th to 12th days of storage (Figure 1).

%TSS

On day 9 of storage, the TSS of the control fruit peaked at 30.56 % TSS. The fruits coated with botanical extract

Table 1. Effect of different botanical extracts on the physiological weight loss (PWL) of mango cv. Amrapali during storage under ambient condition.

Treatments	Physiological weight loss (%PWL) at				
	0 day	3 days	6 days	9 days	12 days
T0	0	6.22	11.98	20.28	–
T1	0	4.90	7.00	10.36	12.50
T2	0	4.86	6.5	12.08	14.48
T3	0	5.76	9.38	14.36	–
T4	0	5.26	8.30	13.88	–
T5	0	4.78	7.47	12.55	15.18
T6	0	4.87	8.13	12.75	13.16
LSD 0.05	–	1.02	1.11	2.29	1.02
LSD 0.01	–	1.43	1.56	3.22	1.54
Level of significance	–	*	**	**	**
CV (%)	–	11.01	7.47	9.4	3.69

* and **indicate significance at 5% and 1% levels of probability, respectively. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

Table 2. Effect of different botanical extracts on fruit firmness of mango cv. Amrapali during storage under ambient condition.

Treatments	Fruit firmness (N) at				
	0 day	3 days	6 days	9 days	12 days
T0	5.40	2.96	0.60	–	–
T1	5.50	3.70	3.00	1.90	0.63
T2	6.40	4.46	3.16	1.96	0.60
T3	6.13	3.46	1.83	1.10	–
T4	5.80	3.53	2.00	1.33	–
T5	6.50	4.43	3.20	1.66	0.50
T6	5.80	4.00	3.10	1.60	0.43
LSD 0.05	0.48	0.61	0.34	0.31	0.31
LSD 0.01	0.67	0.85	0.48	0.44	0.47
Level of significance	**	**	**	**	**
CV (%)	4.53	9.03	7.92	12.91	28.37

**indicates significance at 1% level of probability. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract. After storing for 12 days, the highest firmness (0.63) was obtained from the T1 treatment (stink vine leaf extract), while the lowest firmness (0.43) was found in the T_6 treatment (neem leaf extract).

showed a slow increase in TSS (Table 3). On the 9th day of storage, the lowest TSS (19.92%) was obtained from T_2 (garlic clove extract), which was statistically identical to T1 (20.33%), T5 (20.73%), and T6 (20.76%).

Vitamin C contents

It was observed that the content of vitamin C in fruits under various coating treatments was reduced as storage time elapsed. In the case of untreated control fruits, this declining trend was very quicker, and the value declined from 35.33 mg/100 g to 10.83 mg/100 g by the 9th day of storage, while a slower declining trend was observed for fruits treated with the botanical extract (Table 4).

Fruit pH

Over the course of the storage period, the pH of fruit pulp increased; the control fruits experienced a faster increase in pH than the other treated fruits. Fruit pH was statistically similar for all fruits on the first day of storage. The pH increase of the fruits was delayed for those fruits that were subjected to the different coating treatments (Table 5). In the control fruits, the pH changed from 3.83 to 7.73 by the 9th day of storage, the pH of T6 (Neem leaf extract) increased more slowly over the course of storage, ranging from 4.03 to 7.13 on the 12th day.

% TA

The TA remained higher at the beginning of fruit storage, but it declined faster in the untreated control fruits during the storage period. The TA content changed from 1.34% to 0.07% after 9 days of storage (Table 6). At the same time, the fruits coated with botanical extract showed a slow reduction in TA.

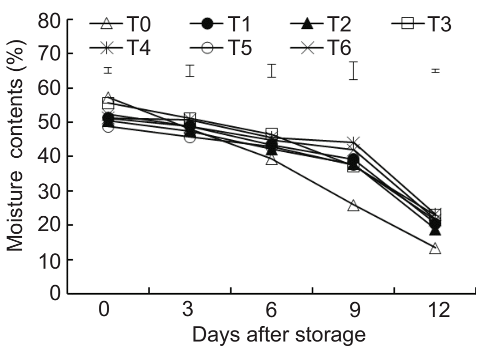

Figure 1. Effects of different botanical extracts on the moisture content of mango cv. Amrapali during storage under ambient condition. Vertical bars represent the LSD at 5% probability level. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

Total sugar contents (%)

For the fruit coated with botanical extract, the rise in the fruit's overall sugar content during storage leveled off, while the total sugar content in the control fruit rapidly increased and changed from 1.65% to 5.38% by the 9th day of storage (Table 7). Among the treatments, T1 (Stink vine leaf extract) had the greatest effect on maintaining a steady rise in the overall amount of sugar during the storage time and the value decreased from 1.84% to 4.92% on the 12th day of storage.

Shelf life

The maximum shelf life of mango (14.67 days) was obtained from the T1 (Stink vine leaf extract) and T5 (*Aloe vera* leaf extract) treatments, followed by the T2 (Garlic clove extract) (14.33) and T6 (Neem leaf extract) treatments (12.33 days), and the minimum shelf life (8.33 days) was featured for the control fruits, as shown in Figure 2.

Sensory evaluation

Sensory evaluation revealed that the botanical extracts significantly influenced the texture, taste, and flavor of the mango cultivar Amrapali, as shown in Table 8. Under control conditions, the fruit became very soft with an unacceptable flavor within a short period of storage,

Table 3. Effect of different botanical extracts on the total soluble solids (TSS) content of mango cv. Amrapali during storage under ambient condition.

Treatments	Total soluble solids (%) at				
	0 day	3 days	6 days	9 days	12 days
T0	7.56	17.10	26.76	30.56	–
T1	8.06	12.53	16.66	20.33	24.40
T2	7.80	11.42	15.49	19.92	21.93
T3	7.50	13.20	18.03	22.53	–
T4	7.60	13.25	17.76	23.36	–
T5	7.96	12.72	16.03	20.73	19.70
T6	7.86	12.47	15.96	20.76	24.46
LSD 0.05	2.12	0.71	1.14	1.10	5.59
LSD 0.01	2.98	0.99	1.59	1.54	8.48
Level of significance	NS	**	**	**	**
CV (%)	15.39	3.02	3.53	2.74	12.39

** indicates significance at the 1% probability level, NS = non-significant. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

Table 4. Effects of different botanical extracts on the vitamin C contents of mango cv. Amrapali during storage under ambient condition.

Treatments	Vitamin C (mg/100 g) contents at				
	0 day	3 days	6 days	9 days	12 days
T0	35.3	19.5	14.83	10.83	–
T1	33.16	27.16	21.73	19.70	14.53
T2	31.66	24.73	19.41	16.28	14.92
T3	31.40	18.73	14.40	11.4	–
T4	28.63	19.08	14.25	11.16	–
T5	29.83	21.83	18.55	16.06	15.75
T6	30.53	20.16	17.40	15.1	12.60
LSD 0.05	3.49	3.81	3.55	2.66	4.69
LSD 0.01	4.89	5.34	4.98	3.73	7.11
Level of significance	*	**	**	**	NS
CV (%)	6.23	9.93	11.6	10.42	16.25

* and **indicate significance at 5% and 1% levels of probability, respectively. NS =non-significant. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.
Among the coating treatments, T1, T2, T5 and T6 significantly restricted the changes in vitamin C. The values remained high at 19.70, 16.28, 16.06 and 15.10 mg/100 g, respectively, even after the 9th day of fruit storage. In particular, T1 (Stink vine leaf extract) strongly restored the biochemical changes during fruit storage.

Table 5. Effects of different botanical extracts on the pH of mango cv. Amrapali fruits during storage under ambient condition.

Treatments	Fruit pH at				
	0 day	3 days	6 days	9 days	12 days
T0	3.83	6.43	7.36	7.73	–
T1	4.03	4.30	6.33	6.90	7.30
T2	4.20	4.36	5.90	6.40	7.33
T3	4.50	4.30	6.40	7.56	–
T4	3.90	4.66	6.80	7.70	–
T5	4.03	4.93	6.16	7.20	7.53
T6	4.03	4.70	5.96	6.70	7.13
LSD 0.05	0.43	1.86	1.50	0.86	0.67
LSD 0.01	0.61	2.61	2.10	1.20	1.01
Level of significance	NS	NS	NS	*	**
CV (%)	6.00	21.76	13.16	6.73	4.60

* and **indicates significance at 5% and 1% levels of probability, respectively: NS=Nonsignificant. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, T6: Neem leaf extract.

while the botanical fruits coated with extract showed a moderate soft texture with a good to very good flavor and a sweet taste. The taste of fruits increases gradually with time as different botanical extract coatings create a physical barrier that reduces metabolism, enzymatic activities, and moisture loss from fruits.

Discussion

The nation's top priority is extending the shelf life of mangos by minimizing postharvest waste. There are limitations to the use of synthetic agrochemicals because of growing environmental and human health concerns. With respect to physiological weight loss, among the botanical extract, stink vine leaf extract caused the slowest change in the PWL as well as fruit firmness, while the PWL changed comparatively rapidly in the control fruit. This result might be because of decreased moisture loss from the fruit surface by the physical barrier formed by the coating of the botanical extract. This result is in agreement with the findings obtained by Veravrbeke *et al.* (2003) and Akalin *et al.* (2006). Parvin *et al.* (2023) also reported that reduction of weight loss by up to 65% was achieved with chitosan

Table 6. Effect of different botanical extracts on the titratable acidity of mango cv. Amrapali during storage under ambient condition.

Treatments	Titratable acidity (%) at				
	0 day	3 days	6 days	9 days	12 days
T0	1.34	0.26	0.13	0.07	–
T1	1.42	0.58	0.36	0.13	0.09
T2	1.62	0.63	0.44	0.29	0.22
T3	1.60	0.36	0.31	0.13	–
T4	1.71	0.29	0.18	0.13	–
T5	1.35	0.44	0.31	0.24	0.13
T6	1.50	0.56	0.36	0.29	0.13
LSD 0.05	0.19	0.09	0.08	0.05	0.04
LSD 0.01	0.27	0.14	0.12	0.07	0.07
Level of significance	**	**	**	**	**
CV (%)	7.05	12.26	15.89	15.09	15.21

**indicates significance at the 1% level of probability. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

Table 7. Effects of different botanical extracts on the total sugar content of mango cv. Amrapali during storage under ambient condition.

Treatments	Total sugar contents (%) at				
	0 day	3 days	6 days	9 days	12 days
T0	1.65	2.36	3.3	5.38	–
T1	1.84	1.71	2.17	3.49	4.92
T2	1.96	2.47	2.56	3.20	5.04
T3	1.86	2.65	2.84	3.92	–
T4	1.73	2.38	3.2	4.28	–
T5	1.83	2.16	2.35	3.45	5.01
T6	1.83	2.48	2.41	3.75	5.26
LSD 0.05	0.54	0.66	0.65	0.29	0.27
LSD 0.01	0.75	0.92	0.91	0.40	0.41
Level of significance	NS	NS	*	**	NS
CV (%)	16.59	16.08	13.57	4.16	2.71

* and **indicates significance at 5% and 1% levels of probability, respectively: NS = not significant. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

coating compared to the uncoated control group. In addition, it has been found that treating mangoes with a film coating lowered their rate of deterioration and weight loss (Pang *et al.*, 2024). They determined that covering of fruit helps to prevent fruits from losing weight while being stored. In fruit farming, covering could preserve the fruit's toughness by lowering its respiration while reducing the catabolic response (Valero *et al.*, 1998). By decreasing the rate of respiration, the fruit ripening process is extended since less starch is converted to sugars, preserving the higher TSS of fruits (Lum and Norazira, 2011). Pang *et al.* (2024) also found that the film coating treatment showed a slow increase in TSS. The AA or vitamin C content of the green mature mangos increased and decreased with time as they were stored. This result might be because of the barrier created by the application of botanical extracts, which restrict the respiration rate as well as moisture loss from the fruit surface, causing the level of AA of fruits to gradually decline as they are being stored. This outcome was compared to the findings of Parvin *et al.* (2023), who reported that chitosan coating retained vitamin C content in mango to a considerable extent. Comparable results were also published by Amarante *et al.* (2001) and Herianus *et al.* (2003).

Fruit pH of mango cv. Amrapali was significantly influenced by different botanical coatings during the storage

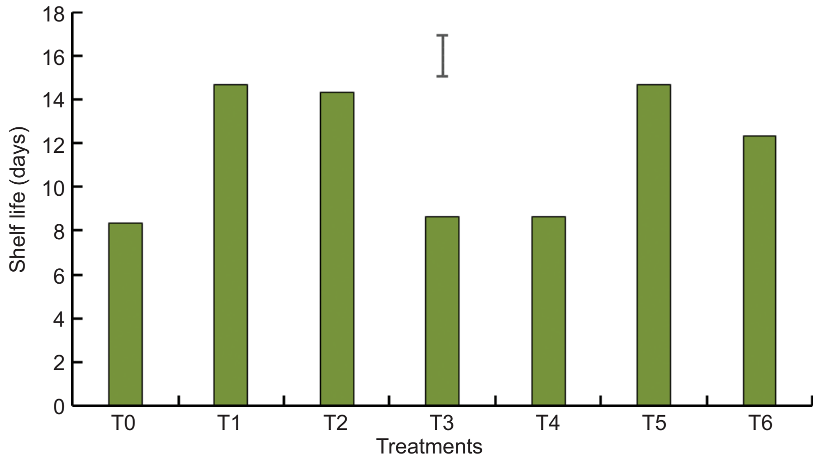

Figure 2. Effects of different botanical extracts on the shelf life of mango cv. Amrapali during storage under ambient condition. The vertical bar represents the LSD at the 5% probability level. T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

Table 8. Sensory evaluation of mango plants treated with botanical extracts.

Coating treatments	Fruit traits	Sensory responses
T0	Texture	Very Soft to Moderate Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Bad to Good
T1	Texture	Very Soft to Moderate Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Good to Very Good
T2	Texture	Moderate Soft to Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Bad to Good
T3	Texture	Very Soft to Moderate Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Good to Very Good
T4	Texture	Moderate Soft to Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Good to Very Good
T5	Texture	Very Soft to Moderate Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Good
T6	Texture	Very Soft to Moderate Soft
	Taste	Moderate Sweet to Sweet
	Flavor	Good to Very Good

T0: Control, T1: Stink vine leaf extract, T2: Garlic clove extract, T3: Lemon leaf extract, T4: Custard apple leaf extract, T5: *Aloe vera* leaf extract, and T6: Neem leaf extract.

period. The pH may rise during storage as a result of various acids oxidizing and producing a higher pH value.

Coating might have suppressed this oxidation process, thus slowing the increase in pH of the treated fruits. In addition, fruits keep well for longer periods of time in storage because coatings delay the ripening process and maintain a low pH for longer periods of time. These findings are consistent with those of Raese and Drake (1993), who claimed that the application of an animal fat coat delays the ripening of fruit. In terms of TA, because plant extracts provide a physical barrier that slows fruit acidity decline by reducing respiration and water loss, they limit variations in fruit acidity (Hamed *et al.*, 2019). Pang *et al.* (2024) also found that film coating treatment slowed fruit acidity decline in mango. In total sugar content, the metabolic conversion of starch to sugar is responsible for the rise in the mango fruits' overall sugar content during the phase of ripening.

Coatings effectively block oxygen from the surroundings while obstructing the metabolic enzymes that quickly convert acids to sugar (Baswal *et al.*, 2020). Moreover, it has been reported that chitosan coating retained total sugar content to a considerable extent in mango (Parvin *et al.*, 2023). In the case of shelf life, in the control fruit, no barrier was created by surface coating; thus, moisture loss continued, respiration and other biochemical changes occurred rapidly, and the storage life became shorter than that of the treated fruits. In coated fruits, a physical barrier has been developed that lowers the rate of respiration and delays the ripening of fruit. The findings of Akalin *et al.* (2006) were consistent with the results of the present study. They reported that fruit respiration was restricted by a coating of animal fat, which slowed the ripening process. It has been reported that the shelf life of mango was extended and the rate of decay was decreased by the film coating treatment (Pang *et al.*, 2024). Parvin *et al.* (2023) also reported that chitosan coatings increased the storage life of mango. Rayhan *et al.* (2023) noticed that water loss from fruit was reduced and eventually the shelf life increased in turmeric-coated banana. In sensory evaluation, respiration and other metabolic processes causing ripening slow when being stored (Amarante *et al*., 2001; Herianus *et al*., 2003).

The use of different botanical covering slows the rate of fruit ripening while preserving the fruit's flavor, color, and texture and extending its shelf life (Dang *et al*., 2008). The fruit tastes better, loses less water, and respiration rate drops as a result of the coating's semipermeable barrier to the passage of oxygen, CO_2, moisture, and solutes.

Conclusions

Plant extracts have a significant impact on the physiochemical properties and lifespan of mango cv. Amrapali. All changes related to ripening such as physiological weight loss, tissue softening, and bio-chemical changes during storage occurred much more quickly and reached their maximum in a short period of time in the control treatment. Fruits coated with plant extracts, however, exhibit a noticeably slower trend. Coating is thought to establish a physical barrier that, by preventing the synthesis of ethylene and other enzymes, eventually reduces biochemical alterations. According to the results of the sensory evaluation, the fruits coated with botanical extract did not produce any unpleasant odor during consumption, and they maintained the good texture and flavor of the mango cv Amrapali. Among the coating treatments, the shelf life of mango cv. Amrapali was extended by T1 (Stink vine leaf extract), T5 (*Aloe vera* leaf extract), and T6 (Neem leaf extract), showing superior effectiveness in lowering the biochemical alterations of fruits. Further studies can be performed to determine the concentrations of the selected botanical leaf extracts for future use in the postharvest management of horticulture products.

Acknowledgement

The authors extend their appreciation to Taif University, Saudi Arabia, for supporting this work through project number (TU-DSPP-2024-07).

Data Availability Statement

The datasets used in this study are available from corresponding authors upon reasonable request.

Author Contributions

Conceptualization was done by M.M.H. and M.M.H.H.; methodology was conceived by A.Y., M.M.H., and M.M.H.H.; experiments were conducted by M.M.H., M.M.H.H., and TR.; data curation and formal analysis were done by M.M.H., M.M.H.H., S.S., A.G., and A.H.; software was looked into by S.S., A.G., and A.H.; writing-original draft preparation was done by A.Y., M.M.H., M.M.H.H., and S.I.; writing-review and editing were done by A.Y., M.M.H., S.S., A.G., A.H., and S.I.; visualization was done by M.M.H.; project administration was performed by M.M.H., S.S., A.G., and A.H.; supervision was done by M.M.H., S.S., A.G., and A.H. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Funding

This research was financially supported by the Ministry of Science and Technology (MoST), Bangladesh. Project No. BS 74 (July 2021-June 2022). This research was also funded by Taif University, Saudi Arabia, Project No. (TU-DSPP-2024-07).

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