



RESEARCH ARTICLE

Elucidating the efficacy of hot water treatment on managing anthracnose and stem-end rot diseases of mango cv. 'Ambika'

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Abstract

'Ambika' is a coloured mango variety with high export potential; however, it suffers substantial postharvest losses due to decay, primarily caused by anthracnose (*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc.) and stem-end rot (*Lasiodiplodia theobromae* (Pat.) Griff. & Maubl.). Being a late-maturing cultivar harvested during the rainy season, infections often originate in the field and progress during postharvest handling, thereby reducing fruit quality, shelf life and marketability. The present study evaluated the effectiveness of different hot-water treatment (HWT) combinations in controlling decay and maintaining quality in mango cv. 'Ambika'. Naturally infected fruits were subjected to hot water treatments at 48 °C for 60 min and 52 °C for 10 min, dips in 5 % salt solution, plain water and an untreated control. After treatment, fruits were air-dried, packed in corrugated fibre board boxes (CFB) with or without ethylene ripening sachets and stored at ambient conditions. The lowest incidence of anthracnose (1.8 %) and stem-end rot (18.2 %) after 9 days of storage was recorded in fruits treated at 52 °C for 10 min. This treatment also maintained higher fruit firmness (> 1.0 kg cm⁻²) and total soluble solids (TSS) (> 20 °Brix). In contrast, fruits treated at 48 °C for 60 min exhibited superior biochemical quality, including higher total phenols, flavonoids, carotenoids, antioxidant activity and improved skin colour development (higher a* and b* values). Overall, hot water treatment at either 48 °C for 60 min or 52 °C for 10 min is recommended as an effective postharvest practice to reduce anthracnose and stem-end rot diseases and enhance the quality of mango cv. 'Ambika' during storage.

Keywords: Ambika; fruit quality; postharvest treatments; storage diseases; subtropical conditions

Introduction

Mango (*Mangifera indica* L.), one of the most important fruit crops of India is grown in an area of 2.32 million ha with an annual production of 20.9 million tonnes; which accounts for 57.18 % of the total world production (1). Besides domestic consumption, mango plays a significant role in international trade. During 2022–23, India exported around 22963.76 metric tonnes (MT) of fresh mangoes valued at ₹378.49 crores. In addition, mango pulp is exported in substantial quantities (77817.51 MT), indicating strong global demand for processed mango products (2). The export potential of mango and its processed products is expected to increase further in the coming years due to expanding international markets and improved postharvest management practices. Among the mango growing states of India, Uttar Pradesh is the leading state accounting for 23 % of the total mango production of the country with an area of 2.79 lakh ha and production of 46.62 lakh tonnes (1). The state is blessed with unique varieties of mango, such as Dashehari, Langra, Chausa. Apart from these traditional varieties, in recent years, colourful varieties of mango like Ambika, Arunika, Pusa Arunima, Pusa Pratibha, Pusa Shreshtha, Pusa Lalima Arka Neelachal Kesari, etc. are becoming popular, particularly in niche domestic markets and export (3). Their appealing skin colour, higher antioxidant

content and consumer preference provide better price realisation compared to traditional green-skinned varieties. 'Ambika', a coloured mango variety developed by ICAR–Central Institute for Subtropical Horticulture, Lucknow, has emerged as a promising cultivar in northern India for both fresh consumption and processing purposes. The variety is appreciated for its attractive reddish-yellow skin, good pulp recovery and superior eating quality. However, being a late maturing cultivar, its harvesting coincides with the rainy season, which predisposes the fruits to severe postharvest losses. The major causes of such losses are fungal diseases, particularly anthracnose caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. (4) and stem-end rot caused by *Lasiodiplodia theobromae* (Pat.) Griff. & Maubl. (5, 6). These pathogens infect the fruit during the field stage and remain latent until ripening, when symptoms appear as black lesions on the fruit surface and around the stem end (7). Such infections significantly reduce fruit quality, marketability and storage life. In severe cases, postharvest losses may reach up to 60–70 % if adequate disinfection measures are not applied (5). Mango being climacteric fruit harvested at mature green stage and therefore latent infections remain undetected during harvesting and handling. As the fruit ripens during storage and marketing, these infections become visible and rapidly spread under favourable environmental conditions, especially high humidity (8). Effective

postharvest management practices are therefore essential to minimise disease incidence and extend shelf life. Among the various postharvest treatments proper washing and hot water treatment are efficient, environment friendly and low-cost method of disinfection of fruits (9). However, previous studies on hot water treatment (HWT) show that the effects depend upon several factors including maturity stage, cultivar, HWT temperature and duration etc. It was reported that fruit subjected to HWT at 45 °C/75 min produced better results as compared to HWT at 48 °C/60 min (9). Treatment with HW at 55 °C for 35 min reduced the incidence of anthracnose in mango cultivars 'Tu Shien' (10), 'Kent', Keitt' and 'Tommy Atkins' (11). Likewise, HW treatment at 51 °C for 3 min decreased the amount of anthracnose disease in mango cv. 'Amba Kurfa' (12). Exceptionally low disease incidence (3 %) was observed in 'Carabao' mango subjected to HWT plus 10 min hydro cooling followed by 30 min drying prior to packing (13). Additionally, HW treatment has been identified as an elicitor for the activation of the defensive response in harvested fruits (14). Although HWT helps prevent postharvest decay in mango fruits, there have been reports of detrimental impacts on the quality of the fruit, including accelerated fruit ripening, fruit skin browning and fruit softening (15). Therefore, it is essential to standardise appropriate HWT protocols tailored to specific cultivars. In this context, the present investigation was undertaken to evaluate the effect of different postharvest treatments, particularly HWT protocols, on disease incidence, fruit quality attributes and storage life of mango cv. 'Ambika'. The study aims to identify suitable treatment combinations that can effectively reduce postharvest decay while maintaining the physico-chemical and sensory quality of fruits during storage and marketing.

Materials and Methods

The experiment was conducted at ICAR-Central Institute for Subtropical Horticulture, Lucknow, India, located at 26°54'16.7" N 80°45'57.1" E; 26°91' N and 80°78' E; an altitude of 123 m above mean sea level. The study area experiences a subtropical climate with an annual rainfall of ~900 mm, average relative humidity of ~72.0 % and average maximum, minimum and means temperatures of 32.7 °C, 19.2 °C and 25.4 °C respectively. Mango fruits (cv. Ambika) of uniform size and physiological maturity were harvested from ICAR-CISH, Lucknow research farm with 4–5 cm stalks attached, early in the morning and promptly brought to the laboratory. The fruits then underwent desapping, stalks were carefully removed close to the fruit and each fruit was positioned stem-end down for complete sap drainage without compromising the fruit's surface integrity (peel). Treatments comprised of fruits exposure to hot water treatment at 48 °C for 60 min (T₁), 52 °C for 10 min (T₂), dipping in 5 % salt solution (T₃), dipping in tap water (T₄) and control (dry handled) (T₅). Fruit in the HWT group were treated using conventional HWT process (fruit dipped in hot water at prescribed temperature and time) followed by forced air-drying for complete removal of moisture. Following drying, fruits from each treatment were packed into corrugated fiberboard boxes (CFB). These boxes were divided into 2 sets: one with ripening sachets (150 ppm ethylene) to accelerate ripening and another without sachets for natural ripening. Both sets were stored under ambient conditions.

The experiment followed a completely randomized design (CRD), with 4 replications per treatment. Each treatment unit consisted of 15 fruits and 5 fruits per treatment were randomly selected for data collection. Observations were recorded at 1, 5 and 9

days after treatment. The severity of anthracnose and stem-end rot in mango was evaluated using disease severity indexes (DSI).

Decay loss (%) was calculated from numbers of fruits infected on each day of observation to the total numbers of fruits taken. Then per cent of decay loss was worked out by the formula.

$$\text{Fruit Decay Loss (\%)} = \frac{N_t - N_u}{N_t} \times 100 \quad \text{Eqn. 1}$$

Where:

N_t = Total number of fruits taken

N_u = Number of uninfected fruits

Fruit firmness was determined by using penetrometer (FR-5120). The fruits were punctured at two places opposite each other in radial axis with a tip of 6 mm and the pressure was measured by displaying it on screen which was expressed in kg/cm². Fruits colour was measured using colorimeter (Model: WR-18, Make: FRU China) at top, middle and bottom portion of the fruits and average colour was expressed as per CIE L*a*b* colour space model. In the CIE L*a*b* model, L* value of 0 represents complete dark and 100 represents complete white, negative a* values represent greenness and positive a* value represents redness whereas negative b* value represents blueness and positive b* value represents yellowness. The TSS was determined in laboratory using digital hand-held refractometer (Model: Brix 54, Bellingham + Stanley Ltd., UK), which was calibrated using distilled water before measurements.

Total phenolic contents (TPC) in the fruit's extracts were determined by Folin-Ciocalteu colorimetric method with some modifications (16). About 2 g samples were ground in 10 mL of 80 % methanol. From the extract, 0.1 mL was transferred into a test tube, followed by the addition of 2.9 mL distilled water and 0.5 mL Folin-Ciocalteu reagent. Subsequently, 2 mL of 20 % sodium carbonate was added and the mixture was incubated in dark for 1 hr. A blank was prepared by following the same procedure, substituting the plant extract with an equal volume of methanol. Absorbance was recorded at 750 nm in a UV-VIS spectrophotometer (Labomed Inc., USA). The standard curves were prepared by using different concentrations of Gallic acid and the result was expressed as mg GAE per 100 g of pulp weight.

Antioxidant activity was determined using the DPPH free radical scavenging assay with some modifications (17). The percentage of inhibition was calculated by using the formula:

$$I\% = \frac{AC - AO}{AC} \times 100 \quad \text{Eqn. 2}$$

Where AC = absorbance of the control (1 mL methanol + 1 mL DPPH solution), AO = absorbance of the sample solution and I% = percentage of inhibition.

Total flavonoid content was determined by aluminum chloride colorimetric assay (18). The total flavonoid content was expressed as quercetin equivalents using the linear equation based on the calibration curve. Similar procedure as described for quercetin was followed for the extracts also and the absorbance was measured by spectrophotometer at 510 nm. Readings were taken in triplicate and the average value of absorbance was used to calculate the total flavonoid content. The total flavonoids content was expressed as quercetin equivalents (mg QCE /100 g) using the linear equation based on the calibration curve. Five grams of mango pulp

was grinded in pestle and mortar using a solution of petroleum ether and acetone (3:2) along with acid washed sand to extract the carotenoid pigments and the OD values were read in spectrophotometer at 452 nm using petroleum ether acetone solution as blank. Total carotenoid content was then calculated with reference to the standard curve prepared with β -carotene and expressed as mg/100 g pulp.

Statistical analysis

The average value of 4 replications was used for statistical analysis. Differences between samples were tested by analysis of variance (ANOVA) to assess differences among group means. $p \leq 0.05$ were considered significant. Pearson's correlation analysis was conducted to determine the relationships among disease incidence, fruit quality attributes and biochemical parameters. Mean values of each parameter were used to compute correlation coefficients. A correlation matrix was generated and visualised using a heat map, where colour intensity represented the strength and direction of relationships.

Results

Table 1 shows that the incidence of anthracnose is more prevalent than stem end rot irrespective of post harvest treatments and ripening conditions. It was also quite clear that infestation of anthracnose is relatively higher under artificial ripening (ethylene mediated) as compared to natural ripening conditions while the stem end rot was not influenced by ripening conditions as severity was similar under both the ripening conditions. However different post harvest treatments considerably influenced the occurrence of anthracnose and stem end rot as compared to untreated control. The lowest incidence of anthracnose (1.8 %) and stem end rot (18.2 %) was noted in HWT at 52 °C for 10 min followed by HWT at 48 °C for 60 min at 9th day of storage. The present investigation therefore suggested that 52 °C for 10 min or 48 °C for 60 min is the optimal exposure for minimising both anthracnose and stem end rot diseases during storage. Fruit decay loss (%) was also followed by similar trends as it was observed maximum in untreated control with more than 50 % losses at the end of storage while it was lowest in HWT at 52 °C for 10 min closely followed by HWT at 48 °C for 60 min.

Fruit firmness is important postharvest quality parameters with respect to eating quality and shelf life of mango fruits which

gradually decrease over the period of ripening and storage. Firmness was affected significantly by using different postharvest treatments as compared to untreated fruits at the end of storage. Mango fruits were firmer in natural ripening conditions as compared to ethylene mediated ripening in respective post harvest treatments. Under both the ripening conditions firmness of mango fruits showed gradual and significant reduction during storage from 5th to 9th days. However, this decrease was comparatively low in fruits treated with hot water dipped at 52 °C for 10 min followed by HWT at 48 °C for 60 min under both the ripening conditions.

The total soluble solids (TSS) showed gradual and significant differences for post harvest treatment of mango fruits. It was observed that the TSS content was decreased from 5th to 9th days under both the conditions of ripening. At the initial stage of storage (5th days) the TSS content was recorded statistically similar in all the post harvest treatments except untreated control. However appreciable differences were observed as it was found highest in HWT at 52 °C for 10 min under ethylene mediated ripening conditions followed by HWT at 48 °C for 60 min under natural ripening conditions. This decrease in TSS content during later stages of storage may be attributed to the utilisation of soluble sugars during respiration and senescence under storage conditions. The overall quality of fruit as fruit firmness, TSS, TA, colour and weight loss was not affected adversely by post harvest heat treatments.

Fruits of mango cultivar Ambika are purple-green at maturity and turn bright yellow with dark red blush upon ripening. As colour of fruits continued to change in the succeeding days of storage, the peel colour as $L^*a^*b^*$ was monitored during storage (Table 2). It is clear from present study that red colouration is significantly enhanced by post harvest treatments as compared to control. Colour coordinate a^* which represents redness increased gradually during storage and it was recorded maximum in fruits dipped in salt water (5 %) followed by HWT at 48 °C for 60 min. Irrespective of storage period and postharvest treatments values of a^* (red blush) is relatively higher under ethylene mediated ripening than natural ripening (Table 3). Colour coordinate b^* which represents peel yellowness decreased significantly from 5th to 9th days of storage in all the treatments including control. However, among the different post harvest treatments it was relatively higher in HWT at 48 °C for 60 min under both ripening conditions. It was interesting to note that coordinate L^* value (represents dark or white /clarity) showed increasing trend over the storage period with highest values in the fruits dipped in hot water at 48 °C for 60 min.

Table 1. Effect of post harvest treatments on diseases occurrence and decay loss of mango cv. 'Ambika' during 9th days after storage

Treatments	Anthracnose (%)		SER (%)		Decay (%)	
	AR	NR	AR	NR	AR	NR
Control	42.13d	39.37d	22.12c	22.70b	42.6c	53.2d
Normal wash	33.15cd	30.55bc	20.21b	21.01b	30.5b	33.3c
Washing with salt water (5 %)	28.10c	25.75b	20.4b	20.8b	27.4b	21.3b
HWT at 48 °C for 60 min.	5.40b	2.5a	12.3a	12.6a	18.7a	10.0a
HWT at 52 °C for 10 min.	2.40a	1.8a	18.6b	18.2a	17.2a	10.1a

AR: artificial ripening (use of ripening sachet); NR: natural ripening; HWT: hot water treatment; SER: stem end rot.

Table 2. Physico-chemical parameters of mango fruits cv. 'Ambika' at the time of harvest

	Firmness (kg/cm ²)	TSS (°B)	L*	a*	b*	Total phenols (mg GAE/100 g)	Total antioxidants (μmol Trolox × 100 g)	Total flavonoids (mg QCE /100 g)	Total carotenoid (mg/100 g)
Fruits	5.61	10.5	75.16	25.63	42.18	45.23	0.58	11.23	2.36

TSS: total soluble solids; GAE: gallic acid equivalent; QCE: quality control evaluation.

Table 3. Effect of postharvest treatments on firmness, total soluble solids and pulp colour of mango cv. 'Ambika'

	Fruit firmness (kg/cm ²)		TSS (°Brix)		L*		a*		b*	
	5 th day	9 th day	5 th day	9 th day	5 th day	9 th day	5 th day	9 th day	5 th day	9 th day
Artificial ripening with ethylene sachets (AR)										
Control	0.73d	0.53d	18.0c	16.1d	49.0d	50.8d	16.2d	17.5d	30.0d	28.2c
Normal wash	0.77d	0.70c	20.2b	17.5c	52.2c	52.8d	18.8b	19.3d	32.4cd	29.8c
Washing with salt water (5 %)	1.10c	0.77c	21.2a	19.5a	62.6a	55.4c	26.4a	31.8a	34.0c	27.8
HWT at 48 °C for 60 min	1.23b	1.00b	19.5	19.4a	59.4ab	61.2a	22.0b	28.4ab	44.0a	42.2b
HWT at 52 °C for 10	1.37 a	1.19a	21.2a	19.8a	60.2a	62.6a	19.8bc	25.6c	41.8ab	46.0a
Natural ripening (NR)										
Control	1.07c	0.63c	18.6c	17.2c	49.4d	51.0d	12.8e	14.2e	34.0c	27.6d
Normal wash	1.10c	0.63c	19.2bc	17.7c	53.2c	51.4d	12.2e	14.8e	34.0c	27.8cd
Washing with salt water (5 %)	1.13c	0.93b	20.5b	18.5b	54.8b	56.2c	17.2b	29.8a	36.0b	31.4c
HWT at 48 °C for 60 min	1.31a	1.20a	21.9a	18.6b	57.4b	63.6a	22.6b	25.4c	37.8b	41.4b
HWT at 52 °C for 10	1.30a	1.18a	20.3b	18.4b	55.0b	60.4b	17.8b	23.8c	42.0a	39.8b

HWT: hot water treatment.

The bioactive compounds and total antioxidants of mango cv. Ambika subjected to different post harvest treatments are presented in Table 4. The results demonstrated that bioactive compounds like total phenols, total flavonoids and total antioxidants decreased over the storage period under both ripening conditions while total carotenoid content showed increasing trend during storage across different post harvest treatments. Total phenols and total flavonoids were non-significantly affected by different post harvest treatments excluding control fruits. At initial stage of storage, the total antioxidants were recorded highest in fruits washed with 5 % salt solution under both ripening conditions but at the end of storage it was recorded higher in fruits dipped in hot water at 48 °C for 60 min followed by hot water at 52 °C for 10 min under both ripening conditions. Further total carotenoid content was recorded higher in fruits treated with hot water at 52 °C for 10 min followed by hot water at 48 °C for 60 min. The stimulation of protective enzymes against oxidation due to optimum exposure

time and temperature might be reason for higher content of bioactive compound in the present study. The disease severity on 'Ambika' mango fruits subjected to different postharvest treatments was showed in Fig. 1.

Interrelationship between disease incidence and various fruit quality attributes

The correlation matrix heatmap presents the relationships among disease incidence, fruit quality attributes and biochemical constituents of mango during storage, which range from -1 to 1. The correlation heat map revealed distinct relationships. A strong positive correlation was observed between anthracnose incidence and decay loss ($r \approx 0.97$), indicating that higher disease severity directly contributed to increased fruit deterioration. Both parameters showed strong negative correlations with firmness ($r \approx -0.95$ to -0.97), demonstrating that disease progression significantly accelerated fruit softening. Fruit firmness exhibited

Table 4. Effect of postharvest treatments on bioactive compounds and total antioxidants of mango pulp cv. 'Ambika' during storage

	Total phenol (mg GAE/100 g)		Total antioxidants (μmol Trolox × 100 g)		Total flavonoids (mg QCE /100 g)		Total carotenoid (mg/100 g)	
	5 th days	9 th days	5 th days	9 th days	5 th days	9 th days	5 th days	9 th days
Artificial ripening with ethylene sachets (AR)								
Control	33.26c	30.19cd	0.26d	0.18d	08.06b	8.09b	1.56d	1.10d
Normal wash	43.44a	37.13a	0.43b	0.31c	09.08b	9.06b	1.63cd	1.84cd
Washing with salt water (5 %)	27.18d	37.55a	0.43b	0.39ab	09.08b	10.10b	1.85c	1.93c
HWT at 48 °C for 60 min	28.17d	30.86cd	0.50a	0.42a	10.09b	12.15a	1.82c	2.91b
HWT at 52 °C for 10 min	27.36d	32.26c	0.43b	0.38b	14.12a	12.10b	3.67a	3.87a
Natural ripening (NR)								
Control	34.39c	30.88cd	0.34c	0.22d	09.10ab	8.07b	1.46d	1.88c
Normal wash	36.75c	32.46c	0.35c	0.26c	10.09b	9.07b	1.46d	1.93c
Washing with salt water (5 %)	39.98b	33.76bc	0.44b	0.37b	13.12a	11.08b	1.74c	2.25b
HWT at 48 °C for 60 min	42.26a	0.38a	0.46a	0.37b	12.10ab	11.09b	2.29b	2.84b
HWT at 52 °C for 10 min	40.85ab	0.35b	0.42b	0.34bc	13.11a	10.07b	2.50b	3.41a

HWT: hot water treatment.



Fig. 1. Showing disease severity on 'Ambika' mango fruits subjected to different postharvest treatments.

strong positive correlations with carotenoids ($r \approx 0.99$) and antioxidants ($r \approx 0.75$), suggesting that treatments preserving fruit texture also enhanced biochemical quality. Similarly, TSS showed strong positive relationships with antioxidants ($r \approx 0.95$) and carotenoids ($r \approx 0.80$), indicating that ripening processes were associated with biochemical enrichment. Total phenols displayed moderate positive correlations with anthracnose incidence and decay loss, implying their possible role as stress-induced defence compounds. However, phenols showed negative relationships with firmness and carotenoids, suggesting an inverse association between stress metabolism and fruit quality attributes. Overall, the heat map clearly demonstrated that disease incidence was negatively associated with fruit quality parameters, while bioactive compounds were positively linked with ripening and fruit quality. These findings highlight the effectiveness of post-harvest treatments in reducing disease severity while maintaining fruit firmness and enhancing nutritional quality. The correlation heat map showing relationships among disease incidence, fruit quality attributes and

bioactive compounds of mango cv. 'Ambika' under different post-harvest treatments (Fig. 2). Positive correlations were indicated by warm colours (yellow to green), while negative correlations were represented by cool colours (blue to purple).

Discussion

The present study clearly demonstrated that all postharvest treatments significantly reduced disease incidence and decay loss compared to the untreated control, highlighting the effectiveness of intervention strategies in minimising postharvest losses. Among the treatments evaluated, hot water dipping at 52 °C for 10 min proved most effective in suppressing anthracnose and stem-end rot, followed closely by treatment at 48 °C for 60 min. These treatments resulted in the lowest disease incidence and decay losses on the 9th day of storage, confirming that optimised heat exposure effectively disinfects fruit surfaces and induce resistance against postharvest

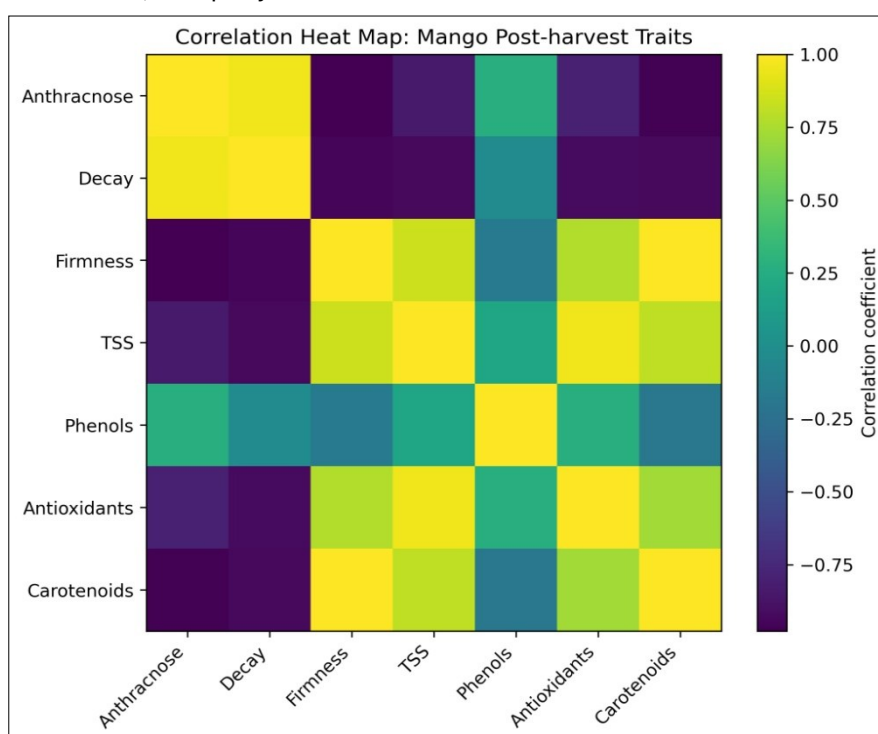


Fig. 2. Correlation heat map showing relationships among disease incidence, fruit quality attributes and bioactive compounds of mango cv. 'Ambika' under different post-harvest treatments. Positive correlations were indicated by warm colours (yellow to green), while negative correlations were represented by cool colours (blue to purple).

pathogens. Similar observations have been reported in several fruit crops where short-duration heat treatments reduced fungal infections by inhibiting pathogen growth and enhancing host defence responses. The reduction in disease severity in treated fruits may also be linked to delayed ethylene production and slowed ripening, thereby limiting the availability of substrates required for pathogen development. Similar results have been reported previously in tomato, mango, apples, mandarin and peach (19–22). Being a climacteric fruit, ethylene plays an important role in ripening of mango fruit. It is possible that heat treatment at given temperature coupled with exposure time may allow acceptable ripening of mango cv. Ambika fruit by reaching a threshold level of ethylene. The short duration and temperature treatment exposure to fruit is believed to disinfect and induce resistance of fruit to pathogens (23). Similarly, the reduction of anthracnose subjected to hot water at 55 °C for 3 min was also reported (24). Furthermore, higher ethylene production in control fruits can be attributed to early onset of diseases like anthracnose and stem end rot during storage, which was merely present in hot water treated fruits. Similar results in room temperature ripening of hot water treated mangoes after low temperature storage were also reported earlier (13). The fungus *Lasiodiplodia theobromae* is naturally residing on the stem end surface of mangoes and only appears as fruit ripen (25). Fruit allows the activity of fungus to obtain their energy sources from the fruit's sugar and other nutrients during storage. Whereas HWT eliminated ripening related ethylene rise and suppressed delayed ripening and sugar conversion during subsequent storage at ambient temperature. Fruit firmness, a key determinant of shelf life and consumer acceptability, declined progressively during storage in all treatments, with faster softening observed under ethylene-mediated ripening. However, hot water-treated fruits retained significantly higher firmness compared to untreated fruits under both ripening conditions. This firmness retention may be attributed to the inhibition of cell wall-degrading enzymes such as polygalacturonase, pectin methylesterase and β -glucanases, which are responsible for pectin solubilisation and tissue softening during ripening (26, 27). Heat treatments are known to stabilise pectic substances, thereby delaying textural breakdown and prolonging storage life (28). The TSS exhibited gradual changes during storage, with initially comparable values across treatments followed by notable differences at later stages. Higher TSS levels observed in hot water-treated fruits may reflect controlled carbohydrate metabolism and slower senescence compared to untreated fruits. The decrease in TSS during extended storage likely resulted from increased respiratory consumption of sugars. These findings align with previous reports as mango fruits cv. The increased Brix compared to untreated fruits and other post-harvest treatments at 45 °C for 30 min or 47 °C for 15 min (29). The increase in SSC could be attributed to the breakdown of carbohydrate into simple sugar and glucose (30). Hot water dipping at 50 °C for 30 min was found better with respect to increased TSS value after 9 days of storage (31). Peel colour development was also positively influenced by postharvest treatments. Enhanced redness (a^*) and maintained yellowness (b^*) in hot water-treated fruits indicate improved visual quality and uniform ripening. The gradual increase in lightness (L^*) suggests clearer and brighter peel appearance, particularly in fruits treated at 48 °C for 60 min. Ethylene exposure accelerated colour changes, which is consistent with its role in chlorophyll degradation and carotenoid synthesis during ripening. However, heat-treated fruits

exhibited more controlled and desirable colour progression compared to untreated fruits. Bioactive compounds, including phenolics, flavonoids and antioxidants, showed a general decline during storage, while carotenoid content increased as ripening progressed. Hot water treatments, especially at 48 °C for 60 min, helped preserve higher antioxidant activity and bioactive compounds at the end of storage, likely due to the activation of defence-related enzymes and reduced oxidative stress. The increase in carotenoids in treated fruits reflects enhanced pigment biosynthesis associated with ripening while maintaining nutritional quality. Similar protective effects of heat treatments on antioxidant systems have been reported in several fruit crops, supporting the role of thermal conditioning in enhancing postharvest fruit physiology (31, 32). Overall, the findings indicate that optimised HWT effectively control postharvest diseases while maintaining physicochemical and nutritional quality of 'Ambika' mango. Treatment at 52 °C for 10 min primarily minimised decay and extended shelf life, whereas treatment at 48 °C for 60 min better preserved biochemical quality and appearance.

Conclusion

Postharvest treatments, particularly hot water dipping, play a crucial role in improving mango fruit quality and reducing major postharvest diseases such as anthracnose (*Colletotrichum gloeosporioides*) and stem-end rot (*Lasiodiplodia theobromae*). The results of the present study demonstrate that HWT at 52 °C for 10 min effectively minimised disease incidence and extended shelf life, while treatment at 48 °C for 60 min enhanced biochemical and visual quality attributes of the fruits. Therefore, both treatment combinations can be recommended as practical and eco-friendly postharvest practices for controlling decay and improving the overall quality and marketability of mango fruits.

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Authors' contributions

AS¹ contributed to conceptualisation, experimentation and writing of the manuscript. DS was responsible for disease monitoring, data collection and manuscript editing. HSS handled the experiment and participated in data collection. KB contributed to data collection and draft preparation. AS² carried out quality analysis and tabulation of data. TD was involved in manuscript editing. All authors read and approved the final manuscript [AS¹ stands for Akath Singh and AS² stands for Abha Singh].

Compliance with ethical standards

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

Ethical issues: None

References

- Bini K, Krishnan AG, Jacob J, Supriya R, Thomas KS. Mango: The King of the Tropics. In: Uthup TK, Karumamkandathil R, editors. Economically Important Trees: Origin, Evolution, Genetic Diversity and Ecology. Sustainable Development and Biodiversity. Singapore: Springer; 2024;37. https://doi.org/10.1007/978-981-97-5940-8_8
- Galan Sauco V. World mango production and trade. Acta Hortic. 2025;1415:1–18. <https://doi.org/10.17660/ActaHortic.2025.1415.1>
- Kumar A, Kumar A, Prakash S, Kumar V, Singh A, Singh MK, et al. Evaluation on morphological and quality attributes of mango cultivars in western Uttar Pradesh. J Adv Bio Biotech. 2024;27:485–98. <https://doi.org/10.9734/jabb/2024/v27i91320>
- Arauz LF. Mango anthracnose: economic impact and current options for integrated management. Plant Dis. 2000;84:600–11. <https://doi.org/10.1094/PDIS.2000.84.6.600>
- Prusky D, Falik E, Kobiler I, Fuchs Y, Zauberman G, Pesis E, et al. Hot water brush and method for control of postharvest diseases caused by *Alternaria* rot in mango fruits. Acta Hortic. 1997;455:780–85. <https://doi.org/10.17660/ActaHortic.1997.455.99>
- Kobiler I, Shalom Y, Roth I, Akerman M, Vinokur Y, Fuchs Y, et al. Effect of 2,4-dichlorophenoxy acetic acid on the incidence of side and stem end rots in mango fruits. Postharvest Biol Technol. 2001;23:23–32. [https://doi.org/10.1016/S0925-5214\(01\)00092-8](https://doi.org/10.1016/S0925-5214(01)00092-8)
- Johnson GI, Hofman PJ. Postharvest technology and quarantine treatments. In: Litz RE, editor. The Mango: Botany, Production and Uses. Wallingford: CAB Int.; 2009:528–605. <https://doi.org/10.1079/9781845934897.0529>
- Haggag WM. Mango diseases in Egypt. Agric Biol J North Am. 2010;1:285–89. <https://doi.org/10.5251/abjna.2010.1.3.285.289>
- Anwar R, Malik AU. Hot water treatment affects ripening quality and storage life of mango (*Mangifera indica* L.). Pak J Agric Sci. 2007;44:27–34.
- Shiesh C, Lin H. Effect of vapor heat and hot water treatments on disease incidence and quality of Taiwan native strain mango fruits. Int J Agric Biol. 2010;12:673–78.
- Mansour F, Abd-El-Aziz S, Helal G. Effect of fruit heat treatment in three mango varieties on incidence of postharvest fungal disease. J Plant Pathol. 2006;88:141–48.
- Dessalegn Y, Ayalew Y, Woldetsadik K. Integrating plant defense inducing chemical, inorganic salt and hot water treatments for the management of postharvest mango anthracnose. Postharvest Biol Technol. 2013;85:83–88. <https://doi.org/10.1016/j.postharvbio.2013.05.003>
- Esguerra EB, Chavez SM, Traya RV. A modified and rapid heat treatment for the control of postharvest diseases of mango (*Mangifera indica* Linn. cv. Carabao) fruits. Philipp Agric Sci. 2006;89:125–33.
- Huan C, Han S, Jiang L, An X, Yu M, Xu Y, et al. Postharvest hot air and hot water treatments affect the antioxidant system in peach fruit during refrigerated storage. Postharvest Biol Technol. 2017;126:1–14. <https://doi.org/10.1016/j.postharvbio.2016.11.018>
- Kim Y, Brecht JK, Talcott ST. Antioxidant phytochemical and fruit quality changes in mango (*Mangifera indica* L.) following hot water immersion and controlled atmosphere storage. Food Chem. 2007;105:1327–34. <https://doi.org/10.1016/j.foodchem.2007.03.050>
- Singleton VL, Orthofer R, Lamuela-Raventos RM. Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In: Methods Enzymol. Academic Press; 1999;299:152–78. [https://doi.org/10.1016/S0076-6879\(99\)99017-1](https://doi.org/10.1016/S0076-6879(99)99017-1)
- Nithianantham K, Shyamala M, Chen Y, Latha LY, Jothy SL, Sasidharan S. Hepatoprotective potential of *Clitoria ternatea* leaf extract against paracetamol induced damage in mice. Molecules. 2011;16:10134–45. <https://doi.org/10.3390/molecules161210134>
- Lenucci MS, Cadinu D, Taurino M, Piro G, Dalessandro G. Antioxidant composition in cherry and high-pigment tomato cultivars. J Agric Food Chem. 2006;54:2606–13. <https://doi.org/10.1021/jf052920c>
- Budde CO, Polenta G, Lucangeli CD, Murray RE. Air and heat treatments affect ethylene production and organoleptic quality of ‘Dixiland’ peaches. Postharvest Biol Technol. 2006;41:32–37. <https://doi.org/10.1016/j.postharvbio.2006.02.009>
- Fallik E, Tuvia-Alkalai S, Feng X, Lurie S. Ripening characterization and decay development of stored apples after a short pre-storage hot water rinsing and brushing. Innov Food Sci Emerg Technol. 2001;2:127–32. [https://doi.org/10.1016/S1466-8564\(01\)00032-7](https://doi.org/10.1016/S1466-8564(01)00032-7)
- Ghasemnezhad M, Marsh K, Shilton R, Babalar M, Woolf A. Effect of hot water treatments on chilling injury and heat damage in ‘Satsuma’ mandarins: antioxidant enzymes and vacuolar ATPase and pyrophosphatase. Postharvest Biol Technol. 2008;48:364–71. <https://doi.org/10.1016/j.postharvbio.2007.09.014>
- Ketsa S, Chidtragool S, Lurie S. Pre-storage heat treatment and post-storage quality of mango fruit. HortScience. 2000;35:247–49. <https://doi.org/10.21273/HORTSCI.35.2.247>
- Pavoncello D, Lurie S, Droby S, Porat R. A hot water treatment induces resistance to *Penicillium digitatum* and promotes the accumulation of heat shock and pathogenesis-related proteins in grapefruit flavedo. Physiol Plant. 2001;111:17–22. <https://doi.org/10.1034/j.1399-3054.2001.1110103.x>
- Le TN, Shiesh CC, Lin HL. Effect of vapor heat and hot water treatments on disease incidence and quality of Taiwan native strain mango fruits. Int J Agric Biol. 2010;12:673–78. <https://doi.org/10.37855/jah.2010.v12i02.23>
- Nelson SC. Mango anthracnose (*Colletotrichum gloeosporioides*). Plant Dis. 2008;PD-48.
- Lazan H, Ali Z, Lee K, Voon J, Chaplin G. The potential role of polygalacturonase in pectin degradation and softening of mango fruit. ASEAN Food J. 1986;2:93–98.
- Ali ZM, Armugam H, Lazan H. Galactosidase and its significance in ripening mango fruit. Phytochemistry. 1995;38:1109–14. [https://doi.org/10.1016/0031-9422\(94\)00804-3](https://doi.org/10.1016/0031-9422(94)00804-3)
- Brecht JK, Yahia EM. Postharvest physiology. In: Litz RE, editor. The Mango: Botany, Production and Uses. Wallingford: CABI Publishing; 2009:484–528. <https://doi.org/10.1079/9781845934897.0484>
- Jacobi KK, Macrae EA, Hetherington SE. Effect of hot air conditioning of ‘Kensington’ mango fruit on the response to hot water treatment. Postharvest Biol Technol. 2000;21:39–49. [https://doi.org/10.1016/S0925-5214\(00\)00163-0](https://doi.org/10.1016/S0925-5214(00)00163-0)
- Chien PJ, Sheu F, Yang FH. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. J Food Eng. 2007;78:225–29. <https://doi.org/10.1016/j.jfoodeng.2005.09.022>
- Djioua T, Charles F, Lopez-Lauri A, Filgueiras H, Coudret A, Ducamp-Collin MN, et al. Improving the storage of minimally processed mangoes (*Mangifera indica* L.) by hot water treatments. Postharvest Biol Technol. 2009;52:221–26. <https://doi.org/10.1016/j.postharvbio.2008.10.006>
- Mirdehghan SH, Rahemi M, Serrano M, Guillen F, Martinez-Romero D, Valero D. Pre-storage heat treatment to maintain nutritive and functional properties during postharvest cold storage of pomegranate. J Agric Food Chem. 2006;54:8495–500. <https://doi.org/10.1021/jf0615146>

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