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Chemical-free postharvest heat treatments for mango fruit cv. Alphonso for boosting quality assurance, and quarantine clearance

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Abstract
Alphonso, the most delicious variety of mango (*Mangifera indica* L.) is known for its excellent texture, taste, and richness with vitamins and minerals. Export of mango from India to different countries is highly dynamic due to phytosanitary and quarantine requirements, and postharvest quality deterioration during storage. During last few years export of Alphonso mango from India has been challenged by strict phytosanitary and quarantine requirements followed by different countries. In order to meet the acceptable standards of different countries and to maintain the quality of Alphonso mangoes for export purposes, the study was focused on use of chemical-free post-harvest treatments. Alphonso mango fruit were subjected to hot water treatment (HWT) at 40 °C/80 min, 50 °C/40 min, and 60 °C/20 min and hot vapor treatment (HVT) at 50 °C/40 min and stored for 25 days (d) under ambient and cold storage conditions. The quality of mango samples was assessed in terms of changes in physical, physiological, biochemical, and visual characteristics. The mangoes subjected to HWT 50 °C/40 min and HVT 50 °C/40 min showed 40.9% less weight loss and a high TSS content of 20.8% at 25 d of storage compared to untreated samples. HWT 40 °C/80 min showed highest carotenoid content of 13.11 mg/10 g and saffron-like yellow color with higher L^* and b^* values. During 25 d of storage slow respiration rate and high retention of firmness in HWT 50 °C/40 min and HVT 50 °C/40 min treatments was observed as compared to untreated and HWT 60 °C/20 min. It was concluded that HWT 50 °C/40 min and HVT 50 °C/40 min can be used as chemical-free postharvest quarantine treatment for export quality retention of Indian Alphonso mango.

Keywords: Chemical free**,** firmness; phytosanitary, physiological, respiration rate, hue value

1. Introduction
Mango (*Mangifera indica* L.) is a popular tropical fruit grown majorly in India, China, Brazil, and Thailand with India as the world's largest producer. India contributed 50% of the total mango production with annual production of 21.01 million MT from an area of about 2.29 million ha. India exported over 49658 MT of mangoes in 2019–20, earning roughly 48.38 million USD from the international market. In 2022–2023, this reduced to 22963 MT, earning 45.72 million USD (Ministry of Commerce, GoI, www.agriexchange.apeda.gov.in). Indian mango has huge demand in the domestic as well as in the international market due to its great taste, pleasant aroma, outstanding flavor, low calories, and high nutritional content [1]. Among different varieties of mango Alphonso is highly sought variety, known for its sweet and creamy taste, bright orange flesh, and vibrant fragrance. Because of this reason it is also called as 'king of mangoes' [2]. The global market for Alphonso mangoes is estimated to be worth several hundred million dollars annually. But Alphonso mango fruit is highly infected by fruit flies, stone weevil invasion, spongy tissue, and anthracnose problems during the formation and maturation on a tree [2-3].
Quality control plays important role in mango export. Several factors such as time and season of harvest, location, high temperature, and biological factors are known to influence the external and internal quality of mango fruit [2]. These constraints contribute to rapid deterioration in postharvest quality of mango fruit. For these reasons, Indian mangoes were prohibited by the United States (US) and the European Union (EU) from previous few years resulting in huge economic losses to country and to mango growers in India every year.

Additionally, the cost of importing Alphonso mangoes can be high due to the perishable nature of the fruit and the logistics involved in transporting them to different parts of the world. For export purpose generally marine freightage is commonly used because of higher volume transported at relatively lower costs. However, this economical export of mangoes is always associated with high risk of quality deterioration especially when such transport is carried without any pre-treatment.

To control postharvest losses and maintain quality various treatments like use of different chemicals (firming agents and antioxidants), fungicides, edible coatings, biological agents, irradiation, different storage temperatures treatments were commonly used [4]. Although, these treatments have been reported effective for quality control of mango, however, the health risks associated with such chemical and radiation-based pre-treatments have put much focus on alternate pre-treatments which are free of chemicals and do not interfere with the quality of fruit. The demand of such chemical-free or minimally processed fruit for consumption is increasing in Indian market as well as internationally [5].

From past few years different heat treatments such as Hot Water treatment (HWT) and Hot Vapor Treatment (HVT) have attracted attention because of their chemical free nature and effectiveness [3]. These treatments have greater potential for control of fruit fly infestation, improving postharvest shelf life and are more suitable for export purposes because of strict regulations in most of the countries on use of chemicals [6]. HWT and HVT significantly destroy insects, pests, fungal rots, and increase resistance to chilling injury in mango fruit [7]. These treatments are mostly used for quarantine purposes essentially demanded by importing countries [8]. Heat treatments showed positive effects on mango fruit in terms of disease and decay control, delaying ripening and overall fruit quality during storage [9]. The effectiveness of heat treatment depends on time and temperature combination, cultivar, size and shape, maturity stage of fruit. To meet phytosanitary import requirements of different countries for Alphonso mango from India, heat treatments seem to be viable quarantine and postharvest treatment for Alphonso mango. It is hypothesised that with these treatments it is possible to maintain export quality and sustain international market demand of Alphonso mango. However, it needs to be ensured that other quality aspects of Alphonso mango such as physical, physiological, biochemical, and visual characteristics are not affected. So, for providing sustainable and assured treatment this study was very essential carried for boosting Alphonso export. In view of this, Alphonso mangoes were subjected to hot water treatment (HWT) hot vapor treatment (HVT) for different durations and at different temperatures under ambient and cold storage conditions and monitored for different physical, physiological, biochemical, and visual quality attributes.

2. Material and Methods

2.1 Fruit material

A Sample of 300 units of Alphonso mango fruit at 75 to 80% maturity (based on color and specific gravity) were collected from commercial orchards in Ratnagiri (16° 59′ 39″ N, 73° 37′ 09″ E) and Sindhudurg 16° 10′ 53″ N, 73° 44′ 86″ E) districts of Maharashtra state, India. After harvesting mangoes were immediately kept for pre-cooling. Sorting and grading of mango was done based on weight and color. In order to maintain uniformity mangoes with weight between 225 to 250 g and dark green in color were only selected for further study. The selected mangoes were washed with chlorinated water (3 mg/L) and stored at 15 °C till further treatment.

2.2 Postharvest treatments and storage conditions

The hot water treatments (HWT) at different temperatures and for different durations were given to mangoes in laboratory scale hot water bath (Make-Accumax India, Model- AI-126). HWT with temperature and time combinations such as 40 °C for 80 minutes, 50 °C for 40 minutes, and 60 °C for 20 minutes were given to fruit batchwise. For each batch, a sample of 60 mangoes was kept in water bath and filled with clean potable water till whole fruit got dipped. Hot vapor treatment (HVT) was performed at 50 °C for 40 min on 60 mangoes in controlled vapor vessel with pressure cooker for supplying steam. For comparison purpose, another sample of 60 mangoes was left untreated to serve as a control.

The heat treated and control samples were packed in separate corrugated boxes (capacity: 12 piece) which is most common packaging material used in domestic market as well as for export purpose. The experiment was conducted during peak harvesting season i.e in the month of May during which average temperature was recorded 35 °C to 40 °C and RH of 50 to 74.1 percent. The packed mango samples were stored under ambient condition and cold storage conditions. In ambient storage, the mango samples were kept in a ventilated room without any modification in temperature and RH. In the case of cold storage conditions temperature of 16±2°C was set and RH of 90±5% was maintained by using salt solutions during the 25 d of storage duration.

2.3 Quality analysis

The quality of fruits during 25 days storage was assessed in terms of weight loss (PLW), total soluble solids (TSS), firmness, peel and pulp colour, carotenoid content, and respiration rate, postharvest physico-chemical changes. While the samples were being stored, every analysis was done in triplicate at 5 d intervals.

2.3.1 Fruit weight loss

Weight of samples was taken with three replicates during storage using a digital weighing balance (Make-Mettler Toledo, Model- ML503, Switzerland, least count- 1 mg). Cumulative weight loss of fruit was determined in 5 d interval throughout the storage duration as difference between initial and final weights of fruit measured with weighing balance of 0.01 g accuracy and compared with initial weight in percentage [10].

2.3.2 Total soluble solids (TSS)

The TSS of mango samples stored under ambient and cold storage conditions was determined by digital hand-held refractometer (Make: ATAGO, Japan, Model: PAL Brix/RI range: 0 to 93% resolution 0.2%). The refractometer was standardized against distilled water (0% TSS). A sample of 10 g mango fruit pulp was crushed using a pestle and mortar and the juice was obtained by filtering the crushed pulp through a muslin cloth. For obtaining TSS, 1 to 2 drops of clear juice were placed on the prism of the refractometer [11].

2.3.3 Peel color

Color of mango peel were expressed in CIELAB parameters L*, a*, and b* values and hue angle (HUE°), (L*) defines lightness, (a*) denotes the red/green value, and (b*) the yellow/blue value using colorimeter (Make-Konica Minolta, Inc. Osaka Japan; model CR-20). Before measuring, the colorimeter was standardized with white and black references. For color determination of each sample, the reflectance spectrum was measured at 3 different points for three replications on the fruit surface and then the mean reflectance spectrum was obtained [5]. Hue angle (HUE°), was computed by using a^* and b^* values as suggested by Perini *et al*. [10] obtained from the colorimeter as following

$HUE° = \tan^{-1}(b^*/a^*)$ when $a > 0$ and $b > 0$,
and $HUE° = 180° + \tan^{-1}(b^*/a^*)$ when $a < 0$ and $b > 0$ (1)

2.3.4 Carotenoid content

The carotenoid content of mango sample was determined by the method described by Ranganna, [12]. For estimation of the carotenoid content of mango pulp 10 g fruit tissue sample was crushed with 5 ml acetone in a motor and pestle and the procedure was repeated till residue became colorless. The extract was transferred to separating funnel followed by addition of 10 ml petroleum ether and 5 ml of 5% sodium sulphate. The mixture was shaken and allowed to stand undisturbed for 5 minutes for phase separation. The top layer was separated and collected into the amber color bottle and making up the volume with 25 ml of petroleum ether. The absorbance value in terms of Optical Density (OD) was taken with the double beam UV-Vis spectrophotometer (Make-Accumax, India, Model- 2201, Wavelength- 195 to 1100 nm) at 452 nm against petroleum ether as a blank. The O.D. values were noted and quantity of total carotenoid measured with standard curve and expressed in mg/10 g of fruit tissue.

$$\text{Total carotenoid content (mg/10 g)} = (3.87 \times Final\ Volume \times Optical\ density \times 100)/(Weight\ of\ sample \times 1000) \quad (2)$$

2.3.5 Firmness evaluation

The firmness of mango fruit was measured by using a texture analyser (TA- XT plus connect texture analyser of Stable Micro Systems, Ltd., Surrey, UK) in compression mode with a 2- mm diameter cylindrical probe (SMS-P/2, Stable Micro Systems, Ltd., Surrey, UK). The operating parameters were pre-test speed (2 mm/sec), test speed (0.5 mm/sec), post-test speed (10 mm/sec), trigger force (5.0 g), and distance (15 mm). During the compression test data acquisition rate was set at 200 points/sec as described by Jha *et al*. [1].

During firmness measurement peel firmness and pulp firmness were measured separately. During peel firmness measurement, mango samples with pulp intact were subjected to compression test. In the case of pulp firmness measurement, mango fruit samples were peeled manually without disturbing the pulp texture and then used for compression test. Firmness was measured as the maximum force recorded in a force–time curve obtained during the compression test of mangoes. The firmness of mango was measured in triplicates at three different locations and average values were recorded for the comparison.

2.3.6 Respiration rate

The respiration rate of mango samples was measured by using O_2 and CO_2 analyser (Model: Systech illionis). Samples were kept in a trap box of known volume (300 ml) for one hour for metabolic activities. Then O_2 and CO_2 analyser equipment started 30 min before the actual analysis. Then samples after one hour were analysed for respiration rate measurement with a pre-calibrated O_2 and CO_2 analyser started 30 min before the actual analysis. The concentration of CO_2 was noted down for further calculation [13]. Respiration rate was expressed as (nmol kg^{-1} s^{-1})

$$\text{Respiration rate} = (CO2\ concentration \times Head\ space\ Volume \times 6.31)/(100 \times Weight\ of\ fruit \times Time\ of\ holding) \quad (3)$$

2.4 Statistical analysis

The data obtained during the experiment was analysed using Factorial Completely Randomized Design (FCRD) in the pattern for optimizing heat treatment, and storage conditions. For treatment effects data was subjected to ANOVA and means were compared using Tukey HSD test at significant level of 5 percent. All the statistical analysis was performed using SPSS software (Version: SPSS Statistics 20. Ink, IBM Corp., USA). Further, the data was subjected to multivariate analysis to find out correlation between parameters using Pearson correlation and principal component analysis (PCA) using Stata software (version-Stata/MP17.0, Statacorp, College station, TX, USA).

3. Results

3.1 Influence of heat treatments and storage conditions on weight loss of fruit

Weight loss of fruit is one important determinant of shelf life and quality. Fig. 1 shows progressive increase in weight loss of fruit were observed in both storage conditions. Under ambient storage condition, the weight loss in mango after 5 d of storage ranged from 2.45 to 4.1 percent. But after 10 d of storage there was drastic increase in weight loss in non-treated (control) samples. The increase in weight loss for such samples under ambient conditions continued up to 25 d of storage from 8.5% at 10 d to 16% at 25 d, respectively. The minimum weight loss was observed in ambient storage conditions in HWT 50 °C/40min and HVT 50 °C/40 min as 10.11 and 9.45% respectively at 25 d of storage compared to HWT 40 °C/80 min and 60 °C/20 min (12.15% and 14.4%). Thus, compared to untreated samples, the weight loss in HWT and HVT treated samples was lesser by about 41 percent (Fig. 1A). In contrast to ambient storage condition results, weight loss for samples under cold storage conditions were found minimum for untreated (8.5%) compared to heat treated samples. Overall, mango samples with HWT of 40 °C/80 min, 50 °C/40min, and 60 °C/20 min and HVT 50 °C/40 min showed 9.7, 9.15, 14.43 and 11.90% respectively weight loss was observed at the end of storage (Fig. 1B). The rate of weight loss for mango samples was slow in cold storage conditions as compared to ambient. In both storage conditions drastic change in weight loss were observed in all treatments after 10 d of storage. Overall, HWT 50 °C/40 min and HVT 50 °C/40 min resulted in significantly less weight loss compared to other treatments.

Also, higher weight loss was observed for untreated samples under ambient storage condition and for HWT 60 °C/20 min treated samples under cold storage condition.

3.2 Influence of heat treatments and storage conditions on TSS

Total soluble solids (TSS) is an important indicator of ripening of fruit. The TSS content of mango after harvesting was in the range of 8.5 to 9% (Fig. 2). During storage rapid increase in TSS content of control samples was observed from 9.3% at 0 d to 22.1% at 20 d and thereafter decreased to 18% at 25 d after storage. Similar trend was followed by samples subjected to HWT 40 °C/80 min i.e., increase in TSS rapidly up to 20 d and then decreased TSS at 25 d of storage under ambient storage condition. Whereas, samples with HWT 50 °C/40 min, 60 °C/20min and HVT 50 °C/40 min showed consistent and slow increase in TSS as shown in Fig. 2A. For samples under cold storage condition, all treatments showed increased trend in TSS content up to end of storage except control samples. TSS content up to 5 d of storage was in range of 10.2 to 11.2% for all treatments but after that irregular trend was recorded. HWT 50°C/40 min and HVT 50°C/40 min showed TSS content of 11.3 to 17.9% and 12.6 to 15.4%, respectively with slowly increasing trend from 10 to 20 d but after that rapid rise in TSS was observed at 25 d (20.8 and 17.5%). At the end of storage, HVT 50 °C/40 shows lowest TSS as compared to other treatments (Fig. 2B). From data it was observed that in control samples, TSS content increased rapidly (i.e., fast ripening) up to 20 d storage but after that decreasing trend was observed. Thus, it was evident that untreated mango samples deteriorated early whereas HWT 50 °C/40 min and HVT 50 °C/40 min showed better quality retention of mangoes up to 25th d of storage.

3.3 Influence of heat treatments and storage conditions on peel color

At beginning L^* value for control samples was 38.9 which was lowest among all treatments. In case of heat-treated samples significant change in L^* values were observed ranging from 45.76 to 51.76 in both ambient and cold storage (Fig. 3). For mango samples under ambient storage HWT 50 °C/40 min, 60 °C/20 min and HVT 50 °C/40 min resulted in higher L^* value with change from 49.33 to 63.76, 51.76 to 68.55 and 50.26 to 62.46, respectively up to end of storage period. Whereas, control and HWT 40 °C/80 min treated samples showed minimum increment in L^* values (Fig. 3A). Similar trend was observed in cold storage where difference in control and heat-treated samples was less as compared to ambient storage. The highest increments were observed in HWT 50 °C/40 min, and 60 °C/20 min and HVT 50 °C/40 min as compared to control (Fig. 3B).

The b^* value of fruit is indicative of yellowness of mango peel. After giving heat treatments, b^* value ranged from 25.96 to 30.53 at the beginning of storage in both storage conditions (Fig. 4). Up to a storage period of initial 5 d no significant changes were observed in all the treatments. At 10 d of storage drastic change in b^* value was observed in HWT 50 °C/40min, and 60 °C/20 min being 38.90 and 38.30, respectively. The observations at 25 d of storage revealed continued and significant increase of b* value for all three treatments i.e. HWT 50 °C/40 min, and 60 °C/20 min and HVT 50 °C/40 min (50.12, 54.77 and 56.77) (Fig. 4A). The highest b^* value was attained with HVT 50 °C/40 min in ambient storage. For samples under cold storage condition HWT 60 °C/20 min resulted in highest b value from beginning to 25th d (30.53 to 56.43) whereas HWT 40 °C/80 min showed lowest values (28.73 to 44.31) (Fig. 4B). Heat treatments of HWT 50 °C/40 min, and 60 °C/20 min resulted in higher b values than control and HWT 40 °C/80 min under both storage conditions. Thus, it is evident that lightness of peel was significantly increased by heat treatments.

Hue angle of mango peel varied from 103.33 to 107.81 at initial stage in all treatments and decreasing trend was observed during 25 d of storage in both storage conditions (Fig. 5). In comparison to heat treated samples, control samples showed significantly less hue value ranging from 107.65 to 67.91 and 107.65 to 72. 95 under ambient and cold storage conditions, respectively. Whereas, HWT 50 °C/40 min, and 60 °C/20 min, and HVT 50 °C/40min shows lower reduction in hue values (76.41, 79.08, 78.27 in ambient and 79.45, 81.07 and 81.18 in cold storage) during complete storage period (Fig. 5A and 5B). Overall, cold storage samples showed higher hue value than ambient storage in all treatments.

3.4 Influence of heat treatments and storage conditions on carotenoid content

The mango samples were harvested at 70 to 75% maturity and the carotenoid content in all samples was about 0.045 mg/10 g. During storage as the ripening process progressed, an increasing trend in carotenoid content was observed (Fig. 6). Under ambient storage the untreated samples, HWT 40 °C/80 min and 60 °C/20 min showed significantly increasing carotenoid content up to 11.32, 12.11 and 11.43 mg/10 g, respectively at 20 d storage. However, the value decreased thereafter and was 8.36, 11.45 and 10.67 mg/10 g, respectively at 25 d of storage indicating degradation of carotenoid content in these treatments (Fig. 6A). In contrast, samples with HWT 50 °C/40 min and HVT 50 °C/40 min showed consistent increasing trend and highest carotenoid content 12.74 and 12.87 mg/10 g, respectively up to end of storage without deterioration in carotenoid content. In case of cold storage condition all treatments showed increased trend in carotenoid content without degradation. Treatments such as HWT 50 °C/40 min, and 60 °C/20 min, and HVT 50 °C/40 min showed higher carotenoid content value of 13.11, 12.41 and 11.23 mg/10 g, respectively as compared to untreated and HWT 40 °C/80 min (Fig. 6B). Irrespective of storage conditions carotenoid content at 15 d and 25 d of storage were increased 1.44 and 2.80 times respectively as compared to carotenoid at 10 d storage.

3.5 Influence of heat treatments and storage conditions on respiration rate

The respiration rate was initially in the range of 186.40 to 239.09 nmol kg^{-1} s^{-1} and 158.51 to 220.3 nmol kg^{-1} s^{-1} for mango samples stored under ambient and cold storage conditions, respectively. Due to the heat treatment, significant changes in respiration rate of samples were observed during storage (Fig 7). For ambient storage conditions, mango samples subjected to HWT 50 °C/40 min, and HVT 50 °C/40 min showed less respiration rate as compared to other treatments and thus indicated increased the shelf life of fruit. Whereas, samples with HWT 60 °C/20

min showed highest respiration rate of 741.05 nmol kg^{-1} s^{-1} at 15 d and thereafter decreased trend with a value of 574.97 nmol kg^{-1} s^{-1} at 25 d coinciding with the senescence of fruit (Fig. 7A). In cold storage samples, drastic change in respiration rate was experienced after 15 d in all treatments except HWT 50 °C/40 min, and HVT 50 °C/40 min. Higher values of respiration rate was recorded in HWT 60 °C/20 min followed by control and HWT 40 °C/80 min treated fruit. Overall, cold storage samples showed significantly low respiration rate as compared to ambient ones (Fig. 7B).

3.6 Influence of heat treatments and storage conditions on firmness of peel and pulp

At initial stage firmness of control samples was higher than heat treated fruit being 34.12 and 28.94 N, respectively (Fig. 8). During storage, loss of peel firmness was observed in both ambient and cold storage samples. In case of ambient storage HWT 50 °C/40 min retained higher peel firmness (9.92 N) compared to control samples (7.56 N) and HWT 40 °C/80 min (5.44 N) samples at 25 d of storage (Fig. 8A). Under cold storage similar trend was observed as HWT 50 °C/40 min retained highest firmness (14.64 N) followed by HVT 50 °C/40 min (13.46 N) followed by HWT 60 °C/20 min (11.36 N) at 25 d of storage. As compared to ambient storage, cold storage samples retained more firmness in all treatments during the all-storage durations (Fig. 8B).

Pulp of mango also showed similar trend of decreasing firmness during whole storage. At beginning pulp firmness recorded was 6.78 N for control samples and 5.41 to 5.89 N for heat treated samples. Under ambient storage control samples and HWT 40 °C/80 min treated samples retained higher firmness throughout the storage as compared to other heat-treated samples (Fig. 9A). During storage of 25 d, there was loss of 78 and 85% in firmness for control and HWT 60 °C/20 min samples, respectively. Under ambient storage lowest value of firmness was observed in HWT 60 C/20 min (0.45 N). In case of cold storage condition HWT 50 °C/40 min, and HVT 50 °C/40 min samples retained higher firmness being 2.54 and 2.34 N, respectively. While as lowest firmness (1.12 N) was retained in samples treated with HWT 60 °C/20 min at the end of storage. During storage HWT 60 °C/20 min treated samples showed rapid and significant loss in firmness values (Fig. 9B). Like other parameters pulp firmness data revealed that samples of all treatments stored in cold storage showed higher firmness value than ambient storage.

3.7 Multivariate analysis

3.7.1 Correlation matrix studies

The relation between mango fruit parameters was expressed by Pearson correlation as shown Fig. 10. The highest positive correlation (r=0.92) was found between peel and pulp firmness indicating direct and close relationship between them. Whereas, highest negative correlation (r= -0.91) was found between hue value and TSS content of fruit indicating inverse relationship between them. Respiration rate had highest positive correlation with PLW (r= 0.91) followed by TSS (r= 0.89), and b^* value (r= 0.79). Carotenoid content showed highest positive correlation with TSS (r= 0.91) followed by b^* value (r=0.87). PLW showed direct correlation with TSS, L value and b^* value (r >0.72) and inverse correlation with hue value and pulp and peel firmness (r >0.84). The multivariate analysis revealed that PLW, TSS, L and b value, carotenoid content and respiration rate had inverse relation with peel and pulp firmness and hue values.

3.7.2 Principal component analysis

The principal component analysis (PCA) was carried to determine changes in physicochemical parameters of cv. Alphonso mango caused by heat treatments during storage. The overall variability in parameters was explained by nine components with major variability explained by first two principal components as shown in Fig 11. A cumulative variance of first two components scored about 92.08% with component 1 (86.31%) and component 2 (5.76%), respectively. The total variation and eigen values of respective components is shown in Table 1. From results, it was concluded that first component has significant contribution in cv. Alphonso during storage. PC1 scored highest because of higher positive weights contribution by PLW (2.630), TSS (2.618), L^* value (2.386), b^* value (2.520), carotenoid (2.672), respiration rate (2.609) and negative weight contribution by hue value (-2.595), peel firmness (-2.677), and pulp firmness (-2.582), respectively. The high positive scores of parameters PLW, TSS, L^* value, b^* value, carotenoid, and respiration rate show significant and positive effect of heat treatments during storage. Moreover, the effect was inverse for hue value and peel and pulp firmness.

4. Discussion

Practises used prior to, during, and after harvest can have an impact on the quality of the fruit after harvest. Among these, the quality of fruit is greatly influenced by post-harvest heat treatments and storage conditions. Their timely application in accordance with the recommended protocol decides the future of the agricultural products; otherwise, the fruits may start to exhibit undesirable characteristics as a result of the onset of physiological diseases. After harvesting respiration of fruits continued for regulating metabolic activities resulting in loss of water through stomata and lenticels to the environment. So significant physiological weight loss during storage was observed [14]. It is interesting to note that in this study fruit treated with moderate heat treatment (50 °C/40 min) showed reduced PLW than untreated and high-temperature treatments. Lower PLW may be caused by a combination of lower 1-Aminocyclopropane-1-carboxylic acid (ACC) oxidase activity and field heat removal, which delays ripening during storage. The primary cause of the significant weight loss may be attributed to the membrane breakdown, significant water and transpiration loss to the environment, and rapid ripening seen in high-temperature treatments and untreated samples. The results from this study are highly correlated with findings obtained from ‘Waterlily’, ‘Chokanan’, ‘Dashehari’, and ‘Golden phoenix’ mangoes [15-16]. Their results revealed a significant variation in physiological weight loss which could be attributed to variability in ripening stage, and storage conditions as reported by Kader, [17]. The results also provide evidence that heat-treated fruit shows enhanced fruit quality and delayed ripening as compared to untreated as reported by different researchers [9]. Due to respiration of fruit carbohydrates and other organic compounds breakdown due to enzymatic and chemical reactions that evolve water resulting in weight loss of fruit [18]. In this study high correlation between PLW and respiration rate also observed.

Due to heat treatment and cold storage slower rate of weight loss was observed in the 'Kesar' mango as compared to control and ambient storage [3].

According to the study's data, senescence in heat-treated fruit did not become apparent until 25 d after storage, whereas it became clearly visible in untreated fruit after 20 d of ambient storage. In contrast to ambient storage, when in cold storage, modest and consistent increases in TSS were seen without overripening. TSS content of cv. 'Copania', 'Atualfo' and 'Chenab Gold', was found to increase during storage in ambient and cold storage conditions [3, 11]. After 25 days of storage, heat-treated samples (50 °C for 40 min) showed improved ripening potential and shelf life, whereas untreated and HWT-treated samples (60 °C for 20 min) approached senescence. It revealed that the ripening of Alphonso fruit was delayed by HWT 50 °C/40 min and HVT 50 °C/40 min.

The yellow color of peel and pulp is mainly due to degradation of chlorophyll content and synthesis of color pigments such as lycopene, carotenoid, and xanthophyll [19]. The Alphonso mango's loss of green colour during storage owing to ripening is indicated by the increasing trend of L* and b* value and decreasing hue value. Heat-treated fruit in this study displayed greater L* and b* values than untreated fruit at 0 d, and this tendency persisted during storage. Fruit exposed to HWT 60 °C/20 min had higher L* and b* values from the beginning to the end of storage as a result of more chlorophyll breakdown compared to other treatments. A similar trend was observed in mango cultivars 'Waterlily', 'Chokanan' and 'Keitt' [5, 16]. In mango cv. 'Ataullfo' hue values decreased from 102 to 85 and L* values increased from 64 to 75 during ripening [11]. Due to chlorophyll degradation and carotenoid biosynthesis hue values decreased during ripening and storage [20]. Scoring high hue values in heat-treated fruits in ambient and cold storage showed delayed ripening. Application of heat treatments to mango before storage gives better positive results than treatment after post-storage [3]. Heat-treated fruits showed the same rate of developing yellow color on the peel as compared with nontreated fruits [21]. In this study, heat-treated fruit kept in cold storage displayed both a pleasing external appearance and an attractive mesocarp.

The increasing trend in carotenoid content in present study was due to metabolic activity carried by consumption of O_2 and evolution of CO_2 due to ethylene. Fruit cell membranes were disrupted by heat treatment, which improved the chemical extractability of total carotenoids. In this investigation, samples with untreated, HWT 40 °C/80 min, and HWT 60 °C/20 min revealed greater levels of carotenoid content at 20 d after storage and decreased to 25 d after storage, which may be related to fast ripening and high respiration rates that cause fruit senescence. Other treatments, such as HWT 50 °C/40 min and HVT 50 °C/40 min, did not experience senescence but did detect a gradual increase in carotenoid levels up to 25 d. Xanthophylls and carotenoids decreased after reaching a specific ripening stage but heat treatment delayed this process and resulted in an accumulation of pigments [10]. In contrast to ambient storage fruit in cold storage with all treatments showed good quality of carotenoid content without overripening or senescence. Similarly, 'Keit' and 'Sufaid Chaunsa' mango maintained higher carotenoids in heat-treated fruit than in control [5]. These results highly corroborated with our study. Talcott *et al.* [22] found that heat treatment given to mango increased antioxidant activity, polyphenols, and carotenoids were observed.

The findings showed that samples with untreated, HWT 40 °C/80 min, and HWT 60 °C/20 min had greater rates of respiration from the start of ambient storage, which peaked at 20 d of storage, then began to fall at 25 d. This may be because mango fruits undergo significant changes after ripening due to a typical increase in respiration rate; uncontrolled and rapid ripening indicates fruit senescence. In our investigation, greater PLW was also noted as a result of higher respiration rates. Therefore, it could be regarded as a crucial indicator of a product's shelf life. Similar results were recorded in 'Ataulfo' mango [11] and 'Cogshall' [23]. Heat treatment affects the quality of fruit such as increased respiration rate, softening due to breakdown of mesocarp cells, pigment, and carbohydrate metabolism during storage. Lower respiration rates were seen for the Alphonso mango at first because to its climacteric character, but after 10 d of storage due to ripening, the same considerably rose in all treatments. Lower respiration rates were seen in the HWT and HVT samples at 50°C/40 min. This could be because the samples might experience controlled ripening with little cell disruption, which lowers metabolic activity and water loss. When comparing respiration rates between different storage conditions, ambient storage records more respiration than cold storage. Tropical fruits showed increasing respiration rate up to particular ripening stage then decreased in later stages due to high temperatures and senescence [11]. Mango fruits with HWT 50 °C/30 min had reduced respiration rate as compared to the control [5]. In 'Keitt', 'Copania' and 'Ivory' mango reduced respiration rate was observed in heat-treated fruit as compared to control [24]. Similar trend of reduction respiration was found in the present study. In contrast, heat-treated fruits did not show clear difference in mango [25].

In this study untreated, HWT 40 °C/80 min and HWT 60 °C/20 min retained significant low firmness than samples treated with HWT 50 °C/40 min and HVT 50 °C/40 min. The reason for lower firmness in untreated and HWT 60 °C/20 min might be accelerated climacteric ripening, higher water loss due to higher respiration rate and metabolic activities contributed to senescence of fruit. Fruit firmness of Alphonso mango decreased during storage and results agreed with the firmness changes reported by different researchers for other mango varieties [26]. The reduction in fruit firmness with storage and heat treatment may be attributed to starch hydrolysis and cell wall modification associated with heat treatment and ripening. Fruit firmness of 'waterlily' showed significant loss (92.82%) during 6 d storage [16]. In 'Atualfo' mango decrease in firmness was observed from 23.8 to 11.7 N during ripening [11]. During ripening modification and degradation of cell walls of fruit cells were carried out by enzymes such as β-galactosidase, pectin methyl esterase, and polygalacturonase which resulted in significant changes in firmness of fruits during storage [27]. Jha *et al.* [28] recorded decrease in firmness of Alphonso mango peel from 25 to 7.5 N and pulp firmness from 10 to 0.3 N during 10 d storage in ambient conditions. Pectin polymers present in cell wall might also be responsible for continuous decline in fruit firmness during fruit ripening. Flavor and volatiles biosynthesis, hydrolysis of starch into sugars and ultra-structural changes in cell walls might responsible for firmness loss in fruit pulp. The partial insolubility of carbonate-soluble pectin fraction is a key factor for retaining firmness in heat-treated fruits. Javed

et al. [3] found that firmness was lost in both ambient and cold storage but rate of declining varies with storage conditions. Fruits with HWT such as mango [29], banana [18] and papaya [30] maintained higher firmness than untreated fruits.

Table 1: Principal Component analysis of quality parameters

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	7.7682	7.2496	0.8631	0.8631
Comp2	0.5186	0.2947	0.0576	0.9208
Comp3	0.2239	0.0765	0.0249	0.9456
Comp4	0.1474	0.0389	0.0164	0.9620
Comp5	0.1084	0.0326	0.0120	0.9741
Comp6	0.0759	0.0177	0.0084	0.9825
Comp7	0.0582	0.0031	0.0065	0.9890
Comp8	0.0551	0.0107	0.0061	0.9951
Comp9	0.0443	.	0.0049	1.0000

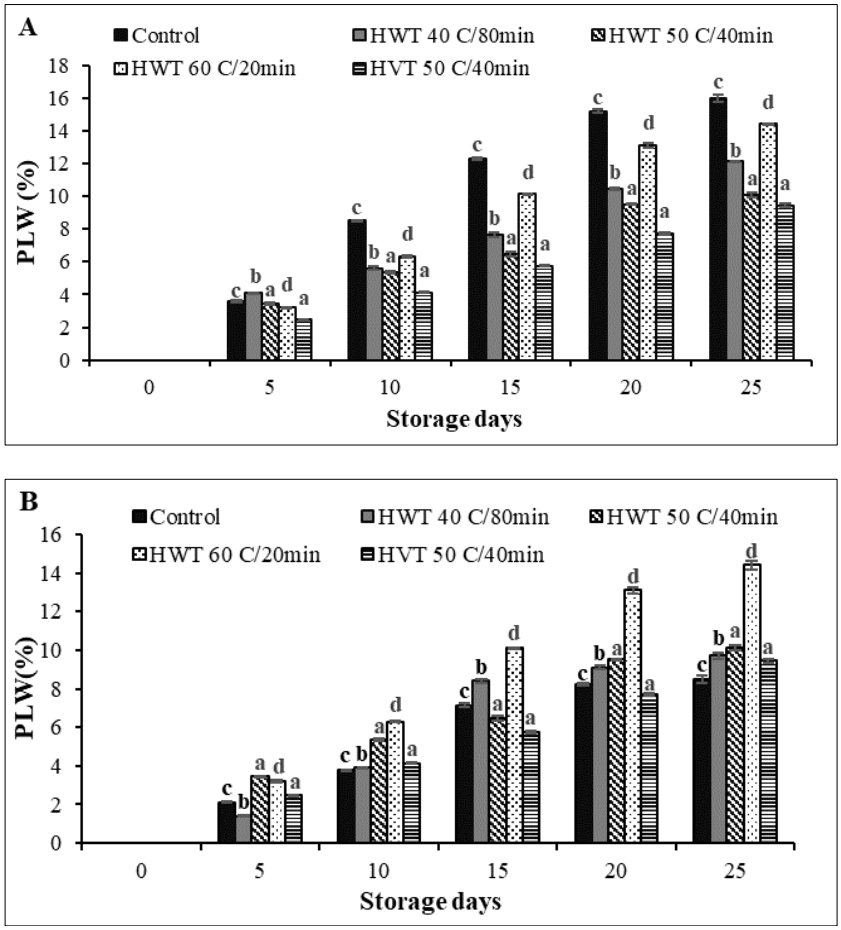
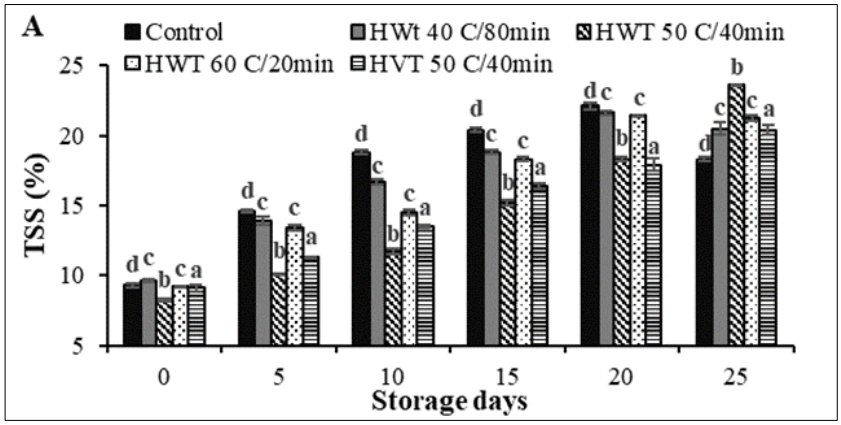


Fig 1: Weight loss of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).



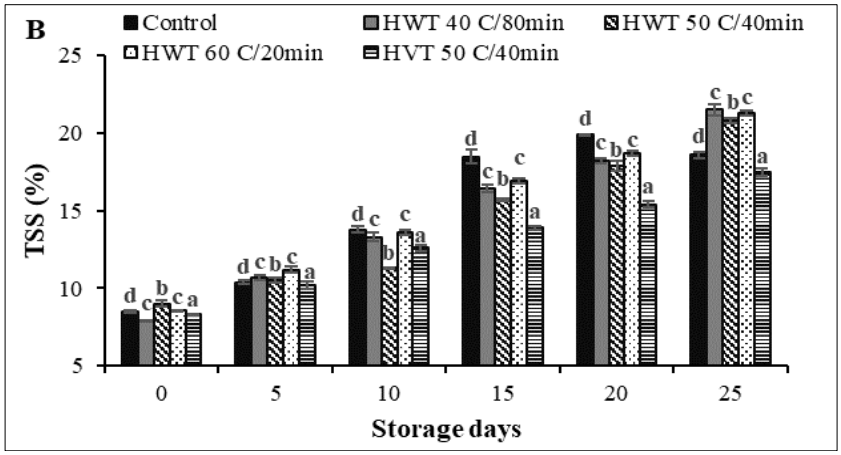


Fig 2: Changes in TSS of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).

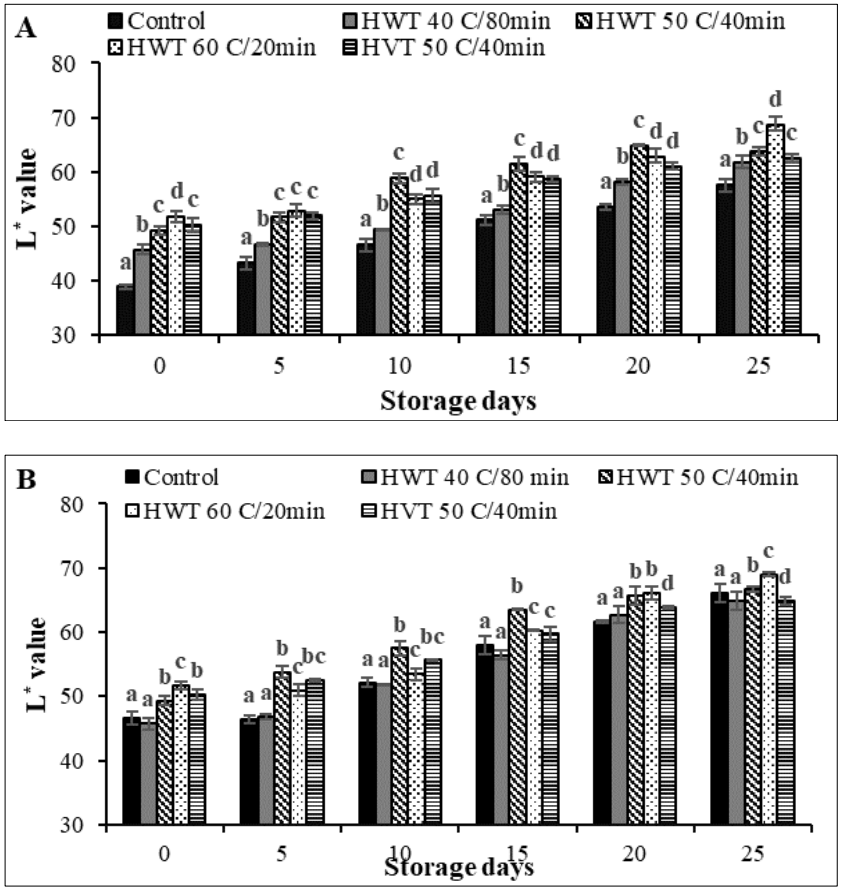
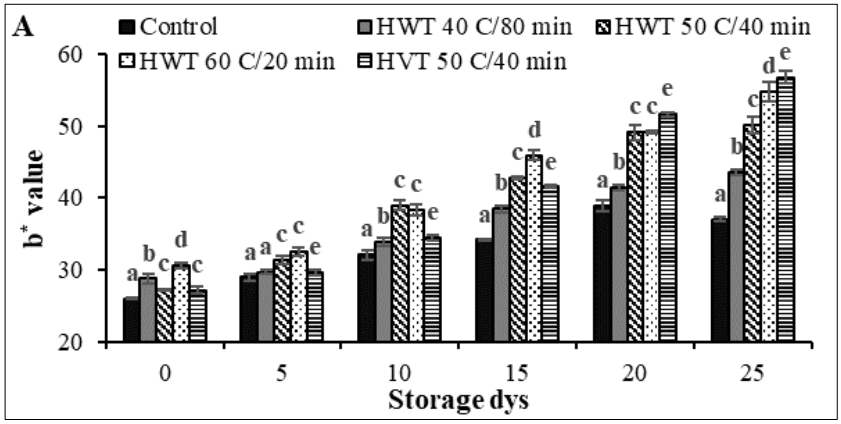


Fig 3: Behaviour of L* value of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).



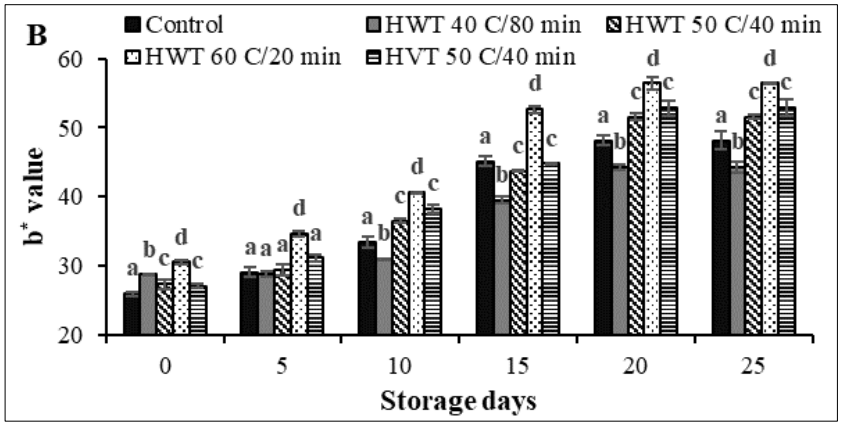


Fig 4: b* value of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).

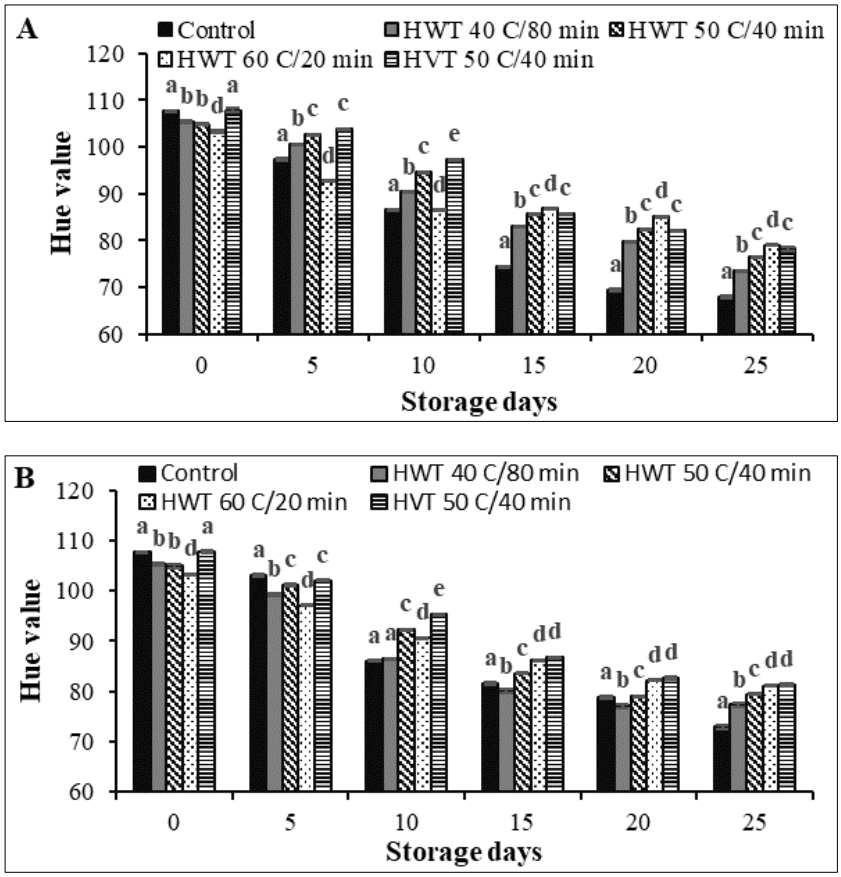
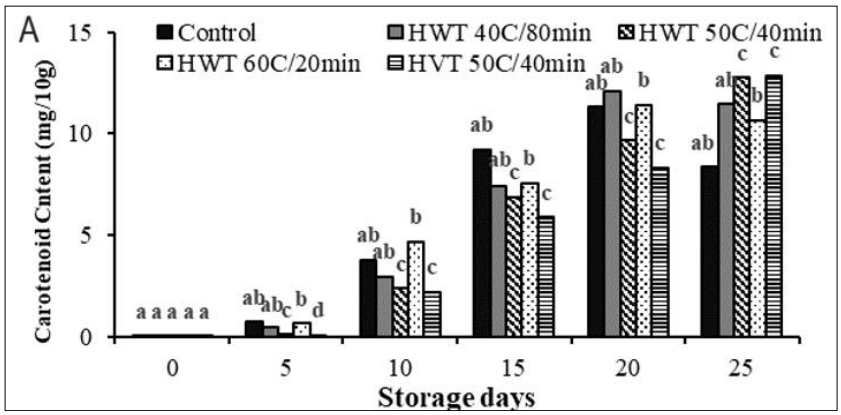


Fig 5: Variation in Hue value of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).



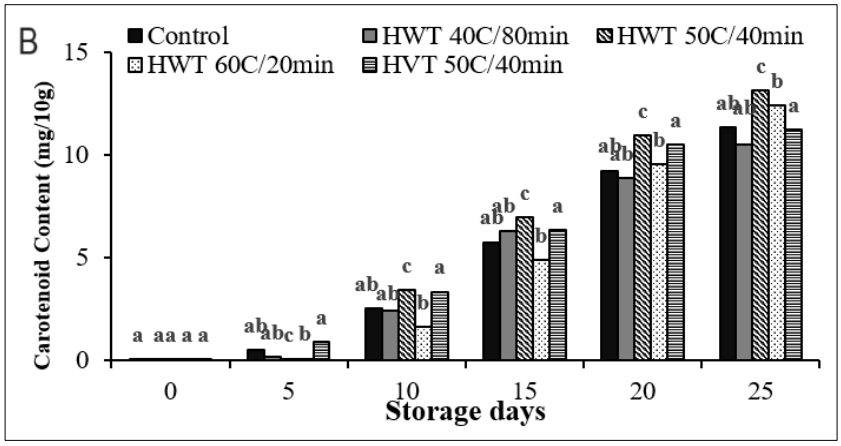


Fig 6: Carotenoid content of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).

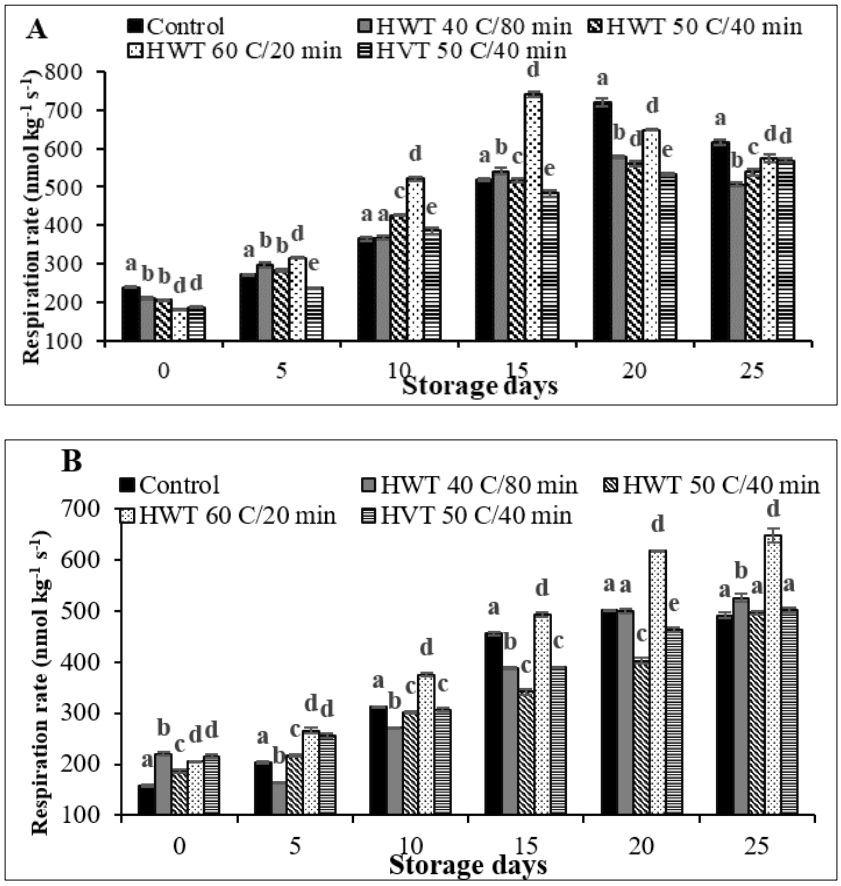
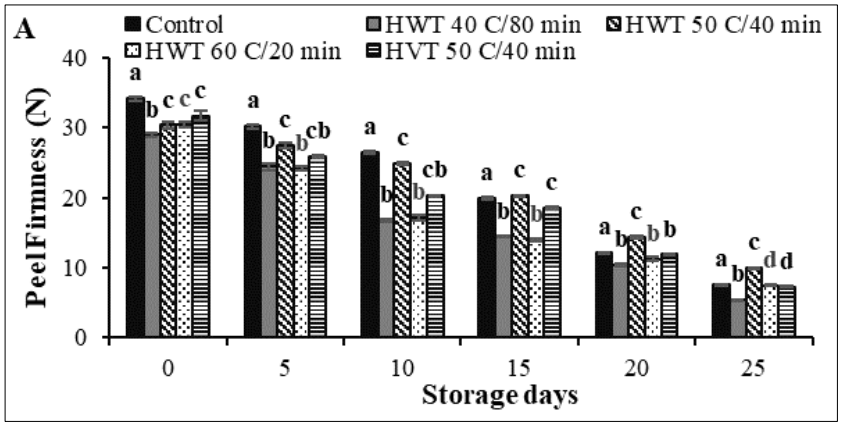


Fig 7: Trend of respiration rate of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).



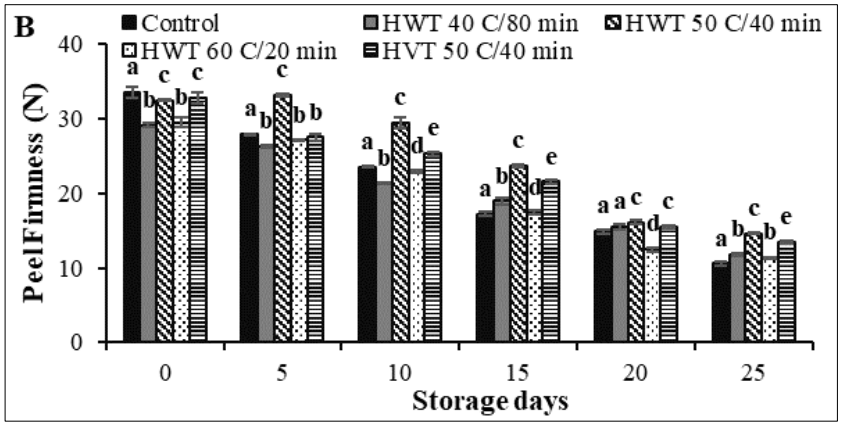


Fig 8: Peel firmness of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).

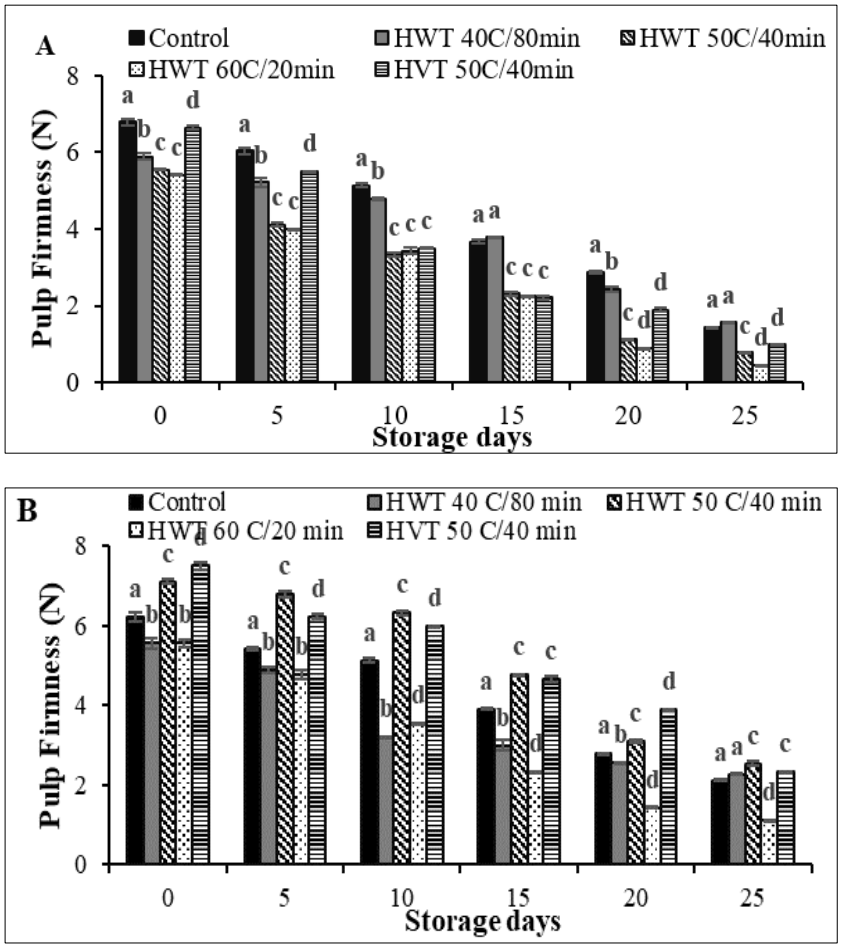


Fig 9: Pulp firmness of mango (cv. Alphonso) in ambient storage (A) and cold storage (B) during 25 d storage after heat treatments (Vertical bars represent standard error of mean and different letters denotes significant difference for each treatment during storage).

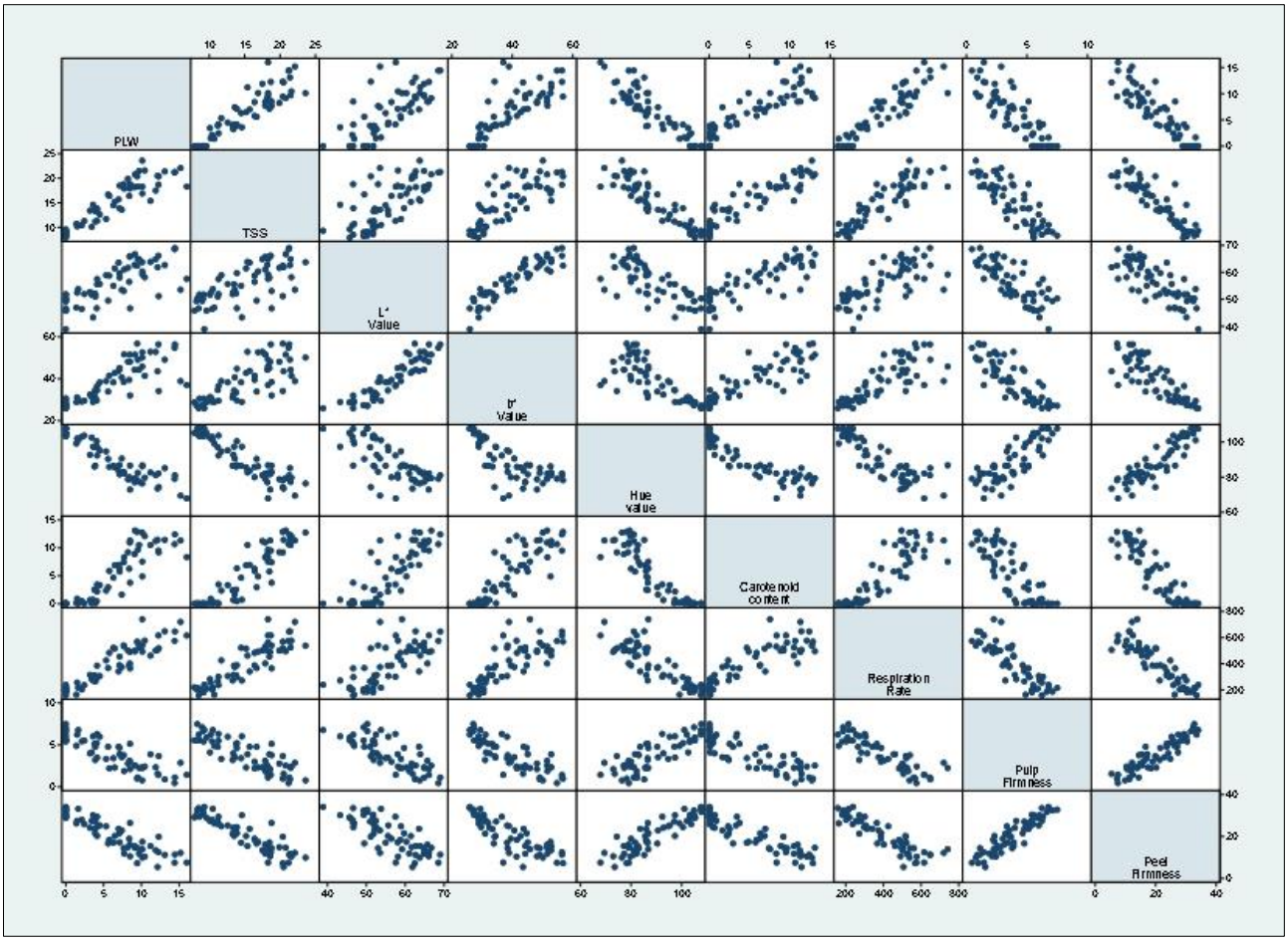


Fig 10: Scatter plot of parameters for cv. Alphonso during storage after heat treatments.

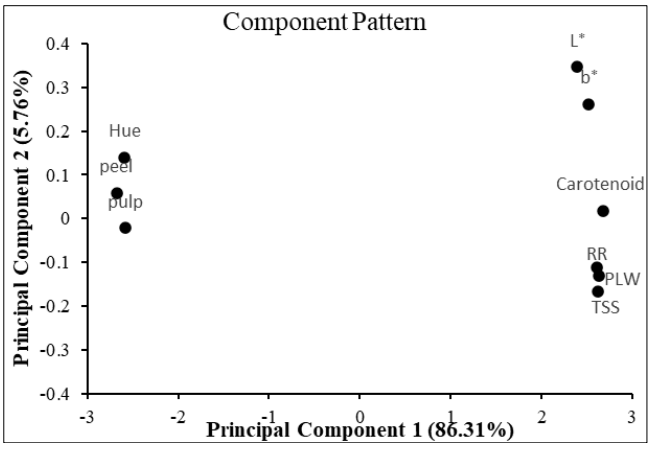


Fig 11: Components pattern of first two principal components with respective wights of parameters

5. Conclusion

The hot water treatments significantly affect the physical, chemical, and physiological properties of Alphonso mango under ambient as well as cold storage conditions. Heat treatments of HWT 50 °C/40 min and HVT 50 °C/40 min have great potential to maintain export quality of Indian Alphonso mango as an alternate to chemical-based pre-treatments retain better quality compared to untreated and other time-temperature heat treatments. Fruits subjected to hot treatments and kept under cold storage conditions at 16 °C shown better retention of quality properties in all treatments up to 25 d of storage. Heat treatment of with HWT 50 °C/40 min and HVT 50 °C/40 min followed by cold storage is the best postharvest quality control strategy for Indian Alphonso mango showed effective during postharvest journey.

The research's conclusions highlight the significance of heat treatments for Alphonso mangoes as one of the key strategies for consistently exporting high-quality product. The above-mentioned heat treatments for Alphonso mangoes illustrate how these treatments have a substantial impact on the mangoes' qualitative traits when they are stored, transported, or put on display for sale. This is advantageous for farmers, dealers, exporters, and government organizations because it enables them to take the appropriate actions to boost farmers' incomes, satisfy domestic and international Alphonso mango supply and demand, and lower postharvest losses throughout the supply chain and storage.

6. Credit authorship contribution statement

Patil Rajvardhan Kiran: Investigation, original draft preparation. Pramod Aradawad: review and editing, Statistical analysis. Roaf Ahmad Parray: conceptualization, methodology, Writing, review and editing. Indra Mani: conceptualization. Arunkumar T. V.: conceptualization, Investigation, review and editing.

7. Declaration of competing interest

The manuscript has been published with the consent of all authors who have read and approved it. I have read the "policy of Conflict of Interest "of Journal of Postharvest Biology and Technology is applicable to the authors and I agree to abide provisions thereof. I am aware of the contents

and consent to the use of my name as an author of a manuscript

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