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Effect of fruit maturity on quality and physiology of high-humidity hot air-treated 'Kensington' mango (*Mangifera indica* Linn.)

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Abstract

Mature and immature 'Kensington' mangoes (*Mangifera indica* Linn.) were treated with an experimental high humidity hot air treatment (HT) to a fruit core temperature of 46.5°C for 10 min for disinfestation purposes and to test for fruit injury reportedly associated with fruit immaturity. Two methods of determining fruit maturity were examined with fruit harvested over two different seasons, in order to gain a broad range of maturities. No internal or external injury was caused to fruit at any maturity stage by the treatment. Mature HT fruit softened faster and had increased skin colour development compared to immature HT fruit. HT shows commercial potential since the physiological changes associated with treatment and maturity can be managed with careful postharvest handling practices. We recommend only mature fruit be harvested and treated since quality and market performance will be maximised.

Keywords: Mango; Disinfestation; High humidity hot air treatment; Maturity; Quality

1. Introduction

The Australian mango industry has expanded rapidly in the last decade. 'Kensington' (also known as 'Kensington Pride', 'Peach', 'Bowen Special') is the main variety, and constitutes 95% of Australian commercial production. Production has increased dramatically in the last few years, and with half of the planting still in the juvenile stage (288,160 out of 589,350 trees, Australian Bureau of Statistics,

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1991–1992), the domestic market is likely to be oversupplied within the next few years. Export markets will need to be expanded to maintain industry viability.

Quarantine restrictions exist for Australian exported produce by several importing countries. For example, 'Kensington' mangoes must be disinfested against tephritid fruit flies before entry to some overseas markets. Following deregistration of the fumigant ethylene dibromide (EDB) by U.S. authorities in 1984, physical methods of treating fresh produce are being sought. Vapour heat treatment (or High Humidity Hot Air Treatment), HT, is one technique used commercially in Thailand and the Philippines for export of mangoes to Japan (Merino et al., 1985; Unahawatti et al., 1986). This treatment involves heating fruit in a water-saturated atmosphere to a required core temperature which is maintained for a certain time. After heating, fruit are cooled using ambient water showers and air dried. The recommended disinfestation treatment for 'Kensington' mango against Queensland (*Bactrocera tryoni* Froggatt) and Mediterranean (*Ceratitis capitata* Wiedemann) fruit flies is a regime of 46.5°C core temperature for 10 min (Heather et al., 1991).

Quality of mangoes after treatment may be influenced by maturity of fruit at the time of disinfestation. Immature mangoes of some varieties have suffered physiological damage after both hot water and vapour heat treatments (Sharp et al., 1989; Esguerra and Lizada, 1990). We were concerned that the recommended HT may cause injury (physical or physiological) to immature 'Kensington' fruit. This paper reports a study on the effect of fruit maturity and HT on 'Kensington' mango quality and physiology.

2. Materials and methods

2.1. Trial 1

Fruit

'Kensington' mangoes were hand-harvested from two orchards during their commercial harvest period in each of the three following production regions: Ayr (lat. 19.34°, long. 147.25°, Central–East Queensland) in December 1990, Mareeba (lat. 16.58°, long. 145.25°, North Queensland) in December 1990, and Nambour (lat. 26.36°, long. 152.59°, South–East Queensland) in January 1991. Within 24 hours of harvest, fruit from Ayr and Mareeba were airfreighted and fruit from Nambour were road-transported to the Hamilton laboratory at ambient temperature (25–35°C). Fruit were flotation graded in ambient water, then air dried at ambient temperature. "Floaters" were considered immature and "sinkers" considered mature. Specific gravity shows a high correlation to eating quality in several mango varieties and has been used successfully as a non-destructive maturity index (e.g., Pal et al., 1987; Esguerra and Lizada, 1990).

Treatments

Fruit were selected for uniformity of shape, colour and size (380–440 g) and any blemished or diseased fruit discarded. They were assigned to two treatments: untreated and high-humidity hot air treated (HT). This resulted in four groups of

16–18 fruit (untreated floaters, HT floaters, untreated sinkers and HT sinkers) for each of the two growers from the three production regions.

High-humidity hot air treatment took place in a Sanshu EHK-1000B vapour heat treatment system (Sanshu Sangyo, Kagoshima, Japan) with a chamber volume of 1 m^3. Chamber temperature was increased linearly from 26 to 47.5°C vapour temperature over 1 hour. Fruit were held within the chamber until the core temperature reached 46.5°C for 10 min (Heather et al., 1991). Fruit were machine-showered with ambient (25°C) water for 20 min following HT and then allowed to air dry before being repacked into cartons for storage at 22°C.

All fruit requiring HT at any one time (four trays representing two growers at two maturities) were included in one operation of the machine. As fruit from the three production regions were harvested at different times, this resulted in three operations. This combining of experimental units for HT was necessitated by the length of time required for set-up and operation of the vapour heat treatment system, in combination with expected changes in fruit ripeness during several machine operations. It was considered that the Sanshu heat treatment system could be consistently set up to deliver the required treatment accurately, but that time lags caused by multiple machine set-ups could introduce undesirable variability into the experiment.

In addition, 5 fruit per treatment for each production region–grower–maturity combination were individually placed in sealed 1-l plastic containers ventilated continuously at 22°C with humidified ethylene-free air (flow rate 80–90 ml min^{-1}) to determine the respiratory response of fruit to HT. This system is similar to that used by Brown et al. (1988) for custard apples. Carbon dioxide was measured every 6 hours using an automatic sampling valve system connected to a Horiba PIR-2000 Infra Red Gas Analyser, and respiration rate calculated (mg kg^{-1} h^{-1} CO_2 produced).

Assessments

Daily ratings of skin colour were made on every fruit by two assessors using a 1 to 6 colour scale (where 1 = fully green and 6 = fully yellow). The time taken for fruit to soften (yield to thumb pressure) following treatment was noted. Fruit were presented at eating ripe stage to a panel of 12 tasters and rated for eating quality using a 1 to 9 Hedonic scale (where 1 = dislike extremely and 9 = like extremely). Total solids (TS) at eating ripe were determined according to AOAC (1984) to give a useful measure of 'Kensington' mango maturity (Baker, 1986) and confirm the non-destructive specific gravity measure of sorting fruit for maturity classes. Fruit injury, both external and internal, was recorded if it occurred.

Statistical analysis

After averaging the measurements from the 16–18 fruit in a tray, data were analysed by analysis of variance for a split-plot design. Production region effects were tested against variability between growers within regions. The error term for testing effects of maturity, treatments, their interaction, and each of their interactions with regions was obtained by combining all interactions involving growers. The

only interaction significant in any analysis was that between production region and treatment. Although this was not always significant, for consistency, tables presented are maturity means and production region by treatment means. Where appropriate, pairwise comparisons of treatment means were made using the least significant difference (LSD) test. All statistical testing was carried out at $P = 0.05$.

2.2. Trial 2

Fruit and treatment

'Kensington' mangoes were hand-harvested from a commercial orchard in Nambour weekly for four consecutive weeks in January 1992. Fruit were selected according to the criteria in trial 1, and the number of floaters and sinkers from each harvest week were recorded. Fruit were then evenly distributed into 10 experimental units, such that each unit consisted of a tray of fruit (16–18 fruit). Four trays of fruit were not treated, four trays were subjected to HT treatment as in trial 1 and the other two trays were used to obtain pre-treatment data. Following HT, fruit were air dried before being repacked into cartons for storage at 22°C.

As in trial 1, all fruit requiring HT at the one time (i.e. the four replicate trays) were included in one operation of the heat treatment system. Thus there were four operations of the heat machine, one for each of the weekly harvests.

Assessments

Skin colour was measured objectively on both sides and averaged for every fruit using a Hunter Labscan 6000 Spectrocolourimeter fitted with a 25-mm orifice, D65 illuminant and 10-degree observer. The L, a and b values were recorded. Hue angle and chroma were calculated (McGuire, 1992). Fruit firmness was measured in Newtons using an Instron Universal Testing Machine, Model 1122, fitted with an 8-mm hemispherical probe (probe penetration 2 mm) interfaced with a computer. Skin colour and firmness measurements were carried out on two pre-treatment trays of fruit and on the other eight trays at 5 days after storage at 22°C. After 12 days storage, skin colour was again measured and fruit were rated for disease using a 1 to 5 scale based on percentage area of each fruit affected by disease (where 1 = 0%, 3 = 6–15% and 5 = 31–100%). Fruit were assessed for eating quality and total solids at eating ripe as in trial 1. Fruit injury, both external and internal, was recorded if it occurred.

Statistical analysis

Data were subjected to analysis of variance for a completely randomised design with four replications. Each replicate was a tray of 16–18 fruit. Analyses of initial values included the factor harvest only, while analyses of subsequent readings also included the factor treatment and its interaction with harvest. As the interaction between harvests and treatment was often significant, for consistency, post-treatment means are always presented in the two-way harvest by treatment array. Pairwise comparisons were made using the protected least significant difference test. All testing was carried out at $P = 0.05$.

3. Results

3.1. Trial 1

Total solids and eating quality

The total solids of mature fruit (sinkers) were significantly higher than immature fruit (floaters) (Table 1). There was no difference in total solids between untreated and HT for any production region. Production regions differed significantly in total solids of their fruit, with Ayr fruit having significantly higher total solids than Nambour and Mareeba fruit. Eating quality was not significantly affected by treatment in any production region. Nambour fruit (means 7.4 and 7.4 for untreated and HT, respectively) were generally preferred to fruit from Ayr (7.0 and 7.1) which, in turn, were favoured over Mareeba fruit (6.7 and 6.8).

Fruit softening

Mature fruit took a significantly shorter time to soften than immature fruit (Table 1). Time to soften for untreated fruit was closely related to their total solids, with Ayr fruit softening in significantly less time than Nambour fruit, which in turn softened significantly more quickly than Mareeba fruit. HT significantly reduced time to soften for Mareeba and Nambour fruit. It had no influence for Ayr fruit which softened quickly whether treated or not.

Skin colour development

Skin colour development varied between maturity, treatment, production region and growers within a region. HT and mature fruit generally coloured at a faster rate than the untreated and immature fruit (data not shown).

Table 1
Total solids (%) and time to soften (days) for 'Kensington' mango from trial 1 at different maturities and for different production region–treatment combinations. Maturity means or means within the production region by treatment array not followed by a common letter are significantly different ($P < 0.05$)

			Untreated		HT
Total solids (%) at eating ripe					
Floaters	13.9 a	Mareeba	12.5 a		12.4 a
Sinkers	14.9 b	Ayr	16.9 b		16.8 b
SE mean	0.12	Nambour	13.9 a		13.9 a
		SE mean		0.21	
Time to soften (days)					
Floaters	5.0 a	Mareeba	7.2 a		5.0 b
Sinkers	4.3 b	Ayr	3.2 c		3.2 c
SE mean	0.15	Nambour	5.8 b		3.5 c
		SE mean		0.26	

Fruit respiration

Mature fruit took a significantly shorter time (5.8 days) to reach their climacteric peak than immature fruit (7.2 days), but there was no significant difference in the peak height achieved. Fruit from different production regions differed in the peak respiration rate achieved. Nambour fruit had a significantly higher peak (147 and 151 mg kg^{-1} h^{-1} CO_2 for untreated and HT, respectively) than Ayr (136 and 128 mg kg^{-1} h^{-1} CO_2) which was significantly higher than Mareeba (116 and 115 mg kg^{-1} h^{-1} CO_2). HT did not influence the time to reach peak respiration or the peak height achieved.

Fruit injury

No internal or external injuries were recorded on any fruit from any maturity group, treatment or production region.

3.2. Trial 2

Maturity

The percentage of fruit sinkers increased with progressive harvests. Harvest 1 (34%) had the lowest number of sinkers, followed by harvest 2 (64%), harvest 3 (92%) and harvest 4 (94%). Commercial harvesting occurred during harvests 3 and 4.

Total solids and eating quality

There were significant differences in total solids between the harvests. Harvest 3 (16.0%) and 4 (15.9%) fruit had significantly higher total solids than harvest 2 (14.4%); and harvests 2, 3 and 4 fruit had significantly higher total solids than harvest 1 (13.4%). There were no differences in eating quality between the treatments for any harvest (Table 2). Harvest 1 fruit had significantly lower eating quality than harvest 2 for untreated fruit and lower than all other harvests for HT fruit.

Disease ratings

The two main diseases noted were Stem End Rot (caused by *Dothiorella dominicana* and *Phomopsis mangiferae*) and Anthracnose (caused by *Colletotrichum gloeosporioides*).

The untreated fruit exhibited a significantly higher level of disease than HT fruit at harvests 2 and 3 (Table 2). The level of disease in untreated fruit increased significantly with progressive harvests. HT had no effect on disease levels of harvest 4 fruit.

Fruit softening

The initial fruit firmness was higher in harvest 1 than harvest 3 and 4 (Table 2). Therefore, as fruit matured (with progressive harvests), fruit were softer when picked.

Table 2
Eating quality (1–9), disease rating (1–5) and firmness (Newtons) of 'Kensington' mango from trial 2 for four harvest dates and either untreated or HT. Means for the same variable and assessment stage not followed by a common letter are significantly different ($P < 0.05$)

Harvest	Untreated		HT
Eating quality at eating ripe			
1	7.1 bc		6.9 c
2	7.5 a		7.4 ab
3	7.3 ab		7.3 ab
4	7.3 ab		7.3 ab
SE mean		0.10	
Disease rating (day 12)			
1	2.6 c		2.3 c
2	3.1 b		2.5 c
3	3.7 a		2.6 c
4	4.1 a		3.9 a
SE mean		0.15	

Firmness (Newtons)

Harvest	Initial	Day 5	
		Untreated	HT
1	52.6 a	27.6 a	17.1 b
2	49.2 ab	14.4 c	10.3 d
3	47.5 bc	12.8 c	8.6 e
4	44.7 c	9.6 de	6.3 f
SE mean	0.91	0.57	

At 5 days after treatment, for each harvest, untreated fruit were significantly firmer than HT fruit, but this difference was much larger at harvest 1 (Table 2).

Skin colour development

The pre-treatment reflectance (L) values were not significantly different between the harvests (Table 3). However, the chroma and hue angle values were significantly lower in harvest 3 fruit than in fruit from either harvest 1 or 2.

At 5 days after treatment, HT fruit had significantly higher reflectance values than untreated fruit for harvests 1 and 3, higher chroma values for harvest 3 and lower hue angles for harvests 3 and 4 (Table 3). As the harvest number (and fruit maturity) increased, reflectance and chroma increased and hue angle decreased.

At 12 days after treatment, the effect of HT on skin colour was less defined (Table 3). In contrast to day 5, reflectance values for HT fruit were significantly lower than for untreated fruit from harvests 2, 3 and 4. Chroma for HT fruit was significantly higher and hue angle significantly lower than for untreated fruit from harvest 1, but the reverse was true for harvest 2. As for day 5, an increase in harvest number was generally accompanied by an increase in reflectance and chroma and a decrease in hue angle.

Table 3
Reflectance (L), chroma and hue angle of 'Kensington' mango skin colour from trial 2 for four harvest dates and either untreated or HT. Means for the same variable and assessment stage not followed by a common letter are significantly different ($P < 0.05$)

Harvest	Initial	Day 5		Day 12	
		Untreated	HT	Untreated	HT
Reflectance (L)					
1	50.9 a	50.3 d	51.5 c	56.7 cd	56.0 d
2	51.3 a	51.3 cd	52.4 c	60.2 ab	57.4 c
3	50.5 a	54.2 b	55.9 a	60.8 a	59.0 b
4	51.1 a	55.4 a	55.4 a	60.1 ab	57.6 c
SE mean	0.50	0.38		0.43	
Chroma					
1	22.9 a	22.4 e	23.3 de	27.6 e	29.1 d
2	22.8 a	23.2 de	23.8 d	32.3 b	30.8 c
3	21.7 b	25.0 c	26.6 b	34.3 a	34.6 a
4	22.1 ab	27.0 ab	27.7 a	34.7 a	33.6 a
SE mean	0.21	0.37		0.40	
Hue angle					
1	104 a	107 a	105 ab	81 a	77 b
2	107 a	102 bc	99 c	69 d	72 c
3	98 b	94 d	87 e	65 e	64 e
4	103 ab	84 e	79 f	63 e	64 e
SE mean	1.2	1.4		0.9	

Fruit injury

No internal or external injuries were recorded on any fruit from any maturity group, treatment or production region.

4. Discussion

Maturity has been reported to influence mango response to heat treatment (Quimio and Quimio, 1973; Esguerra and Lizada, 1990; Esguerra et al., 1990). Esguerra et al. (1990) found immature 'Carabao' mangoes exhibited a higher susceptibility to internal breakdown (IB) following vapour heat treatment than mature fruit. This IB injury is characterised by white, leathery areas within the inner portion of the mesocarp with cavities in the centre of such areas. We found 'Kensington' mango exhibited similar symptoms after experimental hot water disinfestation treatments (Jacobi and Wong, 1992). A starch layer (of varying thickness) developed directly under the skin and starch spot (or 'ricy' spot) developed within the mesocarp.

However, in our present studies treating both immature and mature 'Kensington' mango with HT, we found none of these injuries occurring. By testing a wide range of maturity levels over two methods of determining maturity, two seasons and three production regions, we are confident that the majority of situations likely in

a commercial treatment environment have been satisfied. Our present results also confirm that differences in thermal sensitivity do occur between varieties (Quimio and Quimio, 1973).

We have found that 'Kensington' mango total solids (a maturity index used by some markets) is higher for mature fruit, as is the eating quality, and skin colour development is also more advanced over immature fruit. These attributes would contribute to fruit attaining higher acceptance in both interstate and overseas markets. Other physiological responses of the fruit — firmness and respiration — were influenced by maturity. The decrease in firmness of mature fruit compared to immature fruit may be perceived as a hindrance to marketing, but can be overcome through correct postharvest handling procedures. Therefore, our results confirm those of Medlicott et al. (1988) that mature mangoes ripened faster than immature fruit; and Krishnamurthy and Subramanyam (1970) that the respiratory climacteric maximum was delayed in immature mango fruit.

The particular HT protocol of 46.5°C core temperature for 10 min did not cause internal or external injuries to 'Kensington' mango from any production region. HT shows potential for commercial disinfestation, since it maintains the organoleptic qualities of the fruit. The heating regime is very similar to that used commercially in Thailand and the Philippines for their export mangoes to Japan. The Thai variety 'Nang Klangwan' is treated at 46.5°C core temperature for 10 min (Unahawatti et al., 1986), and the Philippine variety 'Carabao' is treated at 46.0°C for 10 min without impairment to fruit quality (Merino et al., 1985). Ilangantileke and Maglente (1988) tested the Thai mango variety 'Nang Klangwan,' using a range of vapour heat regimes and found that the treatment reduced fruit firmness, delayed fruit decay and increased peel yellowing, but eating quality was not affected. This agrees with our data for HT 'Kensington' mango (Jacobi and Wong, 1992), where fruit softening and skin colour development were accelerated by heat treatment. Our present studies expand our knowledge of the influence of HT in reducing fruit firmness, increasing skin colour development and maintaining eating quality in association with increasing levels of fruit maturity. All these physiological changes are beneficial for fruit performance in the market chain, except fruit softening. However, as mentioned earlier, this change in fruit texture can be managed through careful fruit handling and postharvest management.

HT alone did not provide commercially acceptable levels of disease control over all harvest periods (and therefore, maturities) tested. There are several reasons for this phenomenon. High levels of Stem End Rot were recorded in untreated fruit at all harvests. Coates et al. (1993) found that HT treatments of 'Kensington' mango have given good control of Anthracnose, but variable control of Stem End Rot. This is because heat treatments are non-residual and do not provide residual control in storage as does a fungicide/HT combination treatment. Stem End Rot fungi are also more difficult to control because of their location on/in the fruit structures (Coates and Johnson, 1993). Therefore, our harvest 4 (most mature) fruit would have been exposed to disease organisms for a longer period in the orchard before harvest (as indicated by higher disease rating of untreated fruit). Although HT provided some control of disease in harvests 2 and 3, for commercial situations, we would

recommend some modification to HT alone (i.e. combination treatments of HT/hot water or HT/fungicide) to provide adequate control in the marketing chain.

Production region influenced all parameters measured, confirming earlier results for heat treated 'Kensington' mango (Jacobi and Wong, 1992). Esguerra and Lizada (1990) and Esguerra et al. (1990) treated 'Carabao' mango with vapour heat treatment and found that fruit from different production areas responded differently in peel colour development, weight loss, disease incidence, incidence of internal breakdown and shelf life. Quimio and Quimio (1973) studied the thermal sensitivity of 'Carabao' and 'Pico' mangoes and found that the same varieties grown at different places had different sensitivities. Sinclair and Lindgren (1955) treated citrus and avocado with vapour heat and concluded that the effect of heat treatments on fruit is markedly influenced by variety of fruit, the environment in which it is grown, the fruit maturity and quality at time of treatment.

In summary, the postharvest quality of HT 'Kensington' mangoes is related to a number of factors including maturity and production region. This has been confirmed by other researchers in this field throughout the world. The commercial implications of our studies are that HT does not physically injure 'Kensington' mango at any maturity stage, but we recommend only mature fruit be harvested, treated with HT and then marketed to maximise fruit quality. Despite the lack of injury, we have found physiological changes do occur within HT 'Kensington' mangoes, most of which are beneficial to postharvest quality. The issue of accelerated fruit softening as a consequence of HT and increased fruit maturity can be overcome through careful fruit handling and postharvest management.

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