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IMPACT OF POSTHARVEST HOT WATER TREATMENT ON TWO COMMERCIAL MANGO CULTIVARS OF PAKISTAN UNDER SIMULATED AIR FREIGHT CONDITIONS FOR CHINA

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Mango is highly valued crop traded worldwide. Fruit fly is serious issue in mango producing countries, and being a quarantine pest, needs specific disinfestation treatments to fruit before export. This study was aimed to assess the effect of hot water quarantine treatment on two commercial mango cultivars for mango export to China. Mature, physically de-sapped mangoes of both cultivars (Sammar Bahisht Chaunsa and Sufaid Chaunsa) were subjected to hot water treatment (HWT; 48°C for 60 min) as obligatory quarantine protocol for export to China and held at simulated air freight conditions (24 ± 2 °C, 80% RH) for six and eight days till ripening, respectively. At eating soft ripe stage, HWT-treated fruits appeared to maintain visual quality, skin colour, and flesh colour, with substantially reduced disease incidence (stem end rot, side and body rot), skin defects and flesh defects, as compared to control. It was noted that HWT-treated fruits had higher marketability index, taste, flavor, slightly increased soluble solid contents, sugar acid ratio and ascorbic acid in both cultivars, respectively. Fruit weight loss, skin shriveling, firmness, flesh texture, aroma, titratable acidity and antioxidant activities were not significantly affected by HWT. However, HWT-treated fruits exhibited higher total phenolics and carotenoid contents as compared to untreated control fruits. Conclusively, hot water quarantine treatment maintained better fruit physical, biochemical quality and marketability index compared to control, and thus can be used effectively at commercial scale for export of both cultivars to China.
Keywords*:* Carotenoid contents, Disease incidence, Eating quality, Marketability index, Quarantine treatment.

INTRODUCTION

Mango is one of the most precious fruits in tropical and subtropical regions of the world, for fresh consumption at domestic as well as international markets (Khan *et al.,* 2015). Asia accounts for major proportion (74.3%) of production in the global mango industry followed by America, Africa and Oceania (Lawson *et al.,*2019). Presently, international mango trade is facing various postharvest issues such as infestation of fruit fly, disease incidence, sap burn, non-uniform ripening, lenticel development and incidence of chilling injury during low temperature storage (Sivakumar *et al.,* 2011; Ntsoane *et al.,* 2019). Among these issues, fruit fly poses the most serious challenge since it requires stringent monitoring and management during production. Still, field management alone cannot guarantee that fruits are free from insects, therefore; postharvest disinfestation (quarantine) treatments are being made mandatory for mango export to high end international markets.

Various importing countries have imposed restrictions on mango trade through implementing specific quarantine treatments(Jacobi *et al.,* 2001) such as HWT for export to China, Iran; irradiations for USA; and vapour heat treatment for Australia, Japan and New Zealand, respectively (Sivakumar *et al.,* 2011; Jabbar *et al.,*2012; Singh and Saini, 2014). HWT is widely employed and applicable method due to its high efficacy, non-chemical and low cost (Jacobi *et al.,* 1995: Anwar and Malik, 2007). Quality of fresh produce (including mango) in the market is considered as a critical factor throughout the supply chain. Heat treatments disinfect the commodity by diminishing fruit fly eggs, maggots and improving quality (Paull and Chen, 2000). Similarly, postharvest diseases including stem end rot, anthracnose, alternaria black spot, side and body rot also downgrade fruit quality and reduce overall acceptability (Ntsoane *et al.,* 2019) and it is important to see whether hot water quarantine treatment (HWQT) has some impact on postharvest diseases. The mango industry of Pakistan has potential to increase its export to other Asian markets including 'China' famous for fresh mango consumption. Pakistani commercial mango cultivars (Sindhri, Sammar Bahisht Chaunsa and Sufaid Chaunsa) can attract Chinese and other international consumers due to their appealing colour, promising taste, texture, flavour and aroma (Malik and Hasan, 2019). Previously, Pakistan has signed HWT protocols in 2005 with Iran (HWT at 45°C for 75 min) and China (HWT at 48°C for 60 min) for export (Anwar and Malik, 2007). There have been limited studies on HWT of local mango cultivars (Anwar and Malik, 2007, Jabbar *et al.*, 2011; Jabbar *et al.*, 2012) and these too lack some aspects (non-enzymatic antioxidants, bioactive compounds, related sensory characteristic) about the impacts of phytosanitary treatment. Further, as yet there has been no study on the impact of HWQT on mango cultivar Sufaid Chaunsa, which is the large premium size late season cultivar holding good potential for export to China. However, due to apprehension about HWT, and variable results, there is need of industry to undertake a detailed study of HWQT impacts in relation to cosmetic quality for two commercial mango cultivars 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa'. In addition, mango industry also needs a subjective, non-destructive quality assessment system as developed under ACIAR mango project (ACIAR, 2019) to be used in supply chain operations. Hence, the objectives of the current study were to evaluate the impact of hot water quarantine treatment (following China protocol) on cosmetic quality, sensory attributes, biochemical, and phytochemical quality of commercial cultivars under simulated conditions for export to China through airfreight.

MATERIAL AND METHODS

***Fruit source*:** Fruits of mango cvs. Sammar Bahisht Chaunsa and Sufaid Chaunsa were harvested (along with 4-5cm intact stalk) from 15-18 years old trees, at green mature stage (firm hard with 10 and 8.6°Brix, respectively) from the commercial orchard (having uniform aged and sized trees) located at Nawab Pur (30°19'39.1"N 71°28'25.2"E) Multan, Southern Punjab, Pakistan. After harvest, fruits were physically de-sapped by placing them downwards using de-sapping stands (L × W × H = 190 × 115 × 50cm), and 1-2 cm of fruit stalks were cut for acidic sap release to avoid sap injury. Fruits allowed to stay on the racks for 30 min till appearance of jelly formation, air-dried, packed in commercial fruit bins (L × W × H = 40 cm × 32 × 29 cm) sideways with paper lining were shifted to a commercial mango processing facility (Kashan Hot Water Plant) Multan.

***Treatments*:** In two separate experiments (difference in the maturity of cultivars), fruits of each cultivar (Sammar Bahisht Chaunsa and Sufaid Chaunsa) were treated with respective HWT. Upon arrival at HWT commercial facility, uniform (size and colour), disease and blemish free fruits were washed and treated with hot water following China protocol (48°C temperature for 60 min), while control fruits were just washed. All treated and untreated fruits were air-dried and packed in 16 Kg fruit bins and kept at room temperature until the pulp temperature decreased to 32°C. Fruits were subjected to ripening treatments by placing two ethylene sachets (3g each) per 16 Kg fruits inside the fruit bins (L × W × H = 40 cm × 32 × 29 cm) and covered with blanket for 48 h. After 48 h, ethylene sachets were removed and then fruits were re-packed in export size (L × W × H =40 cm × 29 cm × 10 cm) soft cardboard boxes (9 fruits/box).Fruit boxes were transferred to Postharvest Research and Training Center, Institute of Horticultural Sciences University of Agriculture Faisalabad in an air-conditioned van (24 ± 2 °C). At postharvest lab, fruits were placed in controlled simulated condition (24 ± 2 °C) of air freight till complete ripening. The experiments were conducted using completely randomized design in triplicate.

***Assessment of visual fruit quality and disease incidence*:** At eating soft ripe stage, fruits of both mango cultivars were subjected to physical analysis using 1-5 rating scale. Fruit visual quality [1 = extremely poor (not marketable), 2 = poor (limit of marketability), 3 = fair (lower limit of marketability), 4 = good (good quality, not objectionable),and 5 = excellent (excellent quality, high marketability)] was accessed as reported earlier by Kadar et al. (1973). Fruit skin colour [1 = all green, 2 = more green than yellow, 3 = half yellow-half green, 4 = more yellow than green and 5 = all yellow], and fruit skin defects [1 = extreme (extremely poor, > 25 % of the surface area), 2 = severe (excessive defect, limit of acceptability, <25 % of the surface area), 3 = moderate (slight to moderate, lower limit of attraction, < 10 % of the surface area), 4 = slight (minor defect, not objectionable) and 5 = none defect (essentially free from defects)] were evaluated as earlier described by Homes et al. (2009); whereas, disease incidence were noted [1 = Nill, 2 = < 5%, 3 = 5-10%, 4 = 10-25 % and 5 = >25 %] as reported earlier by Amin et al. (2007).

***Firmness and shriveling*:** Fruit firmness was manually assessed [1 = hard (no 'give'), 2 = rubbery (slight 'give' with strong thumb pressure), 3 = sprung (flesh deforms by 2-3 mm with moderate thumb pressure), 4 = firm soft (whole fruit deformed with moderate hand pressure) and 5 = soft (whole fruit deforms with slight hand pressure)] as described by Homes et al. (2009); while, fruit shriveling was determined using the 1-5 scale method [1 = Nil, 2 = < 10%, 3 = 10-25 %, 4 = 25-50 % and 5 = >50 %].

***Fruit weight loss and marketability index*:** Fruit weight of both cultivars under study was estimated at 2-day interval till complete ripening. Fruits of both treated and non-treated boxes were weighed using electronic digital weight balance (Setra, BL-4100S) and weight loss was estimated by using the following formula and was expressed in percentage (Hasan *et al.*, 2019a).

$$\text{Fruit weight loss (\%)} = \frac{\text{Initial fruit weight} - \text{Final fruit weight}}{\text{Initial fruit weight}} \text{x } 100$$

Marketability index for treated and non-treated fruits was estimated by calculating the number of healthy fruits observed visually (free from blemish, disease, decay and shriveling) was expressed as percent.

$$\text{Marketability index (\%)} = \frac{\text{Number of healthy fruits}}{\text{Total fruits}} \times 100$$

***Flesh colour and defects*:** The fruit were also assessed for flesh colour [1= yellow-white, 2 = light-yellow, 3 = bright-yellow, 4 = yellow-orange and 5 = orange] and flesh defects [1= extreme (extremely poor), 2 = severe (excessive defect, limit of acceptability), 3 = moderate (slightly to moderately objectionable defect, lower limit of attraction), 4 = slight (minor defect, not objectionable) and 5 = none (essentially, free from defect)] as reported earlier by Kader *et al.* (1973).

***Sensory evaluation*:** Representative fruit samples (6 fruit per box) from both boxes (control and HWT) for each cultivar, were presented to a panel of 5 judges (postgraduate students of postharvest lab) for scoring to sensory characters (taste, texture, flavour and aroma)by considering hedonic 1-9 scale (Peryam and Pilgrim, 1957). Fruits were manually peeled, sliced and presented in tagged plates. Instructions were written on developed organoleptic proforma with described scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = Like moderately, 8 = Like very much and 9 = Like extremely) for its smooth evaluation.

***Soluble solid contents, titratable acidity and sugar acid ratio*:** Extracted juice from ripen fruit pulp was subjected to different biochemical attributes for each sample. Soluble solid contents (SSC) was recorded using handheld refractometer (Atago, RX 5000) and value expressed in °Brix (Ali *et al.*, 2016b). Titratable acidity (TA) of juice samples was determined by titration method as procedure stated by Razzaq *et al.*, 2015 for mango fruit and expressed as percent (%) maleic acid. SSC:TA ratio was calculated by simply dividing SSC with corresponding TA values (Hasan *et al.*, 2019a).

***Ascorbic acid and carotenoid contents*:** For ascorbic acid (AA) determination, 10 mL juice sample extracted from mango pulp was added in 90 mL 0.4% oxalic acid. Then 5 mL filtered aliquot was titrated against 2, 6-dichlorophenol-indophenol dye till the appearance of pink colour end point and was expressed as mg $100mL^{-1}$ (Ali *et al.*, 2016a). For determination of total carotenoid contents, 1 g frozen pulp sample was mixed with 20 mL extraction buffer (acetone: n-hexane = 75:60) and 0.5g magnesium carbonate followed by homogenization in the chilled pestle and mortar. Afterwards, samples were vortexed and centrifuged (3000 × *g*) in temperature-controlled centrifuge machine (Z-326K, HERMLE Labortechnik GmbH, Germany) for 5 min. The absorbance of samples was red at663,453, 645 and 550 nm using UV-spectrophotometer (UV-1800, Shimadzu, Japanese and European Pharmacopoeia). The carotenoids contents were reported in mg g^{-1} FW equivalent to the value available in standard curve of β-carotene (Nagata and Yamashita, 1992).

***Total phenolics and antioxidant contents*:** Both phytochemicals were determined from mango pulp tissues stored at -80 °C temperature. After extraction in methanol: ethanol: HCl (90:8:2) essay, resulted supernatant was used for the estimation of total antioxidant activity using the stable purple coloured methanolic solution of 2,2-diphenyl-1-picrylhydrazyl-radical (DPPH). Briefly, 50 µL of supernatant was added in 5 mL of DPPH methanolic solution (0.1 mmol L^{-1}) and mixture essays was incubated in the dark by covering with aluminum foil for 30 min. A blank reading was also assessed without fruit sample. The samples absorbance was measured at 517 nm wavelength and expressed as % inhibition (Brand-Williams *et al.,* 1995).Total phenolic contents (TPC) were measured through Folin-Ciocalteau assay method described by Ainsworth and Gillespie (2007), while sample absorbance was recorded at 765 nm. The level of TPC was expressed in mg gallic acid g^{-1} FW and its value equivalent from GAE value in standard curve.

***Statistical Analysis*:** Data were analyzed according to analysis of variance using Statistix-8.1® software (Analytical Software, Tallahassee, USA), while experiment was laid out under completely randomized design. Least significant difference test was used to assess the level of significance of analyzed data at $P \leq 0.05$.

RESULTS AND DISCUSSION

***Visual fruit quality and disease incidence*:** Results showed that after six days of ripening at best eating soft stage, untreated control 'Sammar Bahisht Chaunsa' fruit were rated almost similar (good to excellent) in visual quality with HWT-treated fruit having 4.6 score and 4.4 scores, respectively (Fig. 1A). Whereas, after eight days of the ripening period, visual quality of HWT-treated 'Sufaid Chaunsa' fruit exhibited a higher score (4.7; good to excellent) in contrast with control (3.8) (Fig, 2A), indicating that in these fruit HWT has improved their visual appearance. Quality assessment of fruit is considered indispensable criteria at any stage of mango supply chain from harvesting (green hard stage) till best eating ripe stage by domestic as well as export market consumers (Holmes *et al.,* 2009). Among quality assessment standards, cosmetic look of commodity is viewed as first indicator striking the consumers choice and acceptability (Djioua *et al.*, 2009). Similarly, exposure to heat treatments prior to storage has been found to maintain visual quality of mango, kale collard and cucumber (Kim *et al*, 2009; Wang, 1998; Nasef, 2018). In these experiments, fruits were pre-sorted to remove the bruised ones before hot water treatment, hence no significant discoloration on fruit skin was observed after HWT. It has been reported that mango fruits with bruises show pronounced skin discoloration after HWT (Anwar and Malik, 2007). Visual skin colour score of HWT-treated 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruits was 4.8

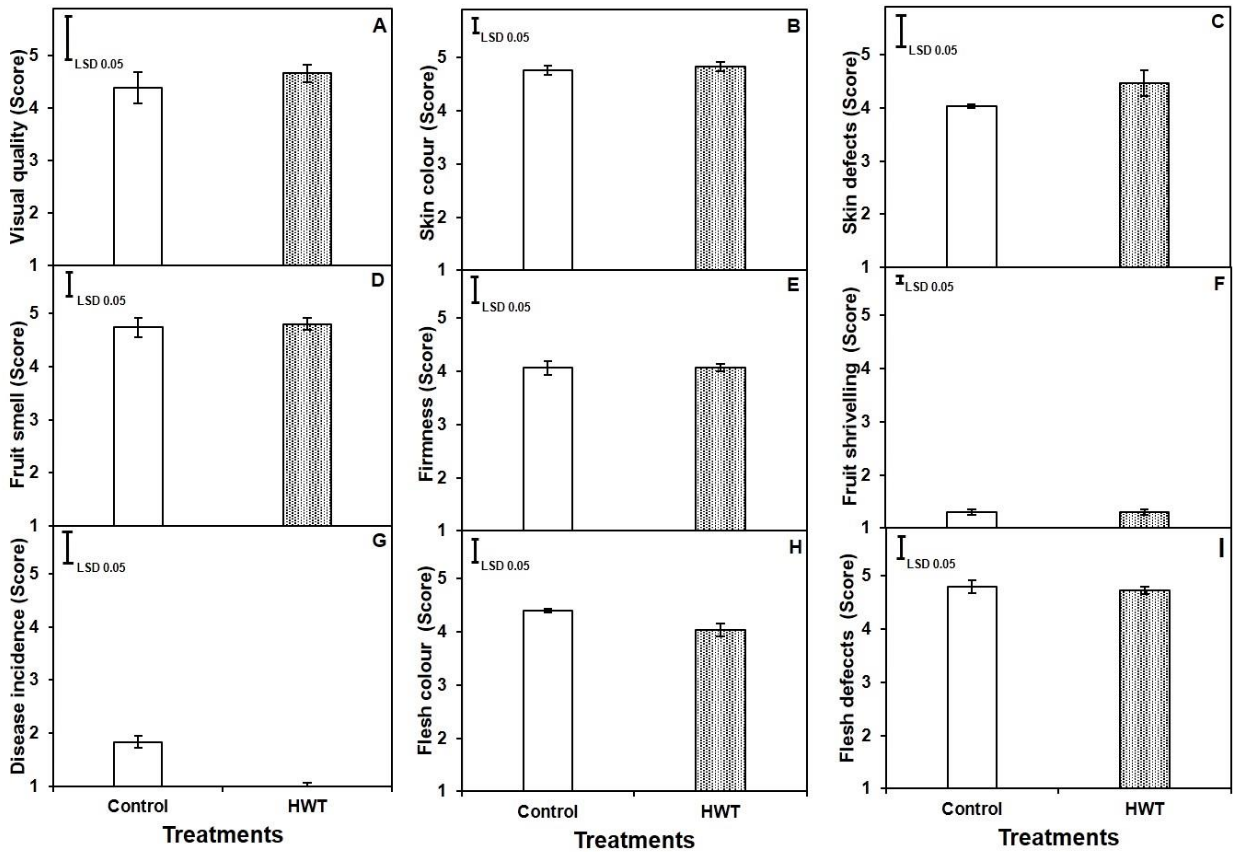


Figure 1. Effect of postharvest hot water quarantine treatment on visual quality (A), skin colour (B), skin defects (C), fruit smell (D), firmness (E), fruit shriveling (F), disease incidence (G), flesh colour (H) and flesh defects (I) of 'Sammar Bahisht Chaunsa' mango fruit. Vertical bars represent ± standard error of the means, invisible bars depicted smaller values difference. n= 27 (9 fruits × 3 replications).

and 4.7 respectively (approaching to complete yellow) as compared to untreated control (4.7 score; yellow and 4.3 score; less green), respectively (Fig. 1B-2B). Uniformly developed yellow colour in HWT-treated fruits might be due to uniform ripening as compared non-treated control fruits (Jacobi *et al.*, 2001; Lurie,1998). Similarly, skin defect score was lower (4.46 score) in HWT-treated 'Sammar Bahisht Chaunsa' fruits, indicating that fruits were almost free from defects; while 4.0 score for control fruits showed minor defects but not objectionable to end user (Fig. 1C). 'Sufaid Chaunsa' mango fruit treated with HWT exhibited significant reduction in skin defects (4.3 score; having minor but non objectionable defects on its surface) and non-treated fruits showed maximum scores (3.2 score) revealed < 10% of affected area which reduced their acceptability for buying by consumers.

Results showed that fruit of mango cv. 'Sammar Bahisht Chaunsa' exhibited significant reduction in DI (1.0 score; none of the signs and symptoms on skin) as compared to un-treated control fruits (1.8 score; less than 5% of surface area with disease symptoms) (Fig. 1G). Similarly, HWT-treated 'Sufaid Chaunsa' mango fruit showed significant ($P \leq 0.05$) decline in DI (1.0 score) as compared to non-treated control fruits (3.05 score) in which surface was covered with 5-10 % of disease symptoms which limits marketability (Fig. 2G). Postharvest diseases including anthracnose, stem end rot, side rot and body rot downgrades the fruit quality of mango (Amin *et al.,* 2012). International trade markets imposed partial restrictions on use of synthetic chemicals *i.e.* fungicide dips prior to transit (Jacobi and Giles, 1997). However, hot water dips widely employed to elicit disease resistance and management of postharvest diseases at varying temperature (52-55°C) for 10-20 min in mango (Dessalegn *et al.,* 2013; Hasan *et al.,* 2019b), banana (Vilaplana *et al.,* 2018) and papaya (Terao *et al.,* 2019) fruits. Sripong *et al.* (2015) reported that HWT along with UV-C application increased the activities of plant defense enzymes (phenylalanine ammonia lyase, peroxidase, chitinase, b-1,3-glucanase) in peel and pulp tissues of mango fruit followed by its higher gene expressions (MI-PAL, MI-POD, MI-CHI and MI-GLU) in peel significantly suppressed anthracnose disease.

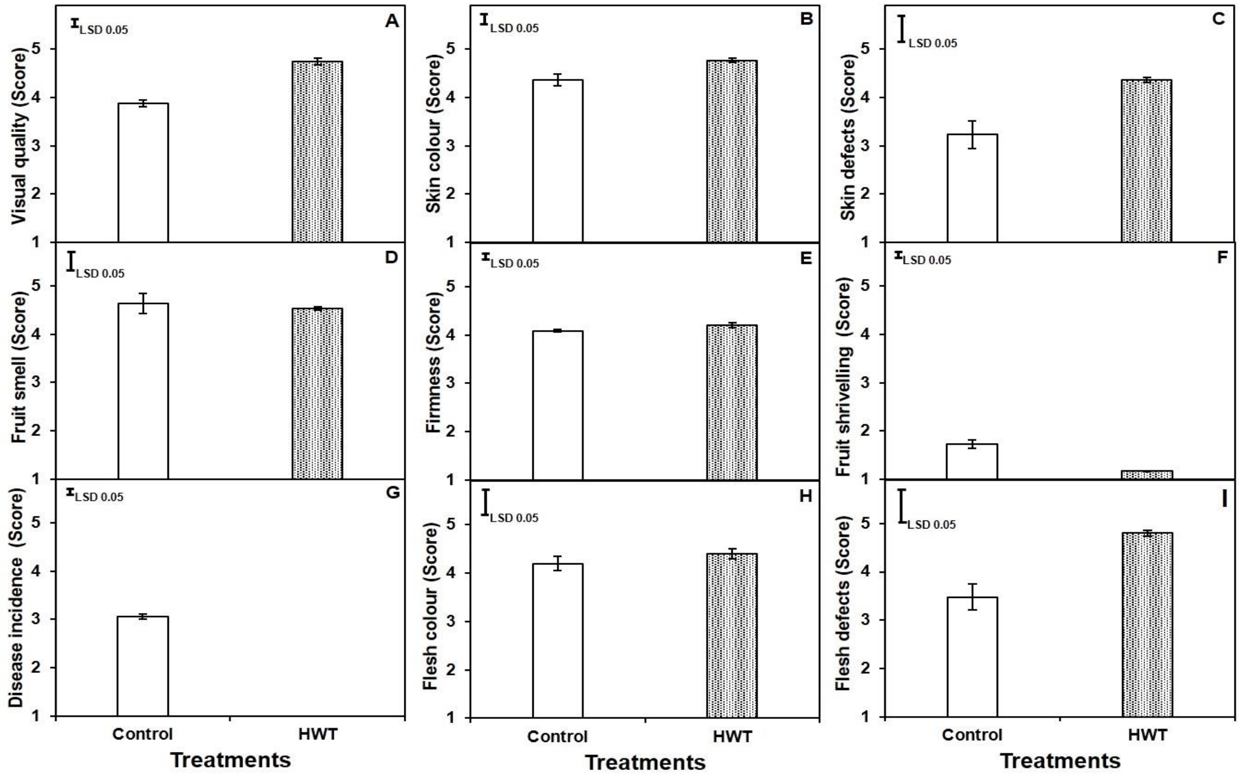


Figure 2. **Effect of postharvest hot water quarantine treatment on visual quality (A), skin colour (B), skin defects (C), fruit smell (D), firmness (E), fruit shriveling (F), disease incidence (G), flesh colour (H) and flesh defects (I) of 'Sufaid Chaunsa' mango fruit. Vertical bars represent ± standard error of the means, invisible bars depicted smaller values difference. n= 27 (9 fruits × 3 replications)**

Firmness and shriveling**:** No negative effect of HWT was observed on fruit shriveling and firmness (indirectly called as softness) in both mango cultivars (Fig. 1E-F and Fig. 2E-F). Similarly, in earlier studies, application of HWT was found to maintain firmness of mango (Sripong *et al.,* 2015), banana (Vilaplana *et al.,* 2018) and papaya (Terao *et al.,* 2019) fruits. Shriveling on fruit skin is another distinguished standard for quality assessment, which depend on cultivar. Studies revealed that mango fruit treated with HWT or packed in heat-shrinkable films displayed minimum peel thickness and less skin shriveling with gradual progress in ripening (Rodov *et al.,* 2003).

Fruit weight loss and marketability index**:** In both experiments, irrespective of HWT, both mango cultivars, did not exhibit any significant change in fruit weight loss. However, fruit weight loss was found slightly higher in HWT-treated fruits as compared to control (Fig 3A-B). One of the reasons for physiological fruit weight loss is the membrane disruption associated with higher rate of transpiration and water loss to the surrounding environment, and weight loss percentage also depends upon the temperature of heat treatment and duration (Perini *et al.,* 2017; Vilaplana *et al.,* 2018).

Figure 3. **Effect of postharvest hot water quarantine treatment on disease incidence (stem end rot and side rot) of 'Sufaid Chaunsa' mango fruit.**

Marketability index is considered as pivotal parameter for mango fruit quality. HWT significantly ($P \leq 0.05$) increased marketable fruit percentage (96.29%) as compared to control (62.96%) in cv. Sammar Bahisht Chaunsa (Fig. 4C). While HWT fruits of cv. Sufaid Chaunsa had maximum marketability (100%) and displayed 1.9-fold increase as compared with non-treated fruits (51.85%) (Fig. 4D). Earlier, HWT along with postharvest dips in aqueous solution of inorganic salts markedly reduced disease incidence and improved cosmetic quality and marketability of mango fruits at consumer end (Dessalegn *et al.*, 2013).

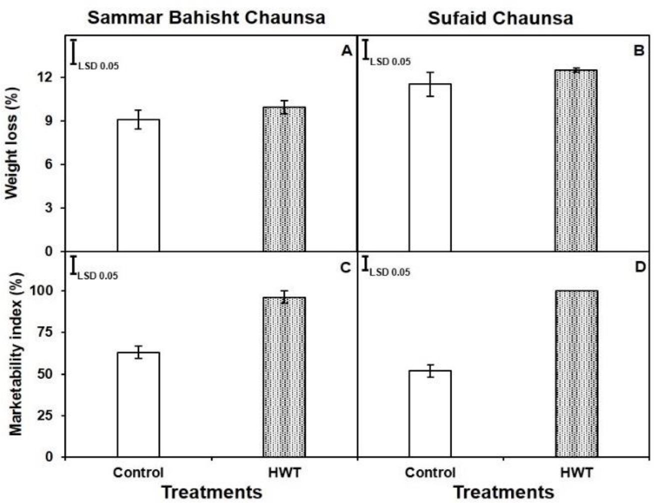


Figure 4. Effect of postharvest hot water quarantine treatment on weight loss (A and B) and marketable index (C and D) of 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruit, respectively at best eating quality. Vertical bars represent ± standard error of the means, invisible bars depicted smaller values difference. n=3 replications.

***Flesh colour and defects*:** As expected, flesh colour was not affected by HWT and treated and non-treated fruit of both cultivars exhibited yellow to orange colour (acceptable to consumer) (Fig. 1H and 2H). Jacobi and Giles (1997) reported that heat treatments increased flesh lightness during ripening in 'Kensington' mangoes. However, HWT did not affect the flesh colour of fresh cut slices of 'Tommy Atkins' mangos and general increase in brightness (yellow to orange) could be attributed due to loss of green colour during storage with gradual progress of ripening (Kim *et al.*, 2007; Dea *et al.*, 2010). At ripe stage, visual observation of flesh defects in 'Sammar Bahisht Chaunsa' mango fruit did not exhibit significant change (Fig. 1I). While HWT-treated 'Sufaid Chaunsa' fruit showed significant 1-29-fold reduction in flesh defects as compared to non-treated control fruit (Fig. 2I). Fresh cut cubes from HWT and non-treated 'Kent' mangoes were not affected during storage and maintained their quality (Dea *et al.*, 2010). However, our observations of cv. 'Sufaid Chaunsa' confirm the earlier findings of Wang *et al.* (2014), who reported that post-cut heat treatment (50-55°C) of sunchoke tubers prevented it from flesh discoloration over eight days of low temperature (5°C) storage. Although, heat treatments at higher temperature (≥60 °C) can cause tissue softening, more translucent cut surface and develop symptoms of damage discoloration.

***Sensory evaluation*:** Eating quality was assessed by evaluating the organoleptic characters of HWT-treated and non-treated 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruits at ripe stage. Among organoleptic quality characters, taste and flavour displayed 1.37- and 1.29-fold higher scores as compared to non-treated control fruits in both mango cultivars (Fig. 5A and E).

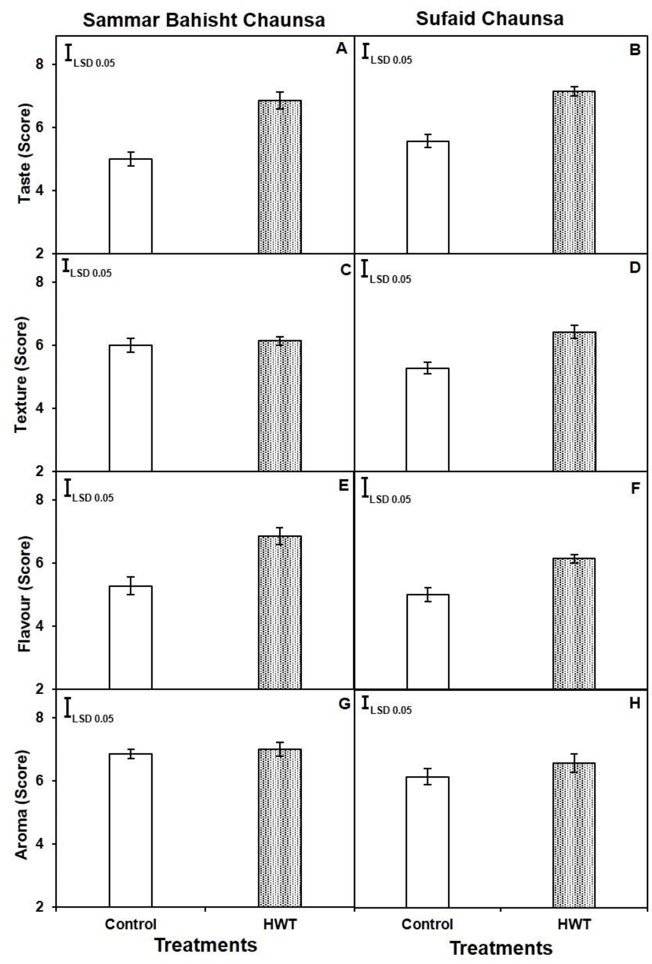


Figure 5. Effect of postharvest hot water quarantine treatment on taste (A and B), texture (C and D), flavour (E and F) and aroma (G and H) of 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruit respectively. Vertical bars represent ± standard error of the means. n=3 replications.

Similarly, HWT-treated 'Sufaid Chaunsa' fruit exhibited 1.28- and 1.22-fold increase in taste and flavour scores as compared to non-treated fruits, respectively (Fig. 5B and F). Higher scores for taste and associated flavour character in treated mango fruit might be due to the better preservation of fruit quality in comparison with control as Nasif (2018) revealed that short hot water dip (55°C for 5 min) maintained eating quality of cucumbers during storage. Our results also confirm the findings of Jabbar *et al*. (2011) who reported HWT (48°C for 60 min) of mango fruit exhibited maximum score for taste under cold storage conditions (10°C). Similarly, mild heat treatment (50°C for 60 min) to whole cantaloupe melon fruits resulted in increased sweet aromatic flavor of fresh cut cubes during cold storage (Lamikanra *et al.*, 2005).

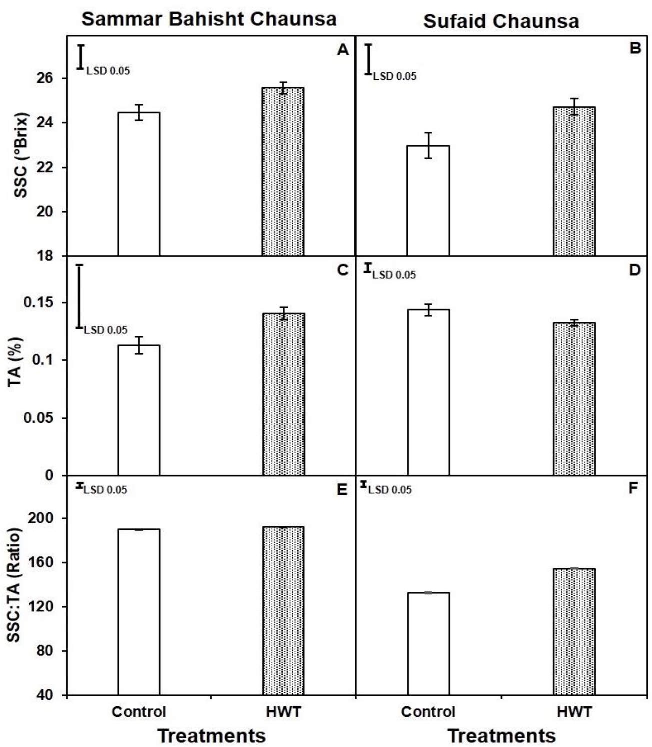
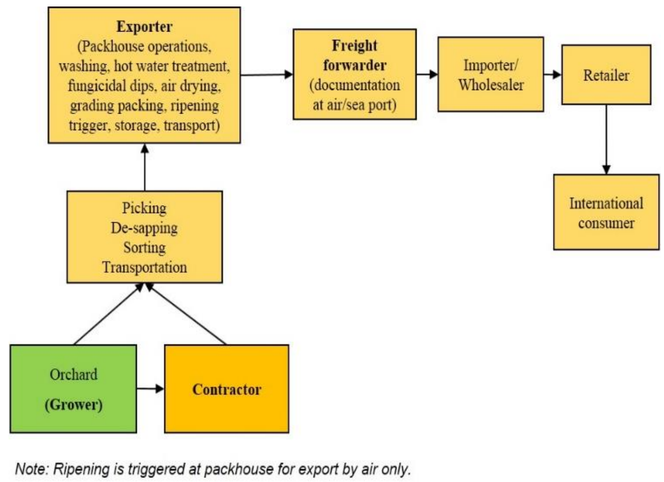


Figure 6. Effect of postharvest hot water quarantine treatment on biochemical quality attributes, soluble solid contents (SSC) (A and B), titratable acidity (TA) (C and D) and sugar: acid ratio (SSC: TA) (E and F) of 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruit respectively. Vertical bars represent ± standard error of the means, invisible bars depicted smaller values difference. n=3 replications.

According to the panelists, texture and aroma characters showed non-significant ($P \leq 0.05$) scores between treated as well as non-treated mango fruits and maintained their best eating quality (Fig. 6C-D and G-H). Our results also conform the findings of Anwar and Malik (2007) who reported that texture quality of Sindhri mango fruit was not changed in response to HWT quarantine treatment. Similarly, Dea *et al*. (2010) also revealed that no difference was observed for 16 volatile aroma compounds between fresh cut 'Kent' fruit slices prepared from HWT-treated and non-treated fruits. Moreover, brief non-destructive/destructive parameters based on the scoring system used may be helpful for growers, processors, exporters and importers for quality assessment at any stage of mango supply chain (Supplementary Fig. 1).



Supplementary Figure 1. Mango export supply chain of Pakistan

***SSC, TA and sugar acid ratio*:** At best eating quality, SSC displayed non-significant ($P \leq 0.05$) difference for treated and non-treated mango fruits. However, HWT-treated fruits showed slightly higher (25.56 °Brix) SSC as compared to control (24.46 °Brix) in cv. 'Sammar Bahisht Chaunsa' (Fig. 6A). Similarly, a slight change of SSC (24.7 °Brix) was observed in HWT-treated than non-treated fruits (22.96 °Brix) of cv. 'Sufaid Chaunsa' (Fig. 6B).Similarly, in earlier reports HWT-treated did not show any significant difference in SSC of fresh cut or whole mango fruits (Anwar and Malik, 2007; Dea *et al.*, 2010; Jabbar *et al.*, 2011). Moreover, exposure to heat treatments did not affect SSC in variety of fruits and vegetables such as banana, papaya, tomato and cucumber (Paull and Chen, 2000; Nasif, 2018; Vilaplana *et al.*, 2018; Terao *et al.*, 2019).

HWT had no negative impact on titratable acidity (TA %) of both mango cultivars (Fig. 6C-D).TA decreased as ripening progress towards eating stage due to sharp rise in respiration and ethylene production (Kim *et al.*, 2007).Similarly, in earlier studies, postharvest heat treatments did not show any significant change in acidity of mango, banana and papaya fruits (Kim *et al.*, 2007; Anwar *et al.*, 2007; Djioua *et al.*, 2009; Vilaplana *et al.*, 2018; Terao *et al.*, 2019). Sugar acid (SSC/TA) ratio slightly increased in HWT-treated mango fruits of both cvs. 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' as compared to untreated-control fruits (Fig. 6E-F). In this regard, our study findings contradict to Anwar and Malik (2007) who reported non-significant results for SSC:TA ratio of treated and non-treated Sindhri fruits. It might be due to the conversion as well as degradation of starch into sugars, difference of cultivar response towards heat treatment and continuous ripening during storage.

***Ascorbic acid and carotenoid contents*:** At eating ripe stage, ascorbic acid content showed non-significant difference for HWT-treated and non-treated 'Sammar Bahisht Chaunsa' mango fruit (Fig. 7A).

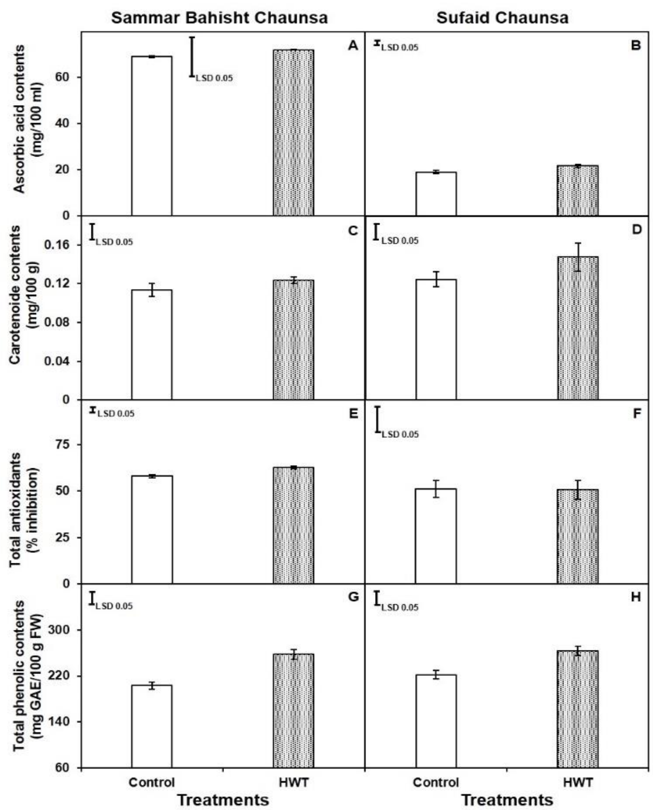


Figure 7. Effect of postharvest hot water quarantine treatment on ascorbic acid contents (A and B), carotenoids contents (C and D), total antioxidants (E and F) and total phenolic contents (G and H) of 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruit respectively. Vertical bars represent ± standard error of the means, invisible bars depicted smaller values difference. n=3 replications.

However, fruit of mango cv. 'Sufaid Chaunsa' responded differently and showed lower ascorbic acid content than 'Sammar Bahisht Chaunsa' which might be due genotypic difference between cultivars. Overall, ascorbic acid content was found to be increased slightly (1.14-fold) in HWT-treated fruits in contrast with control fruit (Fig. 7B). Fruits and vegetables are rich source of ascorbic acid content which is one of the non-enzymatic antioxidants providing help to combat against reactive oxygen species (ROS) produced during postharvest storage (Lee and Kader, 2000; Zhang *et al.*, 2019) Furthermore, different studies reported that generally heat treatments did not affect ascorbic acid content of fruits but slightly maintained irrespective of decline during storage (Djioua *et al.*, 2009; Jabbar *et al.*, 2011). A recent report revealed that hot water dipping and hot water forced convection treatments increased and maintained ascorbic acid contents of zucchini fruit during storage (Zhang *et al.*, 2019). Carotenoids contents are yellow coloured pigments which perform a key role in protection from oxidative tissue damage. In current study, application of HWT increased pulp carotenoid contents about 1.1-fold and 1.16-fold in 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruits, respectively, as compared to control (Fig. 7C-D). Changing of green colour of mango fruit is physiological phenomenon in chlorophyll degrade due to sharp rise in respiration when these fruits are exposed to heat treatments. The sharp rise in respiration rate might be due to acceleration activities of hydrolytic enzymes *i.e.* polygalacturonase and pectin methyl esterase in fruit cell wall (Jacobi *et al.*, 2001). Under temperature stress, bioactivity of carotenoids triggered in terms of oxidation, degradation and isomerization, also became predominant over xanthophylls in latter stages of mango ripening (Van den Berg *et al.*, 2000). Moreover, heat treatments significantly maintained carotenoid contents in minimally processed 'Keit' mangoes and increased in 'Sufaid Chaunsa' fruits during storage (Djioua *et al.*, 2009; Jabbar *et al.*, 2012).

***Total antioxidant and phenolic contents*:** HWT-treated 'Sammar Bahisht Chaunsa' mango fruit exhibited slightly higher (1-fold) total antioxidants as compared with non-treated control fruit (Fig. 7E). Whereas, 'Sufaid Chaunsa' fruit did not exhibit any significant change in pulp antioxidant contents (Fig. 7F). In general, total antioxidants were not affected by quarantine HWT at eating ripe stage. Our study results confirm the earlier findings of Kim et al. (2007) who reported that antioxidant capacity in 'Tommy Atkins' mango fruits was found unaffected by HWT with minor differences irrespective of substantial decline during ripening. Moreover, exposure of hot air (HA) and HWT suppressed ROS and increased antioxidant capacity of peach cv. Xiahui 5 fruits which prevents from oxidative damage (Huan *et al.*, 2017).

Irrespective of the cvs. total phenolic contents significantly ($P \leq 0.05$) increased in HWT-treated fruits in contrast with non-treated control fruits. HWT-treated 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' mango fruits exhibited higher (257.21 mg GAE/100 g FW; 263.34 mg GAE/100 g FW) TPC than non-treated control (203.34 mg GAE/100 g FW; 222.11 mg GAE/100 g FW) fruits, respectively (Fig. 7). Polyphenolic compounds are predominant antioxidants widely available as secondary metabolites. Although, previous reports on 'Tommy Atkins' mango fruits revealed heat treatments resulted non-significant influence on soluble phenolics concentrations (Kim *et al.,* 2007; Kim *et al.,* 2009) which was contradictory to our results. Increase of phenolic concentration may be due to the genotypic variation between the cultivars and attributed reduction of peroxidase and polyphenol oxidase activities. Similarly, short hot water dip enhanced phenolic contents of cucumber during low temperature storage. From our study findings, it can be hypothesized that increase of phenolic concentration possibly reduced the disease incidence in mango fruits (Fig. 3). Our hypothesis is supported by the results of Sun *et al*. (2017) who showed the positive correlation between higher phenolic contents and more disease (blue mold) resistance in wild apple accessions. Similarly, Xu *et al*. (2018) demonstrated that application of phenolic compounds can effectively reduce mycelial growth, suppressed conidial germination and manage postharvest blue mold disease of table grapes in both *in vitro* and *in vivo* conditions.

Conclusion: In this simulated study, hot water quarantine treatment protocol (48°C for 60 min) for mango export to China, maintained fruit visual and biochemical quality, reduced disease incidence, skin defects and flesh defects and displayed higher marketability index, of mango cvs. 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' as assessed after six and eight days of treatment respectively, under ambient storage (24 ± 2 °C, 80% RH) conditions. Eating quality in terms of taste and flavor was observed improved in HW treated fruits of both cultivars. Likewise, the phenolic contents were also triggered in fruits treated with quarantine hot water exposure. Hot water treatment had non-significant difference on fruit weight loss and did not have any significant negative effects on fruit quality attributes. Therefore, HWT protocol could be successfully employed for export of 'Sammar Bahisht Chaunsa' and 'Sufaid Chaunsa' cultivars to China, using air freight.

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REFERENCES

ACIAR. 2019. Mango quality assessment kit. Asia Pacific Mango Network. Australian Center for International Agriculture Research. Available at: http://www.apmangonet.org/research /mango-quality-quality-assessment-kit/

Ainsworth, E.A. and K.M. Gillespie. 2007. Estimation of total phenolic contents and other oxidation substrates in plant tissue using Folin-Ciocalteu reagent. Nat. Protoc. 2:875-877.

Ali, S., A.S. Khan, A.U. Malik and M. Shahid.2016a. Effect of controlled atmosphere storage on pericarp browning, bioactive compounds and antioxidant enzymes of litchi fruits. Food Chem. 2016:18-29.

Ali, S., A.S. Khan and A.U. Malik. 2016b. Postharvest L-cysteine application delayed pericarp browning, suppressed lipid peroxidation and maintained antioxidative activities of litchi fruit. Postharvest Biol. Technol. 121:135-142.

Amin, M., A.U. Malik, A.S. Khan and N. Javed. 2012. Potential of fungicides and plant activator for postharvest disease management in mangoes. Int. J. Agric. Biol. 13:671-676.

Amin, M., A.U. Malik, N. Din, A. Jabbar and I. Ahmad. 2007. Mango soft nose disorder and fruit quality in relation to pre and postharvest treatments. Life Sci. Int. J.1:455-462.

Anwar, R. and A.U. Malik. 2007. Hot water treatment affects ripening quality and storage life of mango (*Mangifera indica* L.). Pak. J. Agric. Sci. 44:304-311.

Brand-Williams, W., M.E. Cuvelier and C. Berset. 1995. Use of a free radical method to evaluate antioxidant activity. LWT-Food Sci. Technol. 28:25-30.

Dea, S. S, J.K. Brecht, M.C.N. Nunes, E.A. Baldwin. 2010. Quality of fresh-cut 'Kent' mango slices prepared from hot water or non-hot water-treated fruit. Postharvest Biol. and Technol. 56:171-180.

Dessalegn, Y., A. Ayalew and K. Woldetsadik. 2013. Integrating plant defense inducing chemical, inorganic salt and hot water treatments for the management of postharvest mango anthracnose. Postharvest Biol. Technol. 85:83-88.

Djioua, T., F. Charles, F. Lopez-Lauri, Filgueiras, A. Coudret, M.F. Jr, M. Ducamp-Collind and H. Sallanon. 2009. Improving the storage of minimally processed mangoes (*Mangifera indica* L.) by hot water treatments. Postharvest Biol. Technol. 52:221-226.

Hasan, M.U., R.N.U. Rehman, A.U. Malik, M.W. Haider, Z. Ahmed, A.S. Khan and R. Anwar. 2019a. Pre-storage application of L- arginine alleviates chilling injury and maintains postharvest quality of cucumber (*Cucumis sativus*). J. Hort. Sci. Technol. 2:102-108.

Hasan, M.U., A.U. Malik, M.S. Shah, R. Anwar, R.N.U. Rehman, M.W. Haider and M. Waqas. 2019b. Influence of hot water quarantine treatment on postharvest quality and disease incidence of mango cv. Sufaid Chaunsa. Intern. Hort. Conf., Bahauddin Zakariya University, Multan, Pakistan. Pp.119.

Holmes, R., P. Hofman and L. Barker. 2009. Mango quality assessment manual: a guide to assessing the post-harvest quality of Australian mangoes. Pp. 1-56.

Huan, C., S. Han, L. Jiang, X. An, M. Yu, Y. Xu, R. Ma and Z. Yu. 2017. Postharvest hot air and hot water treatments affect the antioxidant system in peach fruit during refrigerated storage. Postharvest Biol. Technol. 126:1-14.

Jabbar, A., A.U. Malik, M. Maqbool, M. Amin, M. Saeed and R. Hameed. 2012. Anti-sap chemicals and hot water quarantine treatment effects on storage life and fruit quality of mango cv. Samar Bahisht Chaunsa. Pak. J. Bot.44:757-764.

Jabbar, A., A.U. Malik, M. Saeed, O.H. Malik, M. Amin, A.S. Khan, I.A. Rajwana, B.A. Saleem, R. Hameed and M.S. Mazhar. 2011. Performance of hot water phytosanitary treated mangoes for intended export from Pakistan to Iran and China. Int. J. Agric. Biol. 13:645-651.

Jacobi, K.K. and J.E. Giles. 1997. Quality of 'Kensington' mango (*Mangifera indica* L.) fruit following combined vapour heat disinfestation and hot water disease control treatments. Postharvest Biol. Technol. 12:285-292.

Jacobi, K.K., E.A. Macrae and S.E. Hetherington. 2001. Postharvest heat disinfestation treatments of mango fruit. Sci. Hortic. 89:171-193.

Jacobi, K.K., L.S. Wong and J.E. Giles. 1995. Effect of fruit maturity on quality and physiology of high humidity hot air treated 'Kensington' mango (*Mangifera indica* L.). Postharvest Biol. Technol. 5:149-159.

Kader, A.A., W.J. Lipton and L.L. Morris. 1973. Systems of scoring quality of harvested lettuce. Hort. Sci. 8:408-409.

Khan, A.S., S. Ali and I.A. Khan. 2015. Morphological and molecular characterization and evaluation of mango germplasm: An overview. Sci.Hortic.194:353-366.

Kim, Y., J. Angela, B. Lounds-Singleton and S.T. Talcot. 2009. Antioxidant phytochemical and quality changes associated with hot water immersion treatment of mangoes (*Mangifera indica* L.). Food Chem. 115:989-993.

Kim, Y., J.K. Brecht and S.T. Talcott. 2007. Antioxidant phytochemical and fruit quality changes in mango (*Mangifera indica* L.) following hot water immersion and controlled atmosphere storage. Food Chem. 105:1327-1334.

Lamikanra, O., K. Bett-garber, D. Ingram and M. Watson. 2005. Use of mild heat pretreatment for quality retention of fresh-cut cantaloupe melon. J. Food Sci. 70:53-57.

Lawson, T., W.L. Grantley, A. Asgar and F.C. Chiew. 2019. Characterization of Southeast Asia mangoes (*Mangifera indica* L) according to their physicochemical attributes. Sci.Hortic.243:189-196.

Lee, S.K. and A.A. Kader. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol. 20:207-220.

Lurie, S. 1998. Review-postharvest heat treatments. Postharvest Biol. Technol. 14:257-269.

Malik, A.U. and M.U. Hasan. 2019. Road testing the mango quality manual in Pakistan-A case study of enhancing mango fruit quality in Asian mango chains. Australian Centre for International Agricultural Research. Available at: www.apmangonet.org/research/mango-quality-quality-kit-study-pakistan/ (Assessed: December 01, 2019).

Nagata, M. and I. Yamashita. 1992. Simple method for simultaneously determination of chlorophyll and carotenoids in tomato fruit. J. Japan. Soc. Food. Sci. Technol. 39:925-928.

Nasef, I.N. 2018. Short hot water as safe treatment induces chilling tolerance and antioxidant enzymes, prevents decay and maintains quality of cold-stored cucumbers. Postharvest Biol. Technol. 138:1-10.

Ntsoane, M.L., Z.S. Manuela, M. Pramod and S. Dharini. 2019. Quality assessment and postharvest technology of mango: A review of its current status and future perspectives. Sci. Hortic. 249:77-85.

Paull, R.E. and N.J. Chen. 1990. Heat shock response in field grown ripening papaya fruit. J. Am. Soc. Hort. Sci. 115:623-631.

Paull, R.E. and N.J. Chen. 2000. Heat treatment and fruit ripening. Postharvest Biol. Technol. 21:21-37.

Perini, M.A., I.N. Sin, A.M. Reyes-Jara, M.E. G. Lobato, P.M. Civelloand and G.A. Martínez. 2017. Hot water treatments performed in the base of the broccoli stem reduce postharvest senescence of broccoli (*Brassica oleracea* L. Varitalica) heads stored at 20°C. LWT- Food Sci. Technol. 77:314-322.

Peryam, D.R. and E.J. Pilgrim. 1957. Hedonic scale method for measuring food preferences. Food Technol. 11:9-15.

Razzaq, K., A.S. Khan, A.U. Malik, M. Shahid and S. Ullah. 2015. Effect of oxalic acid application on Samar Bahisht Chaunsa mango during ripening and postharvest. LWT - Food Sci. Technol. 63:152-160.

Rodov, V., R.D.L. Asuncion, J. Perzelan, T. Koltai and S. Ben-Yehoshua. 2001. Testing perforated heat-shrinkable films and carbon dioxide absorbers for packaging of 'Tommy Atkins' mango. Adv. Hort. Sci. 17:127-134.

Singh, S.P. and M.K. Saini. 2014. Postharvest vapour heat treatment as a phytosanitary measure influences the aroma volatiles profile of mango fruit. Food Chem. 167:387-395.

Sivakumar, D., Y. Jiang and E.M. Yahia. 2011. Maintaining mango (*Mangifera indica* L.) fruit quality during the export chain. Food Res. Int. 44:1254-1263.

Sripong, K., P. Jitareerat, S. Tsuyumu, A. Uthairatanakij, V. Srilaong, C. Wongs-Aree, G. Ma, L. Zhang and M. Kato. 2015. Combined treatment with hot water and UV-C elicits disease resistance against anthracnose and improves the quality of harvested mangoes. Crop Protec. 77:1-8.

Sun, J.W.J., Janisiewicz, B. Nichols, W.M. Jurick-II and P. Chen. 2017. Composition of phenolic compounds in wild apple with multiple resistance mechanisms against postharvest blue mold decay. Postharvest Biol. Technol. 127:68-75.

Terao, D., K.D.L. Nechet, R.T.S. Frighetto and F.F.C. Sasaki. 2019. Ozonated water combined with heat treatment to control the stem-end rot of papaya. Sci. Hortic. 257:1-8.

Van den Berg, H., R. Faulks, H.F. Granado, J. Hirschberg, B. Olmedilla, G. Sandmann, S. Southon and W. Stahl. 2000. The potential for the improvement of carotenoid levels in foods and the likely systemic effects. J. Sci. Food Agric. 80:880-912.

Vilaplana, R., G. Hurtado and S. Valencia-Chamorro. 2018. Hot water dips elicit disease resistance against anthracnose caused by *Colletotrichum musae* in organic bananas (*Musa acuminata*). LWT - Food Sci. Technol. 95:247-254.

Wang, C.Y. 1998. Heat treatment affects postharvest quality of kale and collard, but not of brussels sprouts. Hort. Sci. 33:881-883.

Wang, Q., X. Nie and M. Cantwell. 2014. Hot water and ethanol treatments can effectively inhibit the discoloration of fresh-cut sunchoke (*Helianthus tuberosus* L.) tubers. Postharvest Biol. Technol. 94:49-57.

Xu, D., Y. Deng, T. Han, L. Jiang, P. Xi, Q. Wang, Z. Jiang and L. Gao. 2018. In vitro and in vivo effectiveness of phenolic compounds for the control of postharvest gray mold of table grapes. Postharvest Biol. Technol. 139:106-114.

Zhang, M., W. Liu, C. Li, T. Shao, X. Jiang, H. Zhao and W. Ai. 2019. Postharvest hot water dipping and hot water forced convection treatments alleviate chilling injury for zucchini fruit during cold storage. Sci. Hortic. 249: 219-227.

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