# Impact of Postharvest Disease Control Methods and Cold Storage on Volatiles, Color Development and Fruit Quality in Ripe 'Kensington Pride' Mangoes

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Postharvest diseases of mango fruit (*Mangifera indica* L.) cause economic losses during storage and can be controlled by chemical, physical, or biological methods. This study investigated the effects of different physical and/or chemical disease control methods on production of volatiles, color development and other quality parameters in ripe 'Kensington Pride' mango fruit. Hard mature green mango fruit were harvested from an orchard located at Carnavon, Western Australia. The fruit were heat-conditioned (8 h at 40 $\pm$ 0.5 °C and 83.5 $\pm$ 0.5% RH), dipped in hot water (52 °C/10 min), dipped in prochloraz (Sportak 0.55 mL·L$^{-1}$/5 min), dipped in hot prochloraz (Sportak 0.55 mL·L$^{-1}$ at 52 °C/5 min), dipped in carbendazim (Spin Flo 2 mL·L$^{-1}$/5 min), and dipped in hot carbendazim (Spin Flo 2 mL·L$^{-1}$ at 52 °C/5 min). Nontreated fruit served as control. Following the treatments, the fruit were air-dried and kept in cold storage (13 $\pm$ 0.5 °C) for three weeks before being ripened at 21 $\pm$ 1 °C. The ripe pulp of the fruit that was treated with hot prochloraz or carbendazim at ambient and high temperatures showed enhanced concentrations of volatiles, while heat conditioning and hot water dipping did not significantly affect the volatile development. Ripening time, and color development were measured daily while disease incidence and severity, weight loss, firmness, and concentrations of soluble solids, titratable acidity, ascorbic acid, total carotenoids, and volatiles were determined at the eating soft ripe stage. Hot water dipping or fungicide treatments (at ambient or at a high temperature) reduced postharvest diseases incidence and severity. Fruit quality (soluble solids concentration, titratable acidity, ascorbic acid and total caretonoids) was not substantially affected by any of the treatments.

**KEYWORDS:** *Mangifera indica* **L. volatiles; fruit quality; fungicides; heat treatment**

## INTRODUCTION

Postharvest fungal diseases of mango fruit such as anthracnose (*Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc.) and stem-end rot (*Dothiorella dominicana* Petrak and Cif. and *Lasiodiplodia theobromae* Griff. and Maubl.) cause substantial economic losses during storage (*1*). Long-term storage under high humidity at low temperature in combination with the senescence of the fruit offers congenial conditions for development of these diseases. Control of these fungal diseases is prerequisite to extending the storage life and marketing period of mango fruit in both domestic and export markets.

Methods for controlling postharvest fungal diseases of fresh fruit vary and depend on the requirements of target markets. Heat treatment, as a physical disease control method, offers an attractive alternative to the use of fungicides, but it requires a strict sanitary maintenance after treatment to avoid reinfection (*2*). This method is more suitable for tropical fruit such as mango which has a high thermal tolerance. However, vapor heat treatment recommended for insect disinfestations could not control the two aforementioned posharvest fungal diseases of mango fruit (*3*) because the fungal pathogens are present on the fruit surface or just under the fruit skin, hence requiring exposure of fruit to higher temperature and shorter times (*4, 5*). The application of fungicide(s) is an effective method to control these diseases but is not preferred by consumers in some markets (*1*). Hot fungicide dip treatment, which combines chemical and heat treatments, has been reported to more effective in controlling mango postharvest diseases than fungicide dipping without heat (*6*).

Some research work has been reported on the effects of postharvest heat treatments on production of aroma volatiles in different fruits. Fallik et al. (*7*) reported that heat treatment (38 °C for 4 days) before storing 'Golden Delicious' apples at 1 °C

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temporarily inhibited the emission of esters and total aroma volatiles within the first day of treatment, but the effect was reversible because the fruit recovered and developed better total aroma volatiles during the rest of the treatment period as well as after storage. Heat treatment of 'McIntosh', 'Cortland', 'Jonagold', and 'Northern Spy' apples (46 °C for 4−12 h) resulted in increased emission of ethanol and ethyl acetate (170- and 11-fold, respectively) (8). Postharvest high temperature forced-air treatment (47.2 °C core temperature for 2 min) of 'Navel' and 'Valencia' oranges resulted in a reduction in the concentration of limonene, α-pinene, β-myrcene, and limonene (40, 60, 58, and 34%, respectively) during five hours of heat treatment (9). Postharvest heat treatment (45 and 48 °C) of tomato fruit showed reduced concentrations of some aldehydes such as hexanal, *cis*-3-hexenal, and *trans*-2-hexenal (10, 11).

To the best of our knowledge, no research work has been reported on influences of postharvest disease control methods using fungicides, heat treatments, alone or in combination, on volatiles of ripe mango fruit. The objective of the present research work was to investigate the influences of different postharvest disease control methods such as heat treatments and fungicide application, alone or in combination, on volatile production, color development, and fruit quality in 'Kensington Pride' mango fruit.

## MATERIALS AND METHODS

**Fruit.** Hard mature green mango fruit (respiration rate 1.18 ± 0.03 mmol $CO_2 \cdot kg^{-1} \cdot h^{-1}$, firmness 127.2 ± 0.3 N) as described by O'Hare (12) were harvested from a commercial orchard located at Carnavon, Western Australia (lat. 31°25′S, long. 113°39′E), desapped, air-dried, and transported in soft-board trays by a refrigerated truck (13 °C) to Perth, Western Australia. Uniform size fruit, free from any blemish and visual symptoms of diseases, were used for the experiments.

**Treatments.** Mango fruit were treated with heat conditioning (40 ± 0.5 °C for 8 h), hot water dip (52 °C for 10 min), ambient prochloraz dip (Sportak 0.55 $mL \cdot L^{-1}$ for 5 min), hot prochloraz dip (Sportak 0.55 $mL \cdot L^{-1}$ at 52 °C for 5 min), ambient carbendazim (Spin Flo 2 $mL \cdot L^{-1}$ for 5 min), or hot carbendazim dip (Spin Flo 2 $mL \cdot L^{-1}$ at 52 °C for 5 min). Following the treatments, fruit were air-dried at room temperature, packed in soft-board trays, and kept in cold storage (13 ± 0.5 °C and 85 ± 3% RH) for three weeks before being ripened at 21 ± 1 °C and 57.2 ± 12.1% RH until the eating soft stage as described by Shorter and Joyce (13). Untreated fruit were used as the control treatment. The experiment was laid out by following a completely randomized design. Ten fruit were used as an experimental unit and replicated thrice. In the heat conditioning treatment, fruit were heated at 40 ± 0.5 °C (fruit core temperature) and 83.5 ± 0.5% RH for eight hours using a chamber whose temperature and humidity were controlled using Genesis Digital Controller (DDC) Monitoring and Supervision (Innotech Control System Australia Pty Ltd., Brisbane, Australia). For hot water treatment, fruit were dipped for 10 min in a 52 °C water bath fitted with a heating element and an electronic recirculation pump (Haake DC 10, Haake, Karlsruhe, Germany). After the treatment, fruit were immediately cooled under running tap water for 10 min and then allowed to air-dry at room temperature. Sportak is a member of the imidazole group of fungicides while Spin Flo is a systemic fungicide and belongs to benzimidazole fungicide group. In fungicide treatments, fruit were dipped in fungicide emulsions at specified concentrations as mentioned above for 5 min. Tween 20 (0.01%) was used as a surfactant. In the case of hot fungicide dips, the fungicide emulsions were heated in a water bath to 52 °C before dipping mango fruit for 5 min.

**Chemicals.** Sportak (prochloraz 450 $g \cdot L^{-1}$ as an active ingredient) and Spin Flo (carbendazim 500 $g \cdot L^{-1}$ as an active ingredient) were obtained as gift samples from Bayer CropScience Pty Ltd. (Pinkenba, Queensland, Australia). Tween 20 and other chemicals for fruit quality were purchased from Sigma (Sigma-Aldrich, Castle Hill, N.S.W., Australia). Volatile standards, including α-pinene, β-pinene, myrcene, car-2-ene, α-phellandrene, car-3-ene, α-terpinene, *p*-cymene, limonene,

**Table 1.** Retention Indexes and Identification Mode of Volatile Compounds Identified from Ripe Pulp of 'Kensington Pride' Mango

| volatile compound | retention index | identification mode |
|---|---|---|
| ethanol | 3.25 min[a] | RT, CO |
| ethyl acetate | 610 | RI, CO |
| hexanal | 797 | RI, MS |
| ethyl butyrate | 799 | RI, CO, MS |
| *cis*-2-hexenal | 840 | MS, RI |
| *trans*-2-hexenal | 852 | MS |
| *cis*-3-hexenol | 855 | MS |
| 1-hexenol | 868 | MS |
| styrene | 891 | MS, RI |
| heptanal | 901 | MS |
| α-pinene | 935 | RI, CO, MS |
| α-fenchene | 949 | MS |
| camphene | 951 | MS |
| β-pinene | 979 | RI, CO, MS |
| myrcene | 991 | RI, CO, MS |
| car-2-ene | 1002 | RI, CO, MS |
| α-phellandrene | 1006 | RI, CO, MS |
| δ-car-3-ene | 1013 | RI, CO, MS |
| α-terpinene | 1019 | RI, CO, MS |
| *p*-cymene | 1027 | RI, CO, MS |
| limonene | 1031 | RI, CO, MS |
| β-phellandrene | 1032 | RI, MS |
| *cis*-ocimene | 1039 | RI, CO, MS |
| *trans*-β-ocimene | 1049 | RI, MS |
| γ-terpinene | 1061 | RI, CO, MS |
| α-terpinolene | 1095 | RI, CO, MS |
| nonanal | 1104 | RI, MS |
| p-mentha-1,5,8-triene | 1115 | RI, MS |
| (2-methylprop-l-enyl)-cyclohexa-1,5-diene | 1140 | RI, MS |
| *trans*-2-nonenal | 1161 | RI, MS |
| 1,8-menthadien-4-ol | 1181 | MS |
| *p*-cymen-8-ol | 1188 | MS |
| decanal | 1206 | RI, MS |
| γ-octalactone | 1261 | RI, CO, MS |
| α-copaene | 1386 | RI, CO, MS |
| β-elemene | 1401 | MS |
| α-gurjunene | 1423 | RI, CO, MS |
| *trans*-caryophyllene | 1434 | RI, CO, MS |
| geranylacetone | 1453 | RI, CO, MS |
| aromadendrene | 1455 | RI, CO, MS |
| α-humulene | 1468 | RI, CO, MS |
| γ-decalactone | 1473 | MS |
| *allo*-aromadendrene | 1475 | RI, CO, MS |
| γ-gurjunene | 1485 | RI, CO, MS |
| β-ionone | 1494 | RI, CO, MS |
| δ-decalactone | 1503 | RI, MS |
| ledene | 1508 | RI, CO, MS |
| δ-cadinene | 1534 | MS |
| γ-dodecalactone | 1685 | RI, MS |
| methyl myristate | 1725 | RI, CO, MS |
| hexadecanal | 1818 | MS |
| methyl palmitate | 1928 | RI, MS |

[a] Retention time (RT) on HP-5MS. RI: Retention index on HP-5MS. CO: co-injection. MS: mass spectrometry.

γ-terpinene, α-terpinolene, L-linalool, α-terpineol, decanal, benzothiazole, decanol, decanoic acid, α-copaene, tetradecanal, α-gurjunene, *trans*-caryophyllene, aromadendrene, α-humulene, alloaromadendrene, γ-gurjunene, β-ionone, ledene, ethyl dodecanoate, methyl tetradecanoate, tetradecanoic acid, acetic acid, isobutyl acetate, ethyl butyrate, ethyl hexanoate, ethyl *n*-heptanoate, methyl octanoate, ethyl-2-octenoate and ethyl octanoate were obtained from Sigma (Sigma-Aldrich, Castle Hill, NSW, Australia), while γ-dodecalactone was purchased from Bronson and Jacobs (Homebush Bay, NSW, Australia).

**Volatiles.** Volatiles were determined from the pooled pulp of ripe fruit free from disease of each experimental unit (8−10 fruit per replication) destructively assessed when it reached the eating soft stage by following the method of Dang et al. (14). HS-SPME was used for extracting free volatile compounds from pulp. Frozen mango pulp (10 g) was thawed and homogenized with 35 mL of saturated NaCl solution. The homogenate (7 mL) was then transferred into an airtight 15-mL
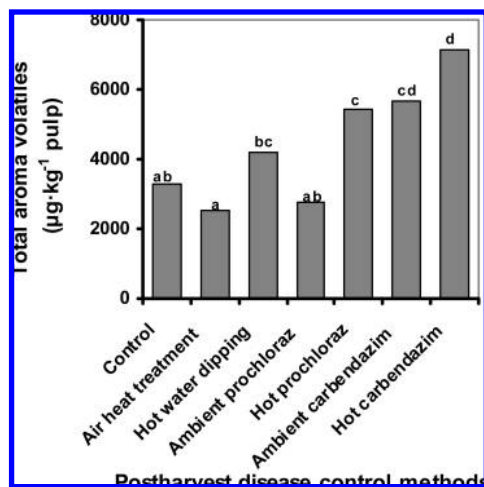
**Figure 1.** Concentrations of total volatiles in the pulp of the ripe mango fruit influenced by various postharvest disease control methods and three weeks of cold storage (13 °C). $N = 3$ replications. LSD ($P \leqslant 0.05$) = 1506.0.

vial together with 1 $\mu$L of the ISTD mixture (methyl hexanoate, tridecane, and hexadecane at a concentration of 20, 20, and 10 $\mu$g·mL$^{-1}$, respectively) for volatile extraction. The extraction temperature and duration were 50 °C and 30 min, respectively. Volatile compounds already adsorbed onto the SPME fiber (100 $\mu$m polydimethylsiloxane, Supelco-Sigma Aldrich, Castle Hill, NSW, Australia) were then thermally desorbed in a splitless injector of a GC−FID or GC−MS for 30 min. Each sample was tested twice.

A GC−FID (Agilent Technologies, 6890N Network GC system, Palo Alto, CA) was used for identification and quantification of volatile compounds from pulp of mango fruit. Oven temperature was maintained at 40 °C for 5 min then ramped at 3 °C per min to 220 °C followed by 2 °C per min to 240 °C and kept for 10 min. Separation was achieved on a capillary column (HP-5MS, 50 m × 0.2 mm i.d. × 0.33 $\mu$m, Agilent Technologies, Palo Alto, CA). Detector and injector temperatures were 290 and 240 °C, respectively. Hydrogen was used as a carrier gas (1 mL·min$^{-1}$). Volatile compounds were identified by comparing their retention index (RI) with those of authentic compounds and those reported in the literature. The RI was calculated using the formula of Van Den Dool (*15*). A list of volatile compounds identified in 'Kensington Pride' mango fruit pulp is shown in **Table 1**.

All tentative volatile compounds were confirmed using GC−mass spectrometry (MS). A MS (MS, Hewlett-Packard 5890 series II) was interfaced with an Agilent 6890 GC which was equipped with a capillary ZB-1 100% methyl polysiloxane (60 m × 0.25 mm i.d. × 0.25 $\mu$m, Phenomenex, NSW, Australia). Helium was a carrier gas at 1.1 mL·min$^{-1}$. Injector temperature was 240 °C. Oven temperature was maintained at 40 °C for 5 min and then increased to 240 at 5 °C per min and held for 10 min. Mass spectra were scanned at 70 eV and matched with the standards in an electronic WILEY275.L library (http://wwww.wiley.com/WileyCDA/WileyTitle/productCD-0471440973.html) for the identification.

Volatile compounds were quantified using external standards (ESTDs) for compounds whose reference standards were available after correcting with ISTDs. The remaining compounds were quantified using ISTDs. Methyl hexanoate was an ISTD for alcohols, esters, aldehydes, and ketones/lactones; tridecane was used as an ISTD for monoterpenes and other hydrocarbons with 13 or fewer carbon atoms while hexadecane was used for sesquiterpenes and hydrocarbon with more than 13 carbon atoms. Diethyl ether was used as a solvent for all standards. The concentration of volatiles was expressed as $\mu$g·kg$^{-1}$ pulp.

**Measurement of Fruit Color Development.** Color of individual fruit skin was recorded daily during ripening period using both visual and the objective fruit color as described by Dang et al. (*14*).
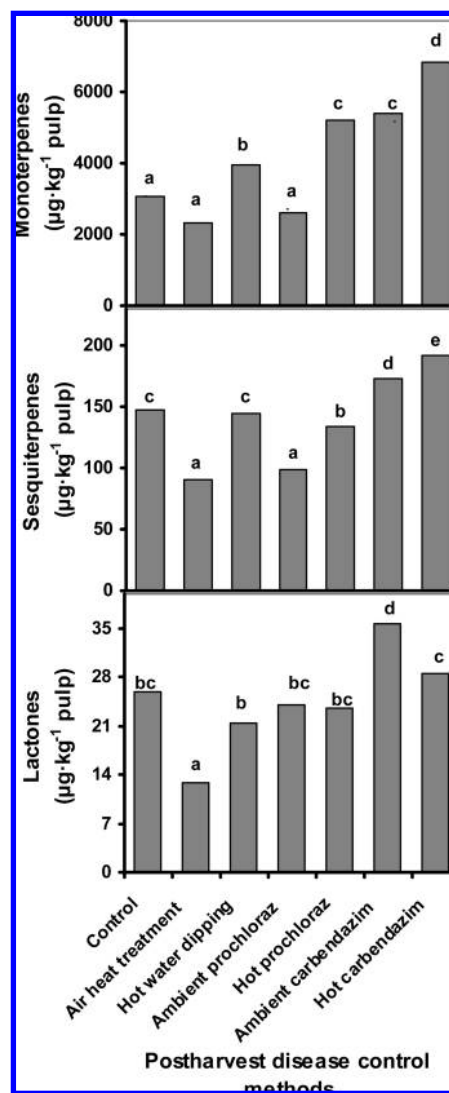


**Figure 2.** Concentrations of total monoterpenes, sesquiterpenes and lactones in the pulp of the ripe mango fruit influenced by various postharvest disease control methods and three weeks of cold storage (13 °C). $n = 3$ replications. LSD ($P \leqslant 0.05$): monoterpenes = 1483.20; sesquiterpenes = 37.23; lactones = 5.73.

**Ripening Time, Weight Loss (WL) and Disease Incidence and Severity.** Ripening time was calculated as the number of days after removal from cold storage until the fruit reached the eating soft stage (hand firmness rating 4 and/or more than 75% yellow skin color development). WL was determined at the end of cold storage time and during ripening period and expressed as percent. Disease infection was assessed from individual fruit at the eating soft stage and expressed as percent incidence and severity by following the method of Jacobi et al. (*16*).

**Soluble Solids Concentration (SSC), Titratable Acidity (TA), Ascorbic Acid and Total Carotenoids.** SSC, TA, ascorbic acid and carotenoids were estimated from each treatment destructively when it reached the eating soft ripe stage explained by Malik et al. (*17*).

**Statistical Analysis.** Effects of different postharvest disease control methods on various fruit ripening and quality parameters were assessed within the ANOVA using Genstat 9, release 9.1.0.147 (Lawes Agricultural Trust, Rothamsted Experimental Station, Rothamsted, U.K.). Least significant difference (Fisher's protected LSD) was calculated at $P \leqslant 0.05$ following a significant $F$ test. Statistical analysis for data of daily observation was conducted as two-way ANOVA (postharvest disease control methods and ripening time). The validity of analysis was ensured by checking all the assumptions of analysis.

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**Table 2.** Effects of Different Postharvest Disease Control Methods on the Concentrations (Micrograms per Kilogram of Pulp) of Monoterpenes in Pulp of the Ripe Mango Fruit Following Three Weeks Cold Storage (13°C)[a]

| compound | control | heat conditioning | hot water dip | prochloraz | hot prochloraz | carbendazim | hot carbendazim | LSD ($P \leqslant 0.05$) |
|---|---|---|---|---|---|---|---|---|
| α-pinene | 55.88ab | 39.23a | 69.16b | 46.83ab | 103.37c | 94.89c | 130.63d | 24.54 |
| α-fenchene | 0.26ab | 0.19a | 0.33bc | 0.24ab | 0.48d | 0.46cd | 0.62e | 0.13 |
| camphene | 0.18a | 0.17a | 0.21ab | 0.15a | 0.29b | 0.29b | 0.43b | 0.09 |
| β-pinene | 2.55ab | 1.87a | 2.84abc | 2.21a | 3.61c | 3.59c | 5.10d | 1.05 |
| myrcene | 64.02a | 50.00a | 79.35ab | 54.37a | 110.79c | 106.09bc | 152.57d | 30.10 |
| car-2-ene | 13.10ab | 10.11a | 16.47bc | 11.26ab | 23.22d | 22.01cd | 30.36e | 5.94 |
| α-phellandrene | 21.21ab | 16.41a | 27.13bc | 17.85ab | 37.30c | 35.91c | 50.59d | 10.25 |
| δ-car-3-ene | 169.37ab | 164.44a | 264.86bc | 184.25ab | 372.51d | 351.38cd | 481.97e | 95.6 |
| α-terpinene | 108.04ab | 81.35a | 138.52bc | 91.67ab | 189.85c | 186.49c | 260.34d | 55.03 |
| limonene | 56.54ab | 41.44a | 73.55b | 46.75ab | 106.16c | 103.21c | 147.53d | 27.30 |
| β-phellandrene | 17.42ab | 13.70a | 21.99bc | 14.93ab | 26.38c | 27.64cd | 34.71d | 7.23 |
| cis-ocimene | 4.54ab | 3.65a | 5.55bc | 3.91ab | 7.56c | 7.33cd | 10.33e | 1.80 |
| trans-β-ocimene | 1.99a | 1.65a | 2.58ab | 1.92a | 3.59b | 3.46b | 4.86c | 1.05 |
| γ-terpinene | 10.45ab | 7.98a | 13.17bc | 8.74ab | 17.97d | 17.68cd | 24.58e | 4.69 |
| α-terpinolene | 2517.19ab | 1897.65a | 3220.32bc | 2093.01ab | 4199.62c | 4411.29cd | 5493.99d | 1245.70 |
| p-mentha-1,5,8-triene | 2.38ab | 1.92a | 2.54ab | 2.05a | 3.19bc | 3.67c | 3.28bc | 0.96 |
| (2-methylprop-l-enyl)-cyclohexa-1,5-diene | 2.28ab | 1.82a | 2.41abc | 1.95a | 3.07bcd | 3.57d | 3.14cd | 0.82 |
| 1,8-menthadien-4-ol | 1.69abc | 1.29ab | 1.61abc | 1.03a | 1.96bc | 1.98c | 2.96d | 0.67 |
| geranylacetone | 0.80 | 0.74 | 0.79 | 0.75 | 0.76 | 0.81 | 0.81 | ns (0.03) |

[a] $n = 3$ replications (each replication contained pulp pooled from 8−10 mangoes, and each replication tested twice). ns = not significant at $P \leqslant 0.05$. Value within the brackets represents SED. Any two means in the same row followed by the same letter are not significantly different.

**Table 3.** Effects of Different Postharvest Disease Control Methods on the Concentrations (Micrograms per Kilogram of Pulp) of Sesquiterpenes in Pulp of the Ripe Mango Fruit Following Three Weeks Cold Storage (13°C)[a]

| compound | control | heat conditioning | hot water dipping | prochloraz | hot prochloraz | carbendazim | hot carbendazim | LSD ($P \leqslant 0.05$) |
|---|---|---|---|---|---|---|---|---|
| α-copaene | 7.57ab | 6.53a | 9.04bc | 6.84ab | 7.67ab | 10.54c | 8.47abc | 2.29 |
| β-elemene | 0.96c | 0.23a | 0.82c | 0.46ab | 0.86c | 0.75bc | 1.67d | 0.31 |
| α-gurjunene | 32.63cd | 17.34a | 27.95bc | 20.88ab | 21.95ab | 32.33cd | 38.41d | 8.79 |
| trans-caryophyllene | 52.53b | 32.58a | 53.96b | 33.93a | 54.30b | 66.36bc | 74.09c | 14.15 |
| aromadendrene | 1.38 | 1.39 | 1.44 | 1.47 | 1.22 | 1.70 | 1.36 | ns (0.13) |
| α-humulene | 33.86bc | 23.26a | 35.28c | 23.69ab | 35.69c | 42.34cd | 46.76d | 10.23 |
| allo-aromadendrene | 2.96bc | 1.20a | 2.70abc | 2.18a | 2.29ab | 2.99bc | 3.33c | 0.77 |
| γ-gurjunene | 3.90bc | 2.42a | 3.48abc | 2.75a | 2.87ab | 3.88bc | 4.43c | 1.09 |
| ledene | 8.36cd | 3.38a | 6.99bc | 4.47a | 5.22ab | 8.57cd | 10.42d | 2.23 |
| δ-cadinene | 2.87bc | 1.34a | 2.89bc | 1.65a | 2.19ab | 3.82d | 3.53cd | 0.87 |

[a] $n = 3$ replications (each replication contained pulp pooled from 8−10 mangoes, and each replication tested twice). ns = not significant at $P \leqslant 0.05$. Value within the brackets represents SED. Any two means in the same row followed by the same letter are not significantly different.

## RESULTS

**Total Volatiles.** Hot prochloraz and ambient as well as hot carbendazim resulted in higher concentrations of total volatiles in the pulp of the ripe fruit (**Figure 1**). Hot carbendazim treated fruit produced the highest concentration of total volatiles (7124.26 $\mu$g·kg$^{-1}$ pulp). In comparison to the control, heat conditioning, hot water dipping and ambient prochloraz did not significantly affect the concentrations of total volatiles.

**Monoterpenes.** The effects of various treatments on the levels of total monoterpenes showed a similar trend to those of the total volatiles (**Figure 2**). The ripe pulp of the fruit that was treated with hot carbendazim showed the highest concentration of total monoterpenes (6838.80 $\mu$g·kg$^{-1}$ pulp). Heat conditioning, hot water dipping and ambient prochloraz did not result in any significant difference in the concentrations of total monoterpenes (as well as all individual monoterpenes) as compared to the untreated fruit (**Figure 2** and **Table 2**).

Regarding individual monoterpenes, the pulp of the hot prochloraz- and both the ambient and hot carbendazim-dipped fruit showed higher concentrations of all the individual monoterpenes than the pulp of the control fruit. Hot carbendazim-dipped fruit exhibited higher concentrations of all individual monoterpenes (with exception of p-mentha-1,5,8-triene, and 2-methylprop-1-enyl-cyclohexa-1,5-diene) as compared to the

fruit from all other treatments. The pulp of the heat-conditioned fruit showed lower concentrations of most of the individual monoterpenes as compared to the pulp of the fruit treated with hot water dipping or hot fungicides.

**Sesquiterpenes.** Hot carbendazim-dipped fruit resulted in the highest levels of total sesquiterpenes (192.48 $\mu$g·kg$^{-1}$ pulp) (**Figure 2**). Heat conditioning and ambient prochloraz dip reduced total sesquiterpene concentrations (90.48 $\mu$g·kg$^{-1}$ pulp and 98.32 $\mu$g·kg$^{-1}$ pulp respectively) as compared to the untreated fruit (147.03 $\mu$g·kg$^{-1}$ pulp). Hot water dipping and hot prochloraz dip did not result in any significant difference in total sesquiterpenes as well as in individual sesquiterpenes (except α-gurjunene and ledene) as compared to the control fruit (**Figure 2** and **Table 3**).

Heat-conditioned and ambient prochloraz-dipped fruit showed lower concentrations of β-elemene, α-gurjunene, trans-caryophyllene, allo-aromadendrene, γ-gurjunene, ledene, and δ-cadinene than the pulp of the control fruit. Hot carbendazim-treated fruit showed higher concentrations of trans-caryophyllene and α-humulene, the two most quantitatively abundant sesquiterpenes, as compared to the control fruit.

**Lactones.** The ripe pulp of the ambient carbendazim-treated fruit showed the highest total lactone concentration (**Figure 2**). Heat-conditioned fruit exhibited lower total lactones than the

**Table 4.** Effects of Different Postharvest Disease Control Methods on the Concentrations (Micrograms per Kilogram of Pulp) of Lactones, Aromatics, and Alcohols in the Pulp of the Ripe Mango Fruit Following Three Weeks Cold Storage (13°C)[a]

| compound | control | heat conditioning | hot water dipping | prochloraz | hot prochloraz | carbendazim | hot carbendazim | LSD ($P \leqslant 0.05$) |
|---|---|---|---|---|---|---|---|---|
| **lactones** | | | | | | | | |
| $\gamma$-octalactone | 8.02c | 3.57a | 5.41ab | 9.78cd | 7.47bc | 11.44d | 9.51cd | 2.41 |
| $\gamma$-decalactone | 7.40b | 4.38a | 6.53ab | 7.97b | 8.02b | 11.66c | 6.38ab | 2.41 |
| $\delta$-decalactone | 8.77cde | 3.55a | 7.64cd | 4.74ab | 6.22bc | 9.66de | 11.04e | 2.60 |
| $\gamma$-dodecalactone | 1.72a | 1.48a | 1.73a | 1.51a | 1.88a | 2.93b | 1.60a | 0.55 |
| **aromatics** | | | | | | | | |
| $p$-cymene | 5.71a | 4.63a | 6.11a | 5.03a | 7.85b | 8.56b | 7.93b | 1.60 |
| $p$-cymen-8-ol | 3.35abcd | 2.51a | 3.11abc | 2.69ab | 3.76bcd | 4.28d | 4.11cd | 1.08 |
| total | 9.06ab | 7.13a | 9.22ab | 7.71a | 11.61bc | 12.84c | 12.04c | 2.55 |
| **alcohols** | | | | | | | | |
| ethanol | 9.94b | 5.69a | 10.82b | 9.40ab | 11.23b | 17.39c | 5.58a | 3.87 |
| *cis*-3-hexenol | 10.40cd | 7.29ab | 11.64d | 7.53ab | 6.55ab | 5.04a | 7.80bc | 2.60 |
| 1-hexenol | 2.17bc | 1.35a | 2.83d | 1.53ab | 2.28cd | 2.68cd | 1.31a | 0.66 |

[a] $n = 3$ replications (each replication contained pulp pooled from 8–10 mangoes, and each replication tested twice). Any two means in the same row followed by the same letter are not significantly different.

fruit from all other treatments. Ambient carbendazim dip also resulted in higher concentrations of most of the individual lactones (except $\delta$-decalactone) as compared to the control fruit (**Table 4**). Heat-conditioned fruit showed lower concentrations of $\gamma$-octalactone and $\gamma$-decalactone, and $\delta$-decalactone (3.57, 4.38, and 3.55 $\mu$g·kg$^{-1}$ pulp, respectively) as compared to the control fruit (8.02, 6.59, and 8.77 $\mu$g·kg$^{-1}$ pulp respectively). Hot water-dipped fruit showed a lower concentration of $\gamma$-octalactone (3.57 $\mu$g·kg$^{-1}$ pulp) as compared to the control fruit.

**Aromatics and Alcohols.** The ripe pulp of the disease control-treated fruit showed significant differences in the concentrations of aromatic compounds (**Table 4**). Fruit from both ambient and hot carbendazim dips exhibited higher levels of total aromatics (12.84 and 12.04 $\mu$g·kg$^{-1}$ pulp for carbendazim dips at ambient and hot temperature, respectively) as compared to the fruit from all other treatments (except hot prochloraz dip). None of the treatments affected the concentration of $p$-cymen-8-ol in the pulp of the ripe fruit.

Heat-conditioned and hot carbendazim-dipped fruit showed lower concentrations of total alcohols than the untreated fruit (14.34, 14.69, and 22.50 $\mu$g·kg$^{-1}$ pulp, respectively) (**Figure 3**). Compared to the control, heat-conditioned fruit exhibited lower concentrations of all three alcohols namely ethanol, *cis*-3-hexanol and 1-hexenol. Hot carbendazim-dipped fruit showed lower concentrations of ethanol and 1-hexenol compared to the control fruit (**Table 4**). However, the ripe pulp of the fruit treated with ambient carbendazim dip showed the highest concentration of ethanol (17.39 $\mu$g·kg$^{-1}$ pulp).

**Aldehydes, Esters, and Norisoprenoids.** Ambient carbendazim-treated fruit resulted in higher levels of total aldehydes (**Figure 3**). There were no significant differences in the concentrations of *trans*-2-nonenal in the pulp of the ripe fruit among the treatments (**Table 5**). Prochloraz and carbendazim dips at ambient temperature resulted in higher concentrations of *trans*-2-hexenal (5.88 and 5.60 $\mu$g·kg$^{-1}$ pulp, respectively) compared to the untreated fruit (5.09 $\mu$g·kg$^{-1}$ pulp), whereas heat-conditioned fruit exhibited lower concentration of this compound (3.13 $\mu$g·kg$^{-1}$ pulp). Hexanal and *trans*-2-hexenal concentrations in the pulp of the ripe fruit were found to be lower in the hot carbendazim-treated fruit as compared to the control (**Table 5**).

Both prochloraz and carbendazim dips at ambient temperature resulted in higher concentrations of total esters (5.81 and 8.86 $\mu$g·kg$^{-1}$ pulp, respectively) than the untreated fruit (4.17
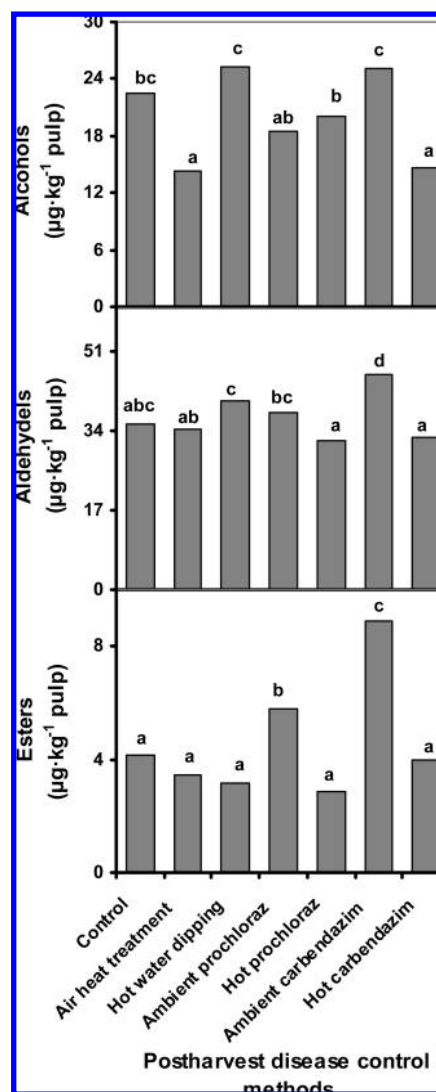


**Figure 3.** Concentrations of total alcohols, aldehydes, and esters in the pulp of the ripe mango fruit influenced by various postharvest disease control methods and three weeks of cold storage (13 °C). $n = 3$ replications. LSD ($P \leqslant 0.05$): alcohols = 4.35; aldehydes = 5.20; esters = 1.56.

$\mu$g·kg$^{-1}$ pulp) (**Figure 3**). The concentrations of methyl myristate was highest in the carbendazim-dipped fruit (1.67 $\mu$g·kg$^{-1}$ pulp) while heat-conditioned, hot water-dipped, and

**Table 5.** Effects of Different Postharvest Disease Control Methods on the Concentrations (Micrograms per Kilogram of Pulp) of Aldehydes, Esters, and Norisoprenoid in Pulp of the Ripe Mango Fruit Following Three Weeks Cold Storage (13°C)[a]

| compound | control | heat conditioning | hot water dipping | prochloraz | hot prochloraz | carbendazim | hot carbendazim | LSD ($P \leqslant 0.05$) |
|---|---|---|---|---|---|---|---|---|
| **aldehydes** | | | | | | | | |
| hexanal | 7.63bcd | 6.31abc | 9.25d | 8.17cd | 5.64ab | 6.13abc | 5.41a | 2.10 |
| *trans*-2-hexenal | 5.09bc | 3.13a | 5.29bc | 5.88d | 3.85ab | 5.60d | 3.22a | 1.55 |
| *trans*-2-nonenal | 5.54 | 4.64 | 5.50 | 5.58 | 5.36 | 6.78 | 4.81 | ns (0.75) |
| decanal | 8.01a | 12.09b | 7.93a | 8.52a | 7.37a | 7.07a | 8.13a | 2.77 |
| hexadecanal | 9.15ab | 8.03a | 12.09b | 9.58ab | 9.68ab | 20.30c | 10.81ab | 3.45 |
| **esters** | | | | | | | | |
| methyl myristate | 0.80bc | 0.38a | 0.46a | 1.07c | 0.44a | 1.67d | 0.57ab | 0.29 |
| methyl palmitate | 3.37a | 3.06a | 2.72a | 4.74b | 2.41a | 7.19c | 3.43ab | 1.34 |
| **norisoprenoid** | | | | | | | | |
| $\beta$-ionone | 1.58 | 2.00 | 1.78 | 1.65 | 1.48 | 1.78 | 1.35 | ns (0.22) |

[a] $n = 3$ replications (each replication contained pulp pooled from 8−10 mangoes, and each replication tested twice). ns = not significant at $P \leqslant 0.05$. Values within the brackets represent standard error of means. Any two means in the same row followed by the same letter are not significantly different.
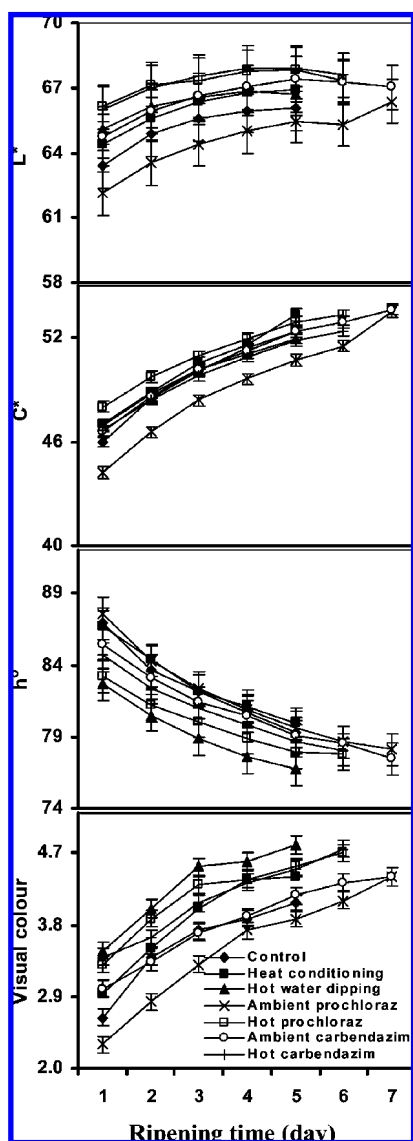


**Figure 4.** Fruit color development affected by various postharvest disease control methods (*T*) and ripening time (RT) in three weeks of cold stored fruit (13 °C). *n* = 3 replications (10 fruit per replication). Vertical bars represent standard error of means. LSD ($P \leqslant 0.05$): L*, *T* = 0.92, RT = 0.78, *T* × RT = ns (1.03); C*, *T* = 0.82, RT = 0.69, *T* × RT = ns (0.92); h°, *T* = 0.98, RT = 0.83, *T* × RT = ns (1.10); visual color, *T* = 0.29, RT = 0.25, *T* × RT = ns (0.33). ns = not significant at $P \leqslant 0.05$. Values within the brackets represent standard error of means.

hot prochloraz-dipped fruit showed reduced concentrations of this compound (0.38, 0.46, 0.44 $\mu$g·kg$^{-1}$ pulp, respectively) (**Table 5**). Methyl palmitate concentration was higher in the pulp of the ripe fruit from both fungicide dips at ambient temperature than in the control fruit.

Regarding the norisoprenoids, the various treatments did not have any significant effects on the concentration of $\beta$-ionone in the pulp of the ripe fruit (**Table 5**).

**Fruit Color Development.** Hot water-, ambient carbendazim-, hot carbendazim-, and hot prochloraz-treated fruit exhibited higher fruit lightness compared to the untreated fruit at the ripe stage (**Figure 4**). Ambient prochloraz-treated fruit showed lower mean lightness and chroma values (64.11 and 47.89, respectively) during the ripening period compared to the control fruit (65.16 and 49.67, respectively).

Hot water and hot fungicide-dipped fruit exhibited lower hue angle than the untreated fruit while heat-conditioned and both fungicide-dipped fruit at ambient temperature showed no significant difference compared to the untreated fruit.). It is generally accepted that a lower hue angle in mango fruit represents more yellow color of the fruit skin.

Fruit treated with hot water, ambient prochloraz or hot carbendazim exhibited higher visual color scores (4.28, 4.07 and 3.99, respectively) than untreated fruit (3.54).

**Ripening time, weight loss (WL) and disease incidence and severity.** All the treatments affected ripening time (**Table 6**). The ambient carbendazim-treated fruit showed delayed ripening time (7 days) compared to the fruit from the control (5.7 days).

Fruit from heat conditioning and hot carbendazim dip exhibited higher WL during the storage (6.15 and 6.69%, respectively) compared to the control fruit (4.76%) (**Table 6**). Hot carbendazim-dipped fruit also exhibited higher WL as compared to hot water (5.32%) and ambient fungicide-dipped fruit (4.64 and 5.31% for prochloraz and carbendazim-dipped fruit, respectively).

The fruit exposed to all the treatments except heat conditioning significantly reduced postharvest disease incidence and severity as compared to the untreated fruit (**Table 6**). Fruit that were heat-conditioned did not show any significant reduction in the postharvest disease incidence and severity as compared to the untreated fruit.

**SSC, TA, SSC/TA, Ascorbic Acid and Total Carotenoids.** Postharvest disease control methods employed in this study did not show any significant effects on fruit quality parameters including SSC, TA, SSC/TA, levels of ascorbic acid and total carotenoids (data not shown).

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**Table 6.** Effects of Various Postharvest Disease Control Methods on Ripening Time, Physiological Weight Loss (PWL), Total Carotenoids, and Disease Incidence in the Ripe Mango Fruit after Three Weeks at 13° C[a]

| treatment | ripening time (day) | physiological weight loss (%) | | total carotenoids (mg·kg$^{-1}$) | disease assessment (%) | |
| | | during storage | ripe | | incidence | severity |
|---|---|---|---|---|---|---|
| control | 5.7bc | 4.76c | 9.36 | 33.15 | 20.0a | 4.00a |
| heat conditioning | 4.7d | 6.15ab | 9.82 | 33.30 | 23.3a | 4.67a |
| hot water dip | 5.0cd | 5.32bc | 9.38 | 37.17 | 3.3b | 0.67b |
| prochloraz | 6.3ab | 4.64c | 9.37 | 35.76 | 6.7b | 1.33b |
| hot prochloraz | 5.7bc | 5.79abc | 10.19 | 29.92 | 3.3b | 0.67b |
| carbendazim | 7.0a | 5.31bc | 10.27 | 32.31 | 6.7b | 1.33b |
| hot carbendazim | 5.7bc | 6.69a | 11.64 | 28.04 | 6.7b | 1.33b |
| LSD ($P \leqslant 0.05$) | 0.86 | 1.23 | ns (1.36) | ns (3.34) | 11.46 | 2.29 |

[a] $n = 3$ replications (each replication contained pulp pooled from 8–10 mangoes). ns = not significant at $P \leqslant 0.05$. Values within the brackets represent SED. Any two means in the same column followed by same letter are not significantly different.

## DISCUSSION

The ripe pulp of the fruit that was treated with hot carbendazim or hot prochloraz or ambient carbendazim dip significantly increased concentrations of total volatiles, total monoterpenes, and major monoterpenes (α-terpinolene, δ-car-3-ene, α-terpinene, and myrcene) compared to the control fruit. It appears that these treatments stimulated the enhanced biosynthesis of these volatiles; however the exact mechanism of this process is not clear and warrants further investigations. In this study α-Terpinolene was found to be the most abundant volatile compound (1.89 −5.49 ppm) in 'Kensington Pride' mango (**Table 2**). Our experimental data show that δ-car-3-ene was the second major monoterpene.

The ripe pulp of the fruit that was treated with hot carbendazim showed high concentrations of two major sesquiterpenes namely *trans*-caryophyllene and α-gurjunene. This in turn contributed to higher total sesquiterpene concentrations. Heat-conditioned fruit exhibited reduced concentration of total sesquiterpenes, whereas hot water-dipped fruit did not show any difference in total sesquiterpene concentration as compared to the untreated fruit. Variable results on the influences of heat treatment on fruit volatiles have been reported in the literature. Perez et al. (*18*) found that intermittent heat treatment (38 and 20 °C) did not adversely affect the concentrations of terpene-oxidized compounds in mandarin (*Citrus reticulata* Blanco.) fruit.

Our experimental data show higher concentration of total lactones in the fruit treated with ambient carbendazim. Low concentration of lactones in the heat-conditioned fruit might be due to the combined degradative effects of high temperature and treatment duration. Lactones have been reported to derive from fatty acid metabolism (*19, 20*). The effects of heat conditioning on fatty acids in mango fruit are not well understood and warrant further investigation.

Heat conditioning accelerated fruit ripening as compared to all other treatments. This might have been due to an elevation of the respiration rate in the fruit. Ambient carbendazim dip delayed fruit ripening but the exact mechanism of this effect is unclear and has yet to be elucidated.

Hot water dipping and hot fungicide treatments improved fruit color development. Heat treatment has previously been reported to improve fruit color development in different mango cultivars (*21*). McCollum et al. (*22*) reported an enhancement in color development of 'Keitt' mango flesh heated at 38 °C for 48 h. Previous research work on heat treatment for disease control or insect disinfestations of 'Kensington Pride' mango has also been reported to improve skin color of the heated fruit (*1, 21*). This was attributed to possible accelerated degradation of chlorophyll (*21*).

Fruit quality parameters such as SSC, TA, SSC/TA, ascorbic acid and total carotenoids were not significantly affected by any of the disease control treatments. Similarly the heat treatments have been reported to show no or very little effects on fruit quality (*1, 23−25*). Hot water treatment has been reported to increase carotenoid concentration in mango fruit (*26, 27*). This was ascribed to different temperature regimes as the temperature was set somewhat lower with longer treatment duration for insect disinfestations.

In the present study hot water dipping and hot prochloraz were equally effective in controlling postharvest diseases in mango fruit (**Table 6**). The effects of hot water dipping in disease control may be ascribed to a restriction in the development of pathogens and a partial melting of cuticular wax layer which fills in microcracks and stomata and prevents the invasion of pathogens through wounded areas (*28*). No synergistic or additive effects of heat and fungicide treatments in controlling diseases were recorded as reported earlier by Schirra et al. (*28*).

The varied results in fruit ripening, color development, and volatile production as responses of the fruit to heat treatment used as postharvest disease control in the present work might be explained by the impact of methods of heat application, temperature applied, and exposure time. Lurie (*4*) reported that the response of fruit to heat treatment was a combined consequence of several factors such as preharvest conditions, fruit maturity, duration and temperature applied, and storage or ripening period following heat treatment.

In conclusion, the ripe pulp of the fruit that was treated with hot prochloraz or carbendazim at ambient and high temperatures showed enhanced concentrations of volatiles, while heat conditioning and hot water dipping did not significantly affect the volatile development. Hot water dipping or fungicide treatments (at ambient or at a high temperature) reduced postharvest diseases incidence and severity. Fruit treated with hot water, ambient prochloraz or hot carbendazim exhibited higher visual color scores than untreated fruit. Fruit quality (soluble solid concentration, titratable acidity, ascorbic acid and total carotenoids) was not substantially affected by any of the treatments.

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