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Natural Preservatives Maintained Postharvest Quality, Reduced Decay Percentage and Increased Shelf Life of Mango

Md. Sefat Ullah, Nishat Jahan Nitu, Prianka Howlader, Md Nazmul Hasan Mehedi, Santosh Kumar Bose*

Department of Horticulture, Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali-8602, Bangladesh

*Corresponding author's email: santosh@pstu.ac.bd

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ABSTRACT

The use of natural preservatives for storing fresh fruits is a time-intensive yet essential approach to healthier and more sustainable food processing. This study was conducted to investigate the effects of different natural preservatives on maintaining the quality and enhancing the shelf life of mangoes during storage. Fully mature, uniformly sized mango fruits from two selected cultivars, 'Langra' and 'Himsagar,' were collected and treated with various natural preservatives, including *Aloe vera* gel (25% and 50%), moringa leaf extract, pomegranate peel extract, and hot water (55 °C). The two-factor experiment was arranged in a completely randomized design with three replications. The results demonstrated that different natural preservatives significantly ($P \leq 0.05$) influenced the quality and shelf life of mangoes compared to untreated fruits. Among the two tested cultivars, 'Langra' exhibited better performance across all studied parameters compared to 'Himsagar.' Among the natural preservative treatments, moringa leaf extract showed the most promising results, followed by pomegranate peel extract. The highest firmness (7.046 N), pH value (7.323), titratable acidity (0.2867%), vitamin C content (33.62 mg 100 g^{-1}), and shelf life (18.33 d) were recorded in the 'Langra' cultivar when treated with moringa leaf extract. Additionally, this treatment resulted in the lowest weight loss (3.373%) and the lowest percentage of disease incidence (17.41%). Based on these findings, moringa leaf extract appears to be an excellent natural alternative to chemical preservatives for maintaining mango fruit quality, reducing decay, and extending shelf life during storage.

Introduction

Mango (*Mangifera indica*), a tropical climacteric fruit, is the most popular fruit in Bangladesh. However, it ripens rapidly under harsh climatic conditions, making its preservation a challenge. Mango is rich in β-carotene, vitamin C, dietary fiber, soluble sugars, and various minerals. Among the fruits grown in Bangladesh, mango ranks 5th in terms of cultivated area and 3rd in production. It is cultivated across 286,823 ha, yielding 1,214,597 metric tons, which accounts for 25.22% of the total fruit cultivation area and 24.38% of total fruit production in Bangladesh (BBS, 2022). Often referred to as the "king of fruits" due to its attractive color, flavor, and juicy pulp, mango is highly perishable.

During peak season, a large volume of mangoes is produced; however, due to inadequate processing and preservation techniques, producers and traders face postharvest losses ranging from 20% to 40%. Spoilage caused by fungal diseases such as end rot and anthracnose further limits its storage potential. The shelf life

of mango is primarily determined by spoilage, with a 10% spoilage threshold used as a standard for storage viability. Water loss due to skin evaporation (transpiration) and respiration leads to weight reduction, which causes shriveling and deterioration in appearance, ultimately lowering its market value (Shahnawz et al., 2012).

Despite the increasing market demand for mangoes, postharvest diseases, chilling injuries, and the fruit's perishable nature have negatively impacted the mango industry in recent years (Singh et al., 2013). The ripening process involves metabolic changes such as increased respiration, structural polysaccharide degradation leading to fruit softening, chlorophyll breakdown, carotenoid biosynthesis, and the hydrolysis of starch into sugars, all of which contribute to the development of an acceptable texture and taste (Gill et al., 2017). However, high moisture content, soft texture, and susceptibility to microbial infections are major limiting factors to mango's shelf life.

Maintaining fruit quality and prolonging shelf life has long been a priority for growers. To ensure an extended supply of high-quality mangoes in both domestic and international markets, various pre- and postharvest techniques have been developed. These include the use of plant growth regulators, ionizing radiation, plant extracts, modified and controlled atmospheres, and edible coatings, all of which help reduce deterioration, extend postharvest life, and maintain fruit quality (Perumal et al., 2017). Additionally, postharvest application of fungicides has been a widely used technique to minimize decay and extend storage life. However, while chemical preservatives are commonly employed to delay spoilage and extend shelf life, their use poses health and environmental risks due to potential toxicity (Bose et al., 2020).

In response to these concerns, non-toxic postharvest treatments with minimal residue and environmental impact have been explored as safer alternatives for prolonging the storage life of various fruits. The growing public demand for chemical-free food has intensified the search for natural, organic alternatives to conventional preservatives (Hashmi et al., 2013). Consumers now prioritize food safety and quality, preferring preservative-free products with extended shelf life. Consequently, numerous storage techniques have been developed to enhance the marketability of fruits postharvest (Atlaw et al., 2018). Several natural products have been tested for their ability to delay ripening and reduce postharvest decay (Tripathi & Dubey, 2004).

Edible coatings, made from natural and biodegradable substances, are among the most promising approaches for increasing the postharvest storage life of fruits (Campos et al., 2011). Recent studies indicate that *Aloe vera* gel-based coatings effectively prolong shelf life and delay quality deterioration in fruits such as sweet cherries and table grapes (Martinez-Romero et al., 2006). *Aloe vera* coatings help prevent moisture loss and firmness reduction, regulate respiratory activity, delay oxidative browning, and inhibit microbial growth (Castillo et al., 2010).

Moringa (*Moringa oleifera*) has emerged as a cost-effective and highly effective natural alternative, offering antimicrobial benefits in postharvest storage. Incorporating moringa extracts into edible coatings such as corn starch and carboxymethyl cellulose (CMC) has been shown to reduce weight loss in citrus fruits (Adetunji et al., 2012) and *Fuerte* avocados (Tesfay & Magwaza, 2017). Pomegranate peel extract is another promising natural preservative, exhibiting strong antioxidant and antimicrobial properties (Rosas-Burgos et al., 2017). Recent research confirms that pomegranate peel extract effectively maintains mango quality and enhances its antioxidant activity (Kumar et al., 2023).

Given these findings, postharvest treatments using natural preservatives are essential for extending mango shelf life while maximizing profitability. Therefore, this study was undertaken to examine the effects of different natural preservative treatments on maintaining mango fruit quality and prolonging its shelf life during storage.

Material and methods

The experiment was conducted in the Postharvest Laboratory, Department of Horticulture, Patuakhali Science and Technology University (PSTU) from July 2022 to June 2023. Fresh mango fruits, cv. 'Langra' and 'Himsagar,' were harvested from a commercial orchard (Chapai Nawabgonj, Bangladesh) at green mature stage. The fruits were immediately transported to the laboratory and graded for their uniformity in size, shape, and an appearance that was free from blemishes. Two factors were A: cultivar; a. 'Langra' (V_1), b. 'Himsagar' (V_2) and factor B: six postharvest treatments a. T_0 = Control (no treatment), b. T_1 = *Aloe vera* gel 25%, c. T_2 = *Aloe vera* gel 50%, d. T_3 = Pomegranate peel extract (10%), e. T_4 = Moringa leaf extract (25%), f. T_5 = Hot water (55 °C) treatment was carried out in a Completely Randomized Design (CRD) with three replications.

Preservatives application

The 25% *Aloe vera* gel was prepared using freshly collected *Aloe vera* leaves. The colorless hydroparenchyma was mixed with distilled water in a 1:3 ratio and then homogenized using a blender. The resulting gel was filtered through a sieve to remove any lumps, yielding a 25% fresh *Aloe vera* gel solution. The 50% *Aloe vera* gel was prepared following the same procedure but with an adjusted concentration.

Pomegranate peel extract was prepared by mixing 10 g of dried pomegranate peel powder with 100 mL of distilled water, following a method by Sandhya et al. (2018) with minor modifications. For moringa leaf extract preparation, fresh moringa leaves were dried in a dryer at 70°C for three days. The dried leaves were then crushed using an electric blender, and the resulting powder was strained through a sieve. A total of 250 g of moringa leaf powder was dissolved in 750 mL of distilled water and gently stirred with a glass rod in a beaker, following a method by Liamngee et al. (2019) with minor modifications.

A total of 288 fresh mango fruits from two cultivars were used in this experiment, with eight fruits from each cultivar assigned to each treatment. The selected fruits were individually dipped into the respective preservative solutions for two min, air-dried for 30 min, and then placed on brown paper for observation at 22 ± 2°C with 70–85% relative humidity. Throughout the storage period, the fruits were carefully monitored on a daily basis, while physicochemical changes influenced by different preservatives were recorded at 3, 6, and 9 days after storage (DAS).

Determination of fruit firmness

A digital penetrometer (Digital Hardness Tester FR-5120, Lutron, Taiwan) along with a measuring probe (5 mm diameter stainless steel) were used for firmness determination. Fruit firmness was measured from two opposite sides of each fruit by penetrating the probe at a distance of 5 mm into the fruit with pre- and post-test speeds of 1 mm s^{-1}. The firmness was calculated as maximum penetration force reached during tissue breakage and expressed as Newton (N).

Calculation of weight loss

The weight of the fruits of each treatment was taken with the help of an electric balance at 3-day intervals, and then the percentage of weight loss was calculated by the following formula:

$$Total\ weight\ loss\ (\%) = \frac{IW - FW}{IW} \times 100$$

Here,
IW = Initial/Fresh weight (g)
FW = Final weight (g)

Titratable acidity (TA) and pH determination

Titratable acidity was determined according to a method by Ranganna (1977), with slight modifications. Mango pulp tissues (10 g) were homogenized with distilled water (40 mL) by using a kitchen blender for 2 min and filtered through a Whatman filter paper No. 2. Five mL of the juice extract solution were taken in a 100 mL conical flask. Two to three drops of phenolphthalein indicator solution were added and then the conical flask was shaken vigorously. The sample was titrated with 0.1 M NaOH solution until the color turned pink and persistent for 15 s. The titer volume was recorded and the result was expressed as percentage of citric acid, which was calculated using the following formula:

Citric acid (%) =
(Titre (mL) × NaOH normality (0.1 M)
× Vol. made up (50 mL)
× Citric acid eq. weight (64 g) × 100)
/(Volume of sample for titrate (5 mL)
× Weight of sample taken (10 g) × 1000)

The remaining juice extract from TA measurement enabled the pH determination of the fruit pulp. The pH was determined by using a glass electrode pH meter.

Estimation of vitamin C

The vitamin C content of mango was determined using the titration method with 2,6-dichlorophenol indophenol (DCPIP) dye solution, as described by Ranganna (1986). This method is based on the reduction of DCPIP dye to a colorless form by ascorbic acid in an alkaline solution. The vitamin C content of the sample was then calculated using the following formula:

$$Vitamin\ C\ (mg\ 100\ g^{-1}\ fruit) = \frac{T \times D \times V_1}{V_2 \times W} \times 100$$

(Here, T = Titre, D = Dye factor, V_2 = Volume made up, V_1 = Volume taken for titration, W = Weight of the sample taken for estimation)

Determination of chlorophyll and total anthocyanin content

The total anthocyanin content of mango peel was determined using the method described by Sims

and Gamon (2002), with minor modifications. A five-gram tissue sample was homogenized with 10 mL of 80% cold acetone (1:2 ratio, 80:20 v:v, pH = 7.8) and then centrifuged at 800 rpm for 4 min at 4°C. The clear supernatant was diluted with acetone to a final volume of 5 mL and used for the determination of total anthocyanin content. Absorbance measurements were recorded using a double-beam spectrophotometer (Dynamica HALO-DB-20S UV-VIS Double Beam Spectrophotometer) at wavelengths of 665, 649, 646, 663, 470, 529, and 650 nm. The content of chlorophyll-a, chlorophyll-b, and anthocyanin was calculated using the following formulae:

$$Chlorophyll\ a - a\ (\mu g\ mL^{-1}) = 12.21\ A_{665} - 6.88\ A_{649}$$

$$Chlorophyll\ a - b\ (\mu g\ mL^{-1}) = 20.13\ A_{646} - 5.03\ A_{663}$$

$$Anthocyanin\ (\mu mol\ mL^{-1}) = A_{529} - 0.288\ A_{650}$$

$$Anthocyanin\ (\mu mol\ g^{-1} \times 207.247 = \mu g\ g^{-1}) = A_{529} - 0.288\ A_{650}$$

Where, A is the absorbance of the extract solution in a 1 cm path length cuvette at wave length x.

Total soluble solids (°Brix) analysis

The total soluble solids (TSS) of mango fruit pulp were determined using a hand refractometer (Model BS Eclipse 3-45) at room temperature, following a method by Nanda et al. (2003). The fruit pulp was homogenized in a kitchen blender for two minutes and then filtered through four layers of muslin cloth. A drop of the extracted juice was placed on the prism of the refractometer, and the reading was recorded directly. The results were expressed as percentage of soluble solids (°Brix).

Determination of total sugar content

Sugar content was estimated by determining the volume of unknown sugar solution of mango pulp required for complete reduction of standard Fehling's solution. Fifty grams of fruit was used for calculating the reducing percentage, non-reducing, and total sugar content using the following formulae:

$$\%\ Reducing\ sugar = \frac{F \times D \times 100}{T \times W \times 100}$$

(Where, I = mg of invert sugar required to reduce to known volume of Fehling's solution,
D = Dilution, T = Titre and W = wt. of the sample)

$$\%\ Non - reducing\ sugar = (\%\ Total\ invert\ sugars - \%\ reducing\ sugars\ originally\ present) \times 0.95$$

(conversion factor)

$$\%\ Total\ sugars = \%\ reducing\ sugar + \%\ non - reducing\ sugar$$

Assessment of disease incidence

The incidence of fruit diseases was recorded at three-day intervals. Mango fruit rot was identified through visual comparison with previously documented symptoms. The incidence of fruit rot was then calculated using the following formula:

$$\%\ Disease\ incidence = \frac{Number\ of\ infected\ fruits}{Total\ number\ of\ fruits\ under\ the\ study} \times 100$$

Shelf life

The shelf life of mango fruits, as influenced by different storage treatments and varieties, was determined by counting the number of days required for the fruits to reach full ripeness while retaining optimal quality.

Statistical analysis

The collected data on various parameters were statistically analyzed using SPSS software (IBM, New York, USA). Analysis of variance (ANOVA) was performed for all characteristics using the F-test, and significant differences among treatment means were determined using Duncan's Multiple Range Test (DMRT) at a 1% level of probability (Gomez and Gomez, 1984).

Results

Changes of fruit firmness

The combined effects of cultivars and various natural preservative treatments were statistically significant regarding changes in fruit firmness during storage (Table 1). At 3 DAS, the highest firmness (10.19 N) was recorded from treatment V_1T_4 while the lowest firmness (6.68 N) was noted from treatment V_2T_0. At 6 and 9 DAS, the highest firmness (8.15 and 7.04 N) was noted from treatment combination V_2T_4 whereas the lowest firmness (6.26 and 3.94 N) was recorded from V_1T_0.

The firmness of fruit pulp gradually decreased through storage time (Fig. 1). The maximum fruit firmness was recorded in 'Langra' (9.41, 7.34, 5.87 N) compared to 'Himsagar' (7.12, 6.44, 5.34 N) after 3, 6 and 9 d of storage.

Table 1. Effect of varieties ('Langra' and 'Himsagar') and natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on firmness and weight loss of mango during storage.

Varieties × Treatments	Firmness (N) at different DAS			Weight loss (%) at different DAS		
	3	6	9	3	6	9
V_1T_0	8.70^{e}	6.26	4.44^{h}	1.91	2.90	3.85
V_1T_1	9.11^{d}	7.28	5.61^{e}	1.72	2.61	3.71
V_1T_2	9.32^{c}	7.65	6.21^{c}	1.67	2.58	3.65
V_1T_3	9.76^{b}	7.47	5.77^{de}	1.52f	2.43	3.5
V_1T_4	10.19^{a}	8.15	7.04^{a}	1.31	2.26	3.37
V_1T_5	9.37^{c}	7.24	6.14^{c}	1.60	2.69	3.67
V_2T_0	6.68^{j}	5.26	3.94^{i}	2.01	3.06	3.88
V_2T_1	7.20^{h}	6.30	5.24f^{g}	1.90	2.78	3.76
V_2T_2	6.79^{j}	6.45	5.10^{g}	1.75	2.74	3.65
V_2T_3	7.32^{g}	6.60	5.37^{f}	1.74	2.68	3.50
V_2T_4	7.67^{f}	7.42	6.53^{b}	1.45	2.36	3.43
V_2T_5	7.06^{i}	6.60	5.90^{d}	1.85	2.84	3.81
Level of Significance	**	NS	**	NS	NS	NS
CV (%)	0.85	2.74	2.26	4.24	3.39	1.90

Here, ** Significant at 1% level of probability, NS = Not significant, DAS = Days after Storage, CV = Co- effici ent of Variation. Values having same letters with the column do not differ significantly at 5% level of probability.

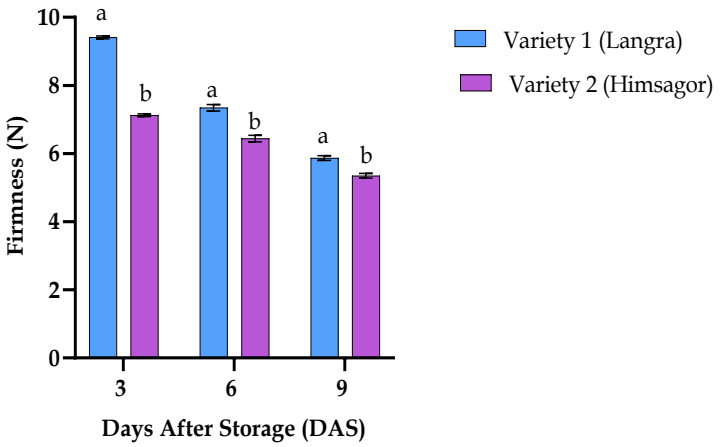

Fig. 1. Effect of variety ('Langra' and 'Himsagor') on firmness of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

It was observed that the changes in firmness occurred at a faster rate in the control, whereas the rates were slower in fruits treated by moringa leaf extract. At 3, 6 and 9 DAS, fruit firmness was maximum (8.93, 6.92, and 6.02 N) in moringa leaf extract-treated fruits and the minimum (7.69, 5.76, and 4.19 N) was recorded in untreated fruits (Fig. 2).

Weight loss

The combined effect of cultivars and various natural preservative treatments on total weight loss at different storage intervals (DAS) was not statistically significant. Among the treatment combinations, the lowest weight loss (1.31%, 2.26%, and 3.37%) was recorded in 'Langra' mangoes treated with moringa leaf extract (V_1T_4) at 3, 6, and 9 DAS, respectively (Table 1). In contrast, the highest weight loss (2.01%, 3.06%, and 3.88%) was observed in untreated 'Himsagar' fruits. Regarding total weight loss, the 'Langra' cultivar exhibited lower weight loss (1.79%,

2.75%, and 3.68%) compared to 'Himsagar' (1.63%, 2.58%, and 3.63%) at 3, 6, and 9 days after storage, respectively (Fig. 3).

Weight loss was lower (1.38, 2.31, and 3.40%) in fruits treated by moringa leaf extract at 3, 6 and 9 d after storage, respectively, while it was statistically different from the other treatment groups. In contrast, a higher weight loss (1.96, 2.98, and 3.86%) was recorded from untreated fruits at 3, 6 and 9 d, respectively (Fig. 4).

Pulp pH

The combined effect of cultivars and various natural preservative treatments on pH content at different storage intervals was statistically significant (Table 2). Among the treatment combinations, 'Himsagar' fruits treated with moringa leaf extract (V_2T_4) recorded the highest pH values of 6.14, 6.97, and 7.96 at 3, 6, and 9 DAS, respectively, showing a significant difference from other treatments. The lowest pH values (4.12 and 4.67) were observed in 'Langra' fruits treated with hot water (V_1T_5) at 3 and 6 DAS, respectively, while the lowest pH at 9 DAS (5.15) was recorded in untreated 'Langra' fruits (V_1T_0). These results indicated that pH values increased through storage time.

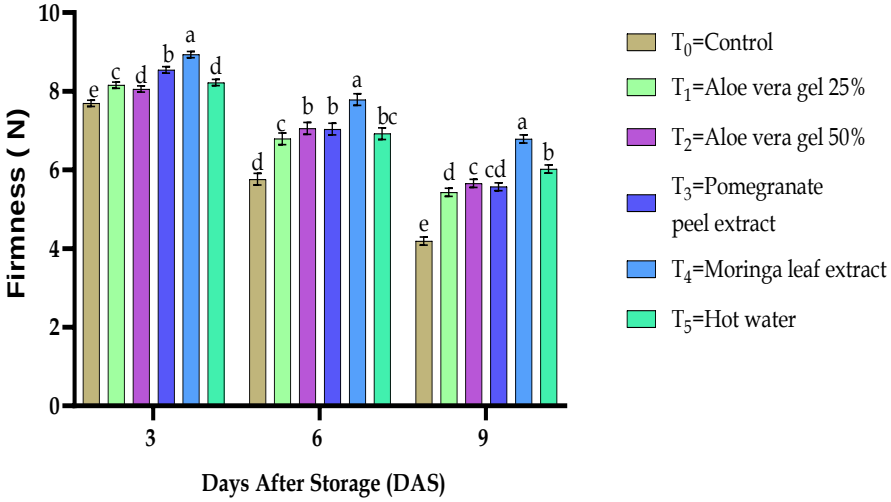

Fig. 2. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on firmness of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

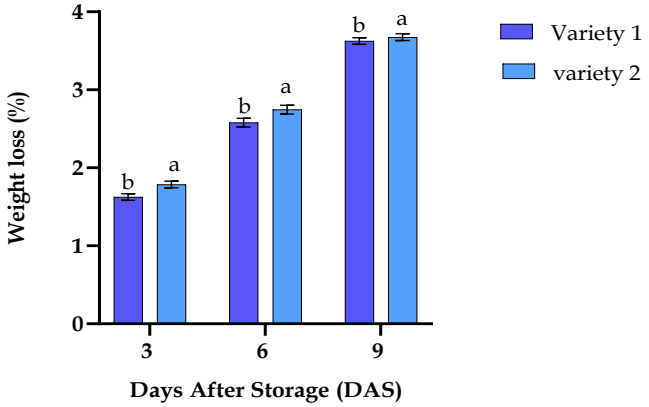

Fig. 3. Effect of variety ('Langra' and 'Himsagor') on total weight loss (%) of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

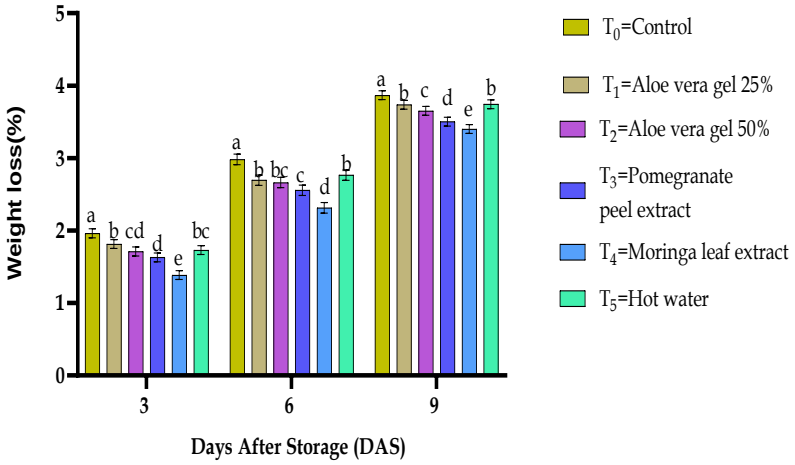

Fig. 4. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on weight loss (%) of mango at different days (3, 6 and 9) after storage. Vertical bars represent standard errors.

Table 2. Effect of varieties ('Langra' and 'Himsagar') and natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on pH and titratable acidity of mango during storage.

Varieties × Treatments	pH at different DAS			Titratable acidity (%) at different DAS		
	3	6	9	3	6	9
V_1T_0	4.39^{i}	4.84^{i}	5.15^{f}	0.26^{fg}	0.23^{ef}	0.19^{ef}
V_1T_1	4.6^{h}	5.25^{g}	6.06^{d}	0.30^{de}	0.28^{cd}	0.24^{bcd}
V_1T_2	4.94^{e}	5.52^{f}	6.23^{d}	0.31^{cdf}	0.27^{cd}	0.22^{cde}
V_1T_3	5.12^{d}	5.92^{d}	6.65^{c}	0.35^{ab}	0.30^{ab}	0.26^{a}
V_1T_4	5.79^{b}	6.29^{c}	7.32^{b}	0.37^{a}	0.32^{a}	0.28^{abc}
V_1T_5	4.12^{j}	4.67^{j}	5.26^{f}	0.29^{de}	0.27^{cd}	0.23^{cd}
V_2T_0	4.79^{g}	5.33^{g}	6.14^{d}	0.24^{h}	0.19^{g}	0.14^{g}
V_2T_1	4.17^{j}	4.98^{h}	5.78^{e}	0.28^{ef}	0.26^{de}	0.21^{de}
V_2T_2	4.88^{f}	5.74^{e}	6.26^{d}	0.31^{cd}	0.26^{de}	0.23^{cd}
V_2T_3	5.43^{c}	6.43^{b}	7.14^{b}	0.33^{bc}	0.29^{abc}	0.26^{ab}
V_2T_4	6.14^{a}	6.97^{a}	7.96^{a}	0.34^{ab}	0.31^{a}	0.27^{a}
V_2T_5	4.88^{f}	5.67^{e}	6.33^{d}	0.25^{gh}	0.21^{fg}	0.17^{fg}
Level of Significance	**	**	**	**	**	*
CV (%)	0.62	1.29	2.54	4.81	5.90	7.86

Here, ** Significant at 1% level of probability, NS = Not significant, DAS = Days after Storage, CV = Co-effici ent of variation. Values having same letters within the column do not differ significantly at 5% level of probability.

The pH value gradually increased through storage time. The highest pH values (5.05, 5.85, and 6.60) were recorded in 'Himsagar' compared to 'Langra' (4.83, 5.41, and 6.11) at 3, 6, and 9 DAS, respectively (Fig. 5). These results indicated that 'Himsagar' exhibited higher pH values than 'Langra', likely due to differences in adaptability and genetic variation between the two varieties under storage conditions.

Among the treatments, the highest pH values (5.97, 6.63, and 7.64) were recorded in fruits treated with moringa leaf extract at 3, 6, and 9 DAS, respectively, showing significant differences from the other postharvest treatments. In contrast, the lowest pH value (4.38) was observed in fruits treated with 25% *Aloe vera* gel at 3 DAS, while untreated fruits (V_1T_0) showed pH values of 5.08 and 5.64 at 6 and 9 DAS, respectively (Fig. 6).

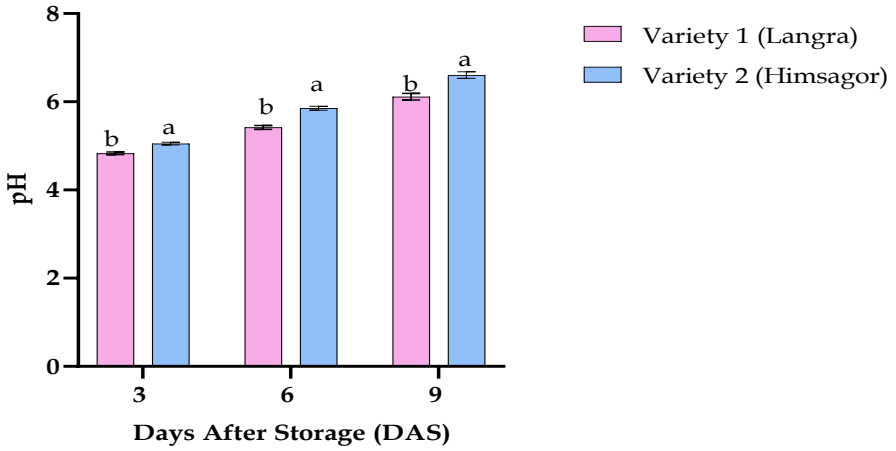

Fig. 5. Effect of variety (Langra and Himsagar) on pH of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard error.

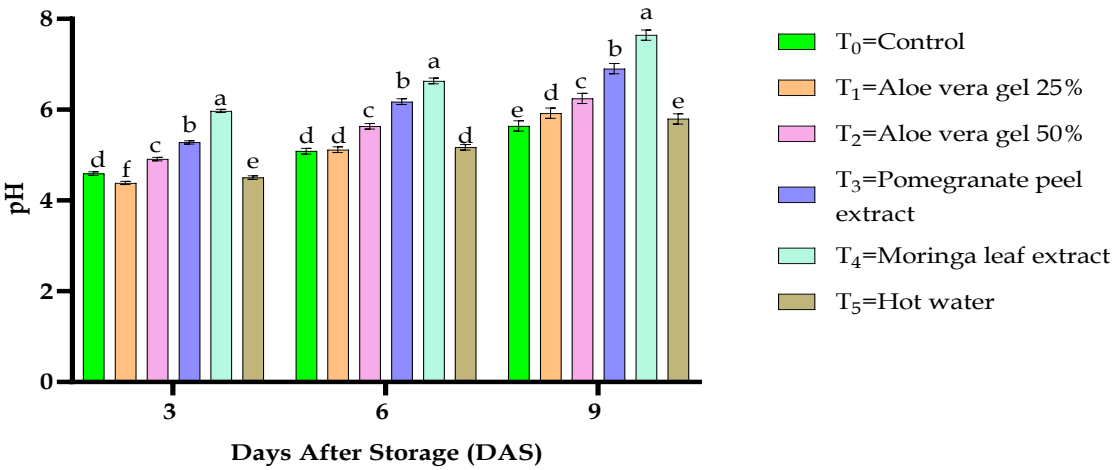

Fig. 6. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on pH of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Titratable acidity

A highly significant variation was observed in the combined effect of cultivars and various natural preservative treatments concerning titratable acidity (TA) at different days after storage (DAS) (Table 2). The highest TA content (0.37%, 0.32%, and 0.28%) was found in 'Langra' fruits treated with moringa leaf extract at 3, 6, and 9 DAS, respectively, showing significant differences from other treatment combinations. The lowest TA content (0.24%, 0.19%, and 0.14%) was observed in untreated 'Himsagar' fruits at 3, 6, and 9 DAS, respectively. Regarding titratable acidity, the highest values (0.31%, 0.27%, and 0.23%) were recorded in 'Langra,' while the lowest values (0.30%, 0.26%, and 0.21%) were recorded in 'Himsagar' at 3, 6, and 9 DAS, respectively. These results indicated that titratable acidity significantly decreased through storage time (Fig. 7).

Mango fruits treated with moringa leaf extract had higher titratable acidity content (0.35, 0.32, and 0.27%), which was closely followed by values in mango fruits treated with pomegranate peel extract (0.34, 0.30, and 0.26%) at 3, 6, and 9 DAS, respectively. However, the lowest titratable acidity content (0.25, 0.21, and 0.17%) was obtained in untreated fruits at 3, 6, and 9 DAS, respectively. TA content decreased through storage time (Fig. 8).

Vitamin C content

The combined effect of cultivars and various natural preservative treatments showed a statistically significant impact on vitamin C content at different days after storage (DAS)

(Table 3). The highest vitamin C content (38.97, 35.87, and 33.62 mg 100 g^{-1} FW) was recorded in 'Langra' fruits treated with moringa leaf extract at 3, 6, and 9 DAS, respectively. In contrast, the lowest vitamin C content (21.21, 18.11, and 17.05 mg 100 g^{-1} FW) was observed in 'Himsagar' fruits treated with hot water, showing a statistically significant difference from other treatments at 3, 6, and 9 DAS.

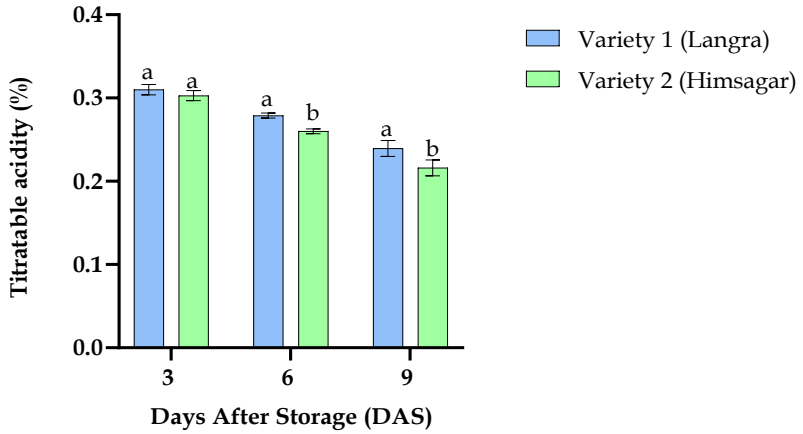

Fig. 7. Effect of variety ('Langra' and 'Himsagar') on titratable acidity of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

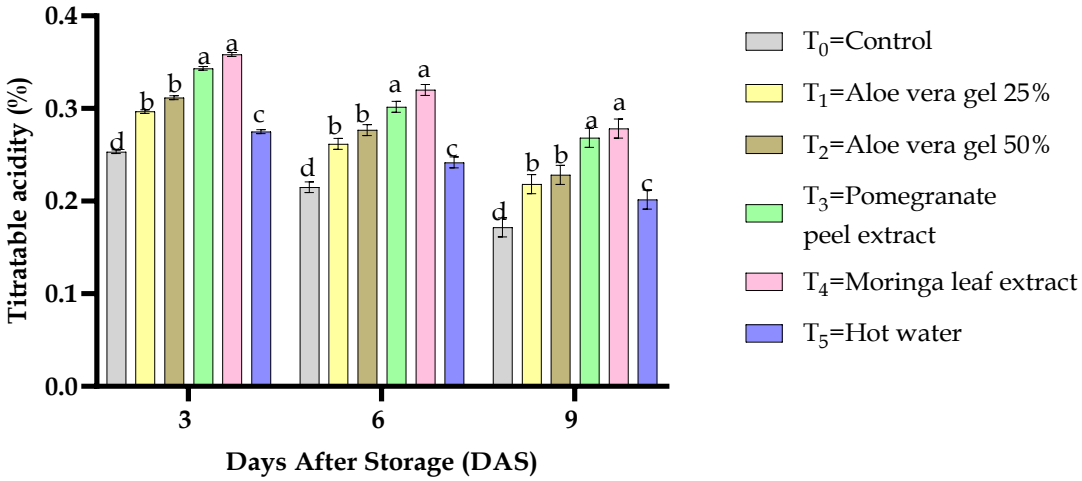

Fig. 8. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on titratable acidity of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Out of the two cultivars, the variety 'Langra' exhibited the maximum vitamin C content (29.76, 26.73, and 24.68 mg 100 g^{-1} FW) compared to 'Himsagar' (27.70, 24.75, and 22.36 mg 100 g^{-1} FW) at 3, 6, and 9 DAS, respectively. These results indicated that the vitamin C content significantly decreased through storage time (Fig. 9).

From Figure 10, it was observed that mango fruits stored at ambient temperature and treated with moringa leaf extract had the highest vitamin C content (38.03, 34.35, and 32.47 mg 100 g–1 FW) at 3, 6, and 9 DAS, respectively. In contrast, the lowest vitamin C content (21.01, 18.30, and 16.89 mg 100 g–1 FW) was recorded in mango fruits treated with hot water, showing statistically significant differences from other treatments at 3, 6, and 9 DAS.

Table 3. Effect of varieties ('Langra' and 'Himsagar') and natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on vitamin C and anthocyanin content of mango during storage.

Varieties × Treatments	Vitamin C (mg 100 g^{-1} FW) at different DAS			Anthocyanin (mg 100 g^{-1} FW) at different DAS		
	3	6	9	3	6	9
V_1T_0	24.14^{g}	21.84^{f}	19.64^{f}	11.16^{h}	15.66^{f}	21.00^{g}
V_1T_1	25.383^{f}	21.95^{e}	20.31^{f}	9.64^{i}	16.55^{ef}	19.63^{h}
V_1T_2	32.2^{d}	28.66^{d}	26.67^{d}	17.26^{d}	22.74^{b}	26.84^{bc}
V_1T_3	37.05^{b}	33.55^{b}	31.11^{b}	19.08^{c}	25.05^{a}	27.54^{b}
V_1T_4	38.93^{a}	35.87^{a}	33.62^{a}	22.18^{a}	25.40^{a}	29.72^{a}
V_1T_5	20.81^{h}	18.5^{h}	16.74^{gh}	15.07^{f}	19.13^{d}	25.18^{d}
V_2T_0	20.80^{h}	18.13^{h}	16.08^{h}	9.92^{i}	15.80^{f}	22.37^{f}
V_2T_1	23.60^{g}	20.75^{g}	17.71^{g}	12.45^{g}	17.06^{e}	24.19^{e}
V_2T_2	28.97^{e}	27.00^{e}	23.30^{e}	17.76^{d}	22.4^{b}	27.46^{bc}
V_2T_3	34.59^{c}	31.67^{c}	28.72^{c}	20.4^{b}	25.63^{a}	29.98^{a}
V_2T_4	37.03^{b}	32.82^{b}	31.33^{b}	15.88^{e}	21.44^{c}	26.73^{c}
V_2T_5	21.21^{h}	18.11^{h}	17.05^{gh}	11.66^{h}	16.32^{ef}	21.85^{f}
Level of Significance	**	**	**	**	**	**
CV (%)	2.00	2.14	2.14	2.76	2.61	1.81

Here, ** Significant at 1% level of probability, NS = Not significant, DAS = Days after Storage, CV = Co-efficient of Variation. Values having same letters within each column do not differ significantly at 5% level of probability.

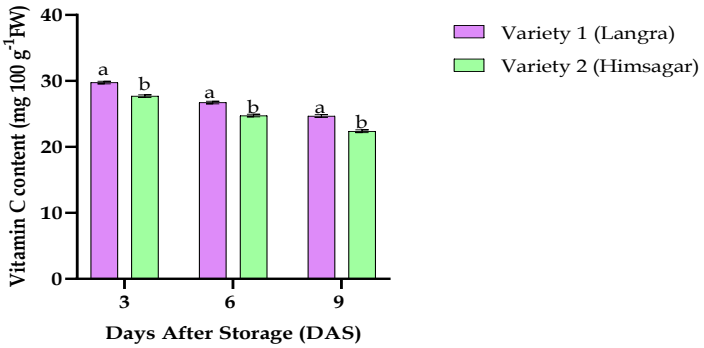

Fig. 9. Effect of variety ('Langra' and 'Himsagar') on vitamin C content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

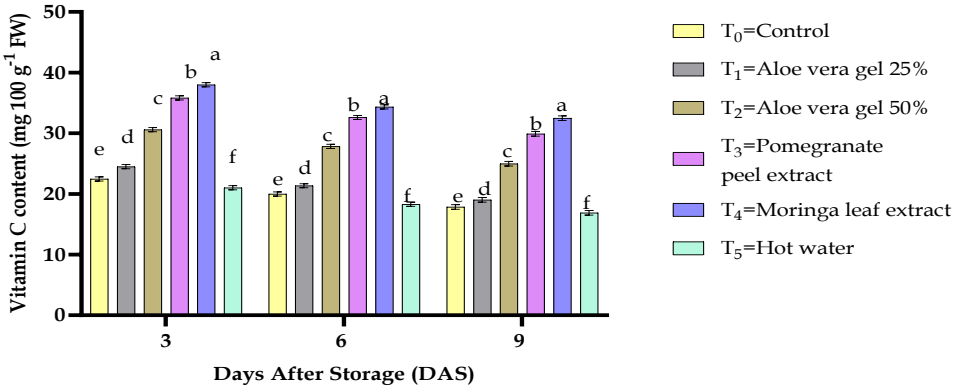

Fig. 10. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on vitamin C content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Anthocyanin content

A highly significant variation was obtained among the combined effect of cultivars and various natural preservative treatments in respect of anthocyanin content at different DAS (Table 3). At 3 DAS, the highest anthocyanin content (22.18 mg 100 g^{-1} FW) was noted in the variety 'Langra,' which was treated with pomegranate peel extract, whereas the lowest anthocyanin content (9.64 mg 100 g^{-1} FW) was observed in 'Langra' fruits treated with 25% *Aloe vera* gel. Moreover, at 6 and 9 DAS, the maximum anthocyanin content (25.63 and 29.98 mg 100 g^{-1} FW, respectively) was obtained in the variety 'Himsagar' when treated with pomegranate peel extract, whereas the lowest anthocyanin content (15.66 and 21.00 mg 100 g^{-1} FW) was found in untreated 'Langra' fruits, which was statistically different from other treatment combinations.

When comparing the two cultivars, 'Langra' exhibited a higher anthocyanin content (15.72 and 20.75 mg 100 g^{-1} FW) than 'Himsagar' (14.67 and 19.77 mg 100 g^{-1} FW) at 3 and 6 DAS, respectively. However, at 9 DAS, the 'Himsagar' variety showed maximum anthocyanin content (25.43 mg 100 g^{-1} FW), which was higher than that of 'Langra' at the same stage. These results indicated that anthocyanin content significantly increased through storage time, suggesting a progressive accumulation of anthocyanins over time (Fig. 11).

Additionally, when considering the effect of storage conditions and preservative treatments, it was observed that the highest anthocyanin content (19.74, 25.34, and 28.76 mg 100 g^{-1} FW) was recorded in mango fruits stored at ambient temperature while treated with pomegranate peel extract at 3, 6, and 9 DAS, respectively. In contrast, the lowest anthocyanin content (10.54, 15.73, and 21.68 mg 100 g^{-1} FW) was recorded from untreated mango fruits under storage conditions at the same time intervals, which was statistically different from other treatments. These findings revealed that anthocyanin content significantly increased with increasing storage duration, further emphasizing the role of natural preservatives like pomegranate peel extract in enhancing anthocyanin accumulation in mango peel during postharvest storage (Fig. 12).

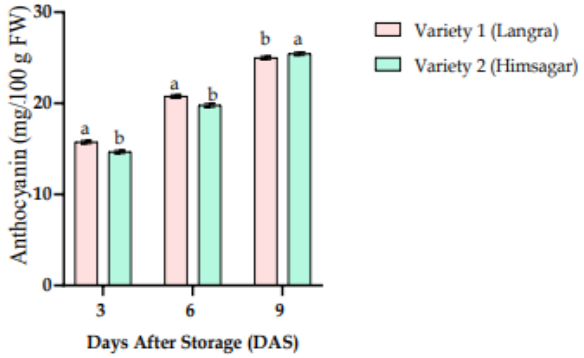

Fig. 11. Effect of variety ('Langra' and 'Himsagar') on anthocyanin content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

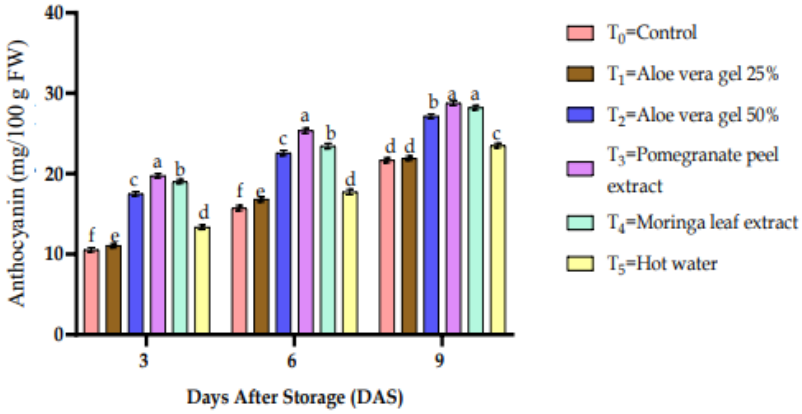

Fig. 12. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on anthocyanin content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Total soluble solid content

The combined effect of mango cultivars and various natural preservative treatments was significant in terms of total soluble solids (% Brix) at different DAS (Table 4). The lowest TSS content was observed in 'Langra' fruits treated with moringa leaf extract, measuring 8.63, 9.56, and 11.76% Brix at 3, 6, and 9 DAS, respectively. In contrast, the highest TSS content (11.31, 14.73, and 17.46% Brix) was recorded in untreated 'Himsagar' fruits at the same time intervals.

These observations indicated that TSS content increased significantly during the storage period, which is consistent with the natural ripening process of mangoes. Furthermore, fruits treated with moringa leaf extract exhibited the lowest TSS accumulation in both 'Langra' and 'Himsagar' varieties, suggesting a potential delay in ripening due to the preservative effect of moringa leaf extract.

The highest TSS content was recorded in the 'Himsagar' variety, with values of 10.12%, 12.26%, and 13.90% Brix at 3, 6, and 9 days after storage (DAS), respectively. In contrast, the 'Langra' variety exhibited the lowest TSS content, measuring 9.16%, 10.37%, and 12.61% Brix at the same time points. These results indicated a significant increase in TSS content with extended storage duration (Fig. 13).

Table 4. Effect of varieties ('Langra' and 'Himsagar') and natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on total soluble solids and total sugar content of mango fruits during storage.

Varieties × Treatments	Total soluble solid (% Brix) at different DAS			Total sugar (%) at different DAS		
	3	6	9	3	6	9
V_1T_0	10.56^{bc}	11.53^{de}	14^{b}	5.2067^{a}	9.16^{a}	13.76^{b}
V_1T_1	9.26^{ef}	10.36^{gh}	12.4^{e}	3.5933^{g}	6.65^{g}	10.743^{g}
V_1T_2	9.03^{fg}	10.3^{gh}	12.86^{d}	3.5167^{g}	6.8233^{f}	10.3^{h}
V_1T_3	8.7^{gh}	9.86^{hi}	11.93^{e}	3.7433^{de}	7.1833^{e}	13.263^{d}
V_1T_4	8.63^{h}	9.56^{i}	11.76^{f}	2.6967^{i}	6.6467^{g}	10.22^{h}
V_1T_5	8.8^{gh}	10.63^{fg}	12.7^{df}	3.53^{g}	7.3567^{d}	13.577^{c}
V_2T_0	11.3^{a}	14.73^{a}	17.46^{a}	4.1933^{b}	9.2567^{a}	14.5^{a}
V_2T_1	10.93^{ab}	12.96^{b}	13.93^{bc}	3.85^{cd}	7.07^{e}	11.08^{f}
V_2T_2	9.83^{d}	12.03^{cd}	12.80^{de}	3.6167^{fg}	6.4^{h}	10.67^{g}
V_2T_3	10.26^{c}	11.13^{ef}	13.56^{c}	3.94^{c}	7.5633^{c}	13.083^{e}
V_2T_4	9^{fgh}	10.33^{gh}	11.90^{f}	2.8167^{h}	5.8267^{i}	10.207^{h}
V_2T_5	9.43^{e}	12.4^{c}	13.73^{bc}	3.716^{ef}	7.8667^{b}	13.807^{b}
Level of Significance	**	**	**	**	**	**
CV (%)	2.43	2.81	1.88	1.75	1.32	0.75

Here, ** significant at 1% level of probability, NS = not significant, DAS = days after storage, CV = co-efficient of variation. Values having same letters within each column do not differ significantly at 5% level of probability.

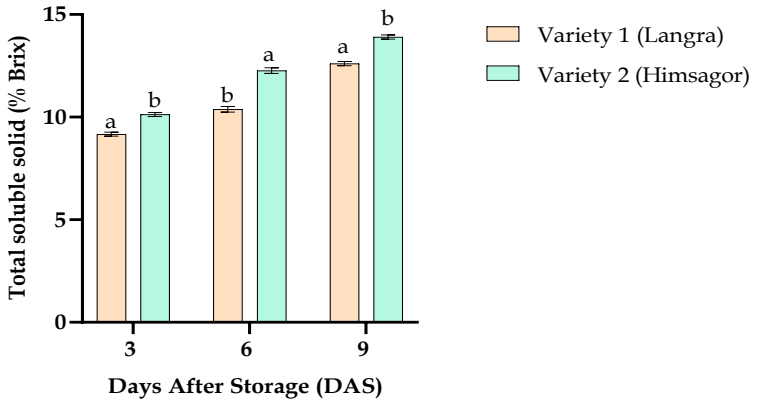

Fig. 13. Effect of variety ('Langra' and 'Himsagar') on TSS of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Fruits treated with moringa leaf extract showed the lowest TSS (8.81, 9.95, and 11.83% Brix) while untreated fruits showed the highest TSS (10.93, 13.13, and 15.73% Brix) at 3, 6, and 9 DAS, respectively (Fig. 14).

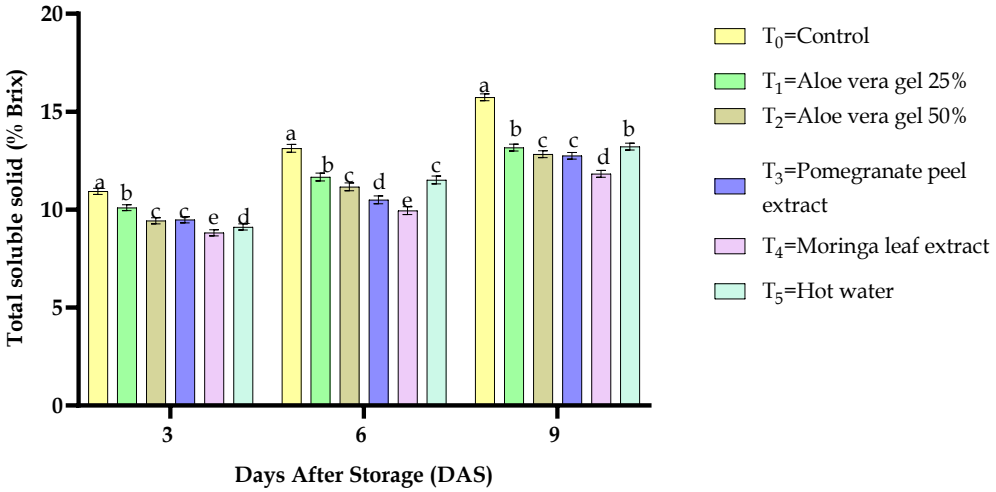

Fig. 14. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on total soluble solid (% Brix) content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Total sugar

The combined effect of the studied mango cultivars and various natural preservative treatments had a statistically significant impact on total sugar content at different days after storage (Table 4). The lowest total sugar content was recorded in 'Himsagar' fruits treated with moringa leaf extract, measuring 5.826% and 10.20% at 6 and 9 DAS, respectively. In contrast, the highest total sugar content (9.25% and 14.5%) was observed in untreated 'Himsagar' fruits at the same time points (Fig. 15).

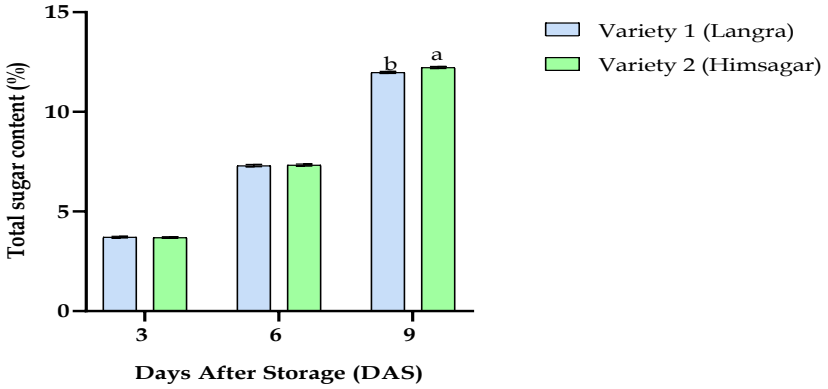

Fig. 15. Effect of variety ('Langra' and 'Himsagar') on total sugar content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

At 3 and 6 DAS, both cultivars exhibited statistically identical total sugar content. However, by 9 DAS, the Himsagar cultivar had a higher total sugar content (12.22%) compared to Langra (11.97%). Among the treatments, fruits treated with moringa leaf extract recorded the lowest total sugar content, measuring 2.75%, 6.23%, and 10.21% at 3, 6, and 9 DAS, respectively, showing a statistically significant difference from other postharvest treatments. In contrast, untreated fruits had the highest total sugar content, with values of 4.7%, 9.20%, and 14.13% at the corresponding time points (Fig. 16).

Disease incidence

The combined effect of the studied mango cultivars and the application of different natural preservative treatments had a significant influence on disease incidence at various storage

durations (Table 5). Among the treatment combinations, the highest disease incidence (20.33%, 39.62%, and 59.80%) was observed in untreated 'Himsagar' fruits at 3, 6, and 9 DAS, respectively. However, no disease incidence was recorded at 3 DAS in either cultivar when treated with moringa leaf extract or pomegranate peel extract. The lowest disease incidence (8.43% and 17.41%) was found in Langra fruits treated with moringa leaf extract at 6 and 9 DAS, respectively.

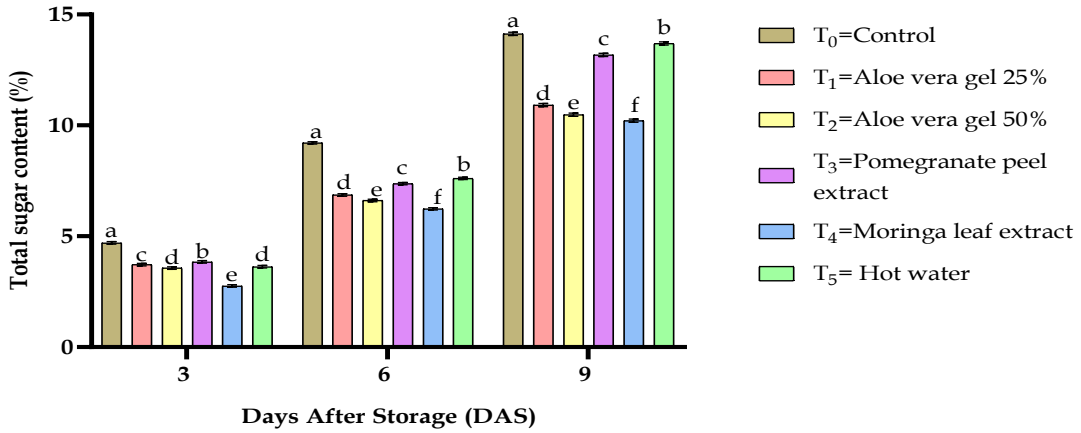

Fig. 16. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on total sugar content of mango at different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Table 5. Effect of varieties ('Langra' and 'Himsagar') and natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on disease incidence and shelf life of mango during storage.

Varieties × Treatments	Disease incidence (%) at different DAS			Shelf life (DAS)
	3	6	9	
V_1T_0	15.36^{c}	36.47^{b}	52.55^{b}	8.66
V_1T_1	8.21^{f}	23.03^{f}	39.49^{e}	11.66
V_1T_2	4.22^{g}	14.76^{i}	34.63^{g}	13.66
V_1T_3	0.00^{h}	12.93^{j}	31.60^{h}	15.66
V_1T_4	0.00^{h}	8.43^{k}	17.41^{k}	18.33
V_1T_5	11.83^{e}	28.93^{e}	42.85^{d}	12.00
V_2T_0	20.33^{a}	39.6^{a}	59.80^{a}	7.33
V_2T_1	13.20^{d}	30.17^{d}	43.63^{d}	11.00
V_2T_2	8.043^{f}	20.47^{g}	37.00^{f}	12.66
V_2T_3	0.00^{h}	15.64^{h}	29.80^{i}	15.33
V_2T_4	0.00^{h}	12.65^{j}	23.67^{j}	17.66
V_2T_5	16.81^{b}	33.1^{c}	49.88^{c}	10.66
Level of Significance	**	**	**	NS
CV (%)	3.52	1.92	1.25	4.20

Here ** significant at 1% level of probability, NS = not significant, DAS = days after storage, CV = Co-efficient of variation. Values having same letters within each column do not differ significantly at 5% level of probability.

Among the two cultivars, 'Himsagar' fruits were more susceptible to disease, exhibiting higher disease incidence rates of 9.73%, 25.28%, and 40.63% at 3, 6, and 9 DAS, respectively. In contrast, 'Langra' fruits showed lower disease incidence, with values of 6.60%, 20.76%, and 36.42% at the corresponding time points. These results indicated that disease incidence was lower in 'Langra' than in 'Himsagar,' suggesting that 'Langra' had a longer shelf life (Fig. 17).

The lowest disease incidence (0, 10.54, and 20.54%) was observed from moringa leaf extract

treated fruits, whereas the untreated fruits showed the highest incidence of disease (17.84, 38.05, and 56.17%) at 3, 6, and 9 DAS respectively. These results revealed that disease incidence was significantly increased in response to a longer storage period (Fig. 18).

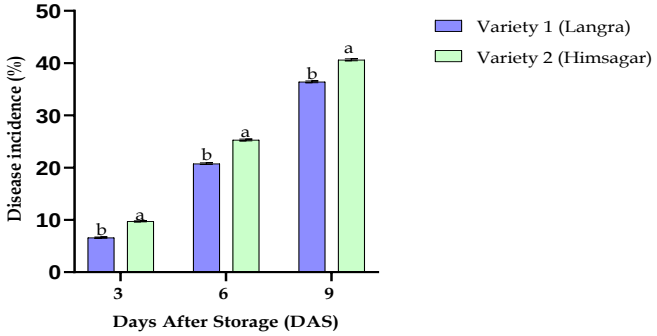

Fig. 17. Effect of variety ('Langra' and 'Himsagar') on disease incidence of mango on different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

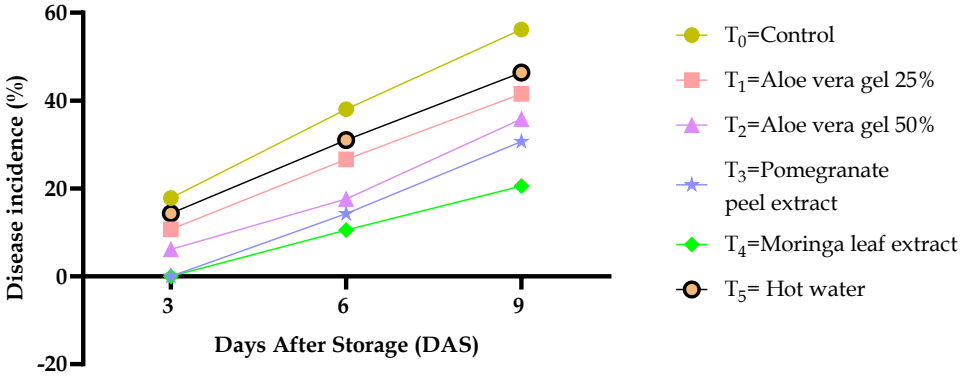

Fig. 18. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on disease incidence of mango on different days (3, 6, and 9) after storage. Vertical bars represent standard errors.

Shelf life

The combined effect of the studied mango cultivars and various natural preservative treatments did not significantly differ in terms of shelf life (Table 5). The longest shelf life (18.33 days) was observed in 'Langra' fruits treated with moringa leaf extract, which was statistically distinct from the other treatment combinations. In contrast, the shortest shelf life (7.33 d) was recorded in untreated 'Himsagar' fruits. Figure 19 shows that, overall, 'Langra' fruits had a higher average shelf life (13.33 d) compared to 'Himsagar' fruits (12.44 d).

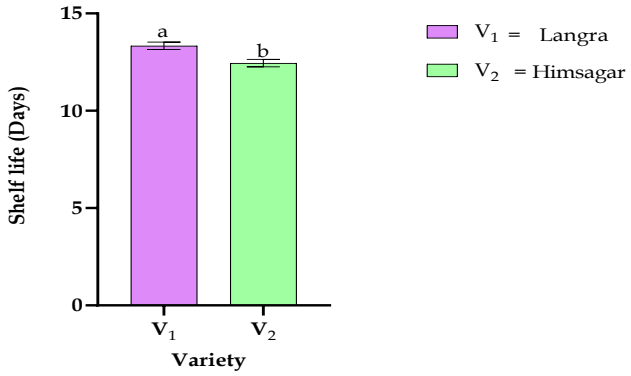

Fig. 19. Effect of variety ('Langra' and 'Himsagar') on the shelf life of mango fruits during storage. Vertical bars represent standard errors.

These results indicated that the longest shelf life (18 d) was observed in fruits treated with moringa leaf extract, followed by those treated with pomegranate peel extract (15.5 d). The shortest shelf life (8 d) was recorded in untreated fruits. Among the other postharvest treatments, fruits treated with 25% *Aloe vera* gel, 50% *Aloe vera* gel, and hot water had shelf lives of 11.33, 13.16, and 11.33 d, respectively (Fig. 20).

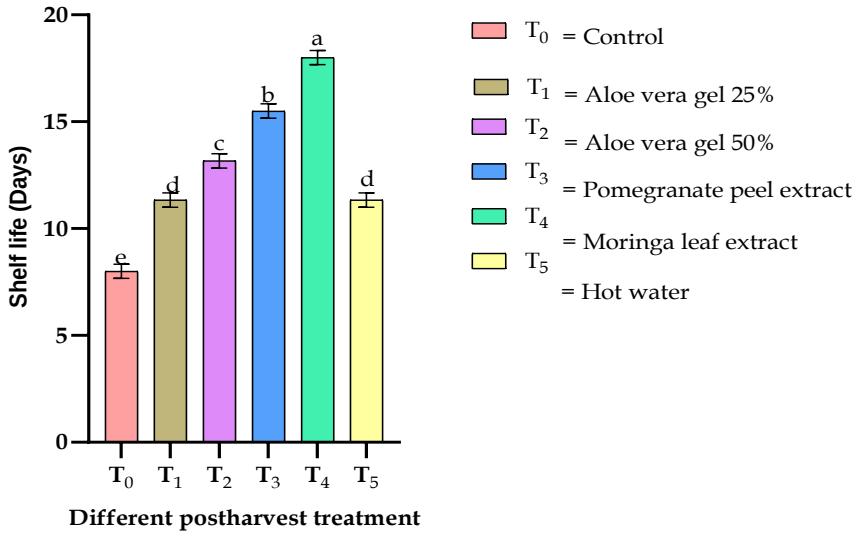

Fig. 20. Effect of natural preservatives (T_0 = control, T_1 = *Aloe vera* gel 25%, T_2 = *Aloe vera* gel 50%, T_3 = pomegranate peel extract, T_4 = moringa leaf extract, T_5 = hot water) on shelf life of mango fruits during storage. Vertical bars represent standard errors.

Discussion

Fruit firmness is a key quality indicator closely associated with softening during ripening (Bose et al., 2021). Our study revealed that fruit firmness significantly decreased in both treated and untreated fruits as storage progressed, reaching its lowest values by the end of the storage period. Between the two mango varieties, Langra exhibited higher firmness than Himsagar. Natural preservative treatments significantly slowed the decline in firmness compared to untreated fruits. This observation aligns with the findings of Jha et al. (2010) and Mondal et al. (2023), who reported that mango peel firmness gradually decreased during storage, with postharvest treatments delaying this loss. Similarly, Tesfay and Magwaza (2017) found that a combination of CMC 1% and 2% moringa leaf extract effectively preserved higher firmness in avocados during storage.

Fruit softening during ripening primarily results from the degradation of the middle lamella and cell wall, which intensifies in the final stages of ripening, leading to firmness loss (He et al., 2019). Weight loss also increased over the storage period in both treated and untreated mangoes. However, natural preservative treatments significantly reduced weight loss compared to untreated fruits. The primary cause of weight loss in stored fruits is water loss to the atmosphere through transpiration, along with the depletion of carbon reserves due to respiration and an increased respiration rate (Atlaw, 2018; Azam et al., 2020). Our results align with those of Kaliq et al. (2016), who reported that natural preservative treatments help delay ripening, reduce weight loss, preserve quality, and minimize biochemical changes. Mondal et al. (2007) similarly observed that untreated fruits consistently exhibited higher weight loss than treated fruits, supporting our findings.

Moringa leaf extract, rich in antioxidants, plays a role in reducing respiration and transpiration by acting as an electron donor that mitigates free radical activity, thereby promoting stomatal closure (Sartaj et al., 2013). Our results also concur with Liamngee et al. (2019), who found that moringa leaf extract formed a protective coating on tomatoes, reducing respiration rates and subsequent weight loss.

Fruit pulp pH is another critical indicator of quality, as it reflects sweetness. Throughout the storage period, the pH of mango pulp increased significantly, with treated fruits exhibiting a slower pH rise compared to untreated ones. This aligns with the findings of Geransayeh et al. (2015), who reported that postharvest salicylic acid (SA) treatment delayed pH increases in stored strawberries. Similar trends were

observed by Azam et al. (2020) and He et al. (2018), who noted that pH values gradually increased during storage, with untreated fruits showing higher pH levels than treated ones. The rise in pulp pH is likely due to the breakdown and utilization of organic acids in respiration and other metabolic processes during ripening.

Titratable acidity, which indicates fruit acidity and is directly related to organic acid content, also decreased in both treated and untreated fruits. However, natural preservative treatments delayed this decline compared to untreated fruits. By the end of storage, the highest titratable acidity was recorded in mangoes treated with moringa leaf extract, while the lowest was observed in untreated fruits. These findings align with Caron et al. (2013), who reported a gradual decrease in titratable acidity over time across all treatment combinations. Sophia et al. (2015) also found that Aloe vera (50% and 75%) treatments significantly slowed the loss of titratable acidity in stored mangoes. The decline in acidity during storage is likely due to the oxidation of organic acids and their utilization in metabolic processes.

Vitamin C, also known as ascorbic acid, is a powerful antioxidant found in various fruits and vegetables and is a key indicator of fruit quality. Our study revealed that vitamin C content gradually declined in both treated and untreated fruits over the storage period. However, natural preservative treatments slowed this decline compared to the control. Mustari et al. (2020) similarly reported that vitamin C content in mango fruits decreased progressively during storage. This reduction is likely due to the rapid conversion of acid to sugar, which is subsequently utilized in the fruit's metabolic processes (Caron et al., 2013).

Moringa leaf extract treatments were particularly effective in minimizing vitamin C loss in mangoes, likely due to their low oxygen permeability, which reduced enzymatic activity and prevented oxidation (Abd El-Razek et al., 2019). Fruit quality also depends on anthocyanin content, which enhances pigmentation, making fruits more visually appealing and suitable as natural food colorants (Ajila et al., 2007). Anthocyanins, a group of phenolic compounds, possess strong antioxidant properties (Bose et al., 2019). The present study demonstrated a significant increase in anthocyanin content in both treated and untreated fruits during storage, with treated fruits exhibiting higher anthocyanin levels by the end of the storage period. These findings align with Bose et al. (2019), who also observed an increase in anthocyanin content in stored strawberries.

TSS is another crucial parameter influencing fruit taste, as they indicate sweetness. Our results showed a gradual increase in TSS content in both treated and untreated mangoes throughout the storage period, with higher levels recorded in treated fruits at the end of storage. These findings are consistent with Fan et al. (2022), who reported that TSS levels increased as mangoes ripened, though untreated fruits exhibited slightly higher TSS content than treated ones. The rise in TSS is likely due to the conversion of complex carbohydrates into simple sugars during ripening, a common process in climacteric fruits. The higher TSS levels in mangoes coated with moringa leaf extract may be attributed to its role as an oxygen barrier, reducing respiration rates.

Total sugar content is another fundamental criterion for evaluating fruit ripening. Our study found that total sugar levels increased throughout the storage period, with moringa leaf extract proving more effective in preserving sugar content than other postharvest treatments. These findings are in agreement with Bose et al. (2020) and other researchers. The increase in sugar content is likely due to the enzymatic conversion of complex carbohydrates into simple sugars, as reported by Supa et al. (2023). Similar observations were also made by Bose et al. (2019) and Islam et al. (2014).

Disease incidence is a critical factor influencing the shelf life of stored fruits. The longevity of stored fruits is directly affected by the percentage of disease incidence, as infected fruits deteriorate rapidly, leading to a significant reduction in shelf life. Our study revealed that disease incidence increased significantly over time across all treatment combinations. However, mangoes treated with moringa leaf extract exhibited the lowest disease incidence compared to other treatments under storage conditions.

The reduced disease occurrence in moringa-treated fruits can likely be attributed to the antimicrobial properties of natural preservatives, which inhibited pathogenic growth and development. Similar findings were reported by Mondal et al. (2023), who noted that various preservatives effectively delayed disease onset in stored mangoes. Our results also align with those of Liamngee et al. (2019), who observed that moringa leaf extract significantly reduced decay levels in tomatoes, suggesting its potential as an alternative for preventing pathogen-induced spoilage. The extract's effectiveness in minimizing decay is likely due to its ability to suppress the activity of spoilage-causing fungi during storage.

Furthermore, our study confirmed that mangoes treated with natural preservatives had a longer

shelf life than untreated fruits. The longest shelf life was recorded for Langra mangoes treated with moringa leaf extract, which exhibited lower weight loss, reduced disease incidence, and higher titratable acidity and vitamin content. Similar observations were made by Liamngee et al. (2019), who found that moringa leaf extract-treated tomatoes maintained better physicochemical quality and an extended shelf life. Fruits naturally degrade over time, breaking down into simple inorganic compounds (CO_2, H_2O, and NH_3) while experiencing a decline in free energy and an increase in respiration. This accelerated respiration ultimately reduces shelf life and diminishes fruit quality (Mondal et al., 2023).

Conclusions

Mango is a climacteric fruit that ripens rapidly after harvest, making it highly susceptible to mechanical injuries and postharvest pathogen infections, which contribute to significant losses. To mitigate these postharvest losses, the use of natural preservatives has emerged as a novel preservation technique that extends shelf life and enhances the transport potential of mangoes. The findings of this study demonstrate that natural preservative treatments effectively retained mango fruit quality during storage. Between the two studied varieties, 'Langra' exhibited superior performance in terms of physicochemical properties and shelf life compared to 'Himsagar.' Among all natural preservative treatments, moringa leaf extract proved to be the most effective in maintaining fruit quality and prolonging shelf life. 'Langra' mangoes treated with moringa leaf extract showed the best overall performance compared to other treatment combinations. These results suggest that moringa leaf extract could serve as an excellent natural alternative to chemical preservatives for maintaining mango quality and extending its shelf life during storage.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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