Effect of ripening temperature on quality and compositional changes of mango (*Mangifera indica* L.) cv. Kensington

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Summary. Preclimacteric mangoes (*Mangifera indica* L.) cv. Kensington were treated with ethylene (200 μL/L) for 36 h, then ripened under a range of temperatures from 13 to 30°C and under 2 diurnal temperature regimes (18/24°C in 12/12 h and 18/6 h cycles). Fruit were assessed for quality (skin colour, pulp colour, eating quality) and compositional changes over the ripening period.

Fruit that was ripened at 18–22°C achieved the highest quality scores, with all quality parameters reaching a maximum within about 2 days of each other. Diurnal temperature cycling provided no advantage over non-cycled temperatures. Fruit ripened at 13 and 30°C had lower skin colour quality scores, related to poor carotenoid development and high chlorophyll retention, respectively. The poor carotenoid development at 13°C also resulted in lower pulp colour quality scores. Eating quality was significantly lower at 13 and 30°C, related to the slow decline in titratable acidity and poor flavour, respectively. Quality parameters became unsynchronised at 13 and 30°C, with skin colour quality reaching a maximum 5 days earlier than eating quality at 13°C, and 3 days later at 30°C.

Introduction

Mangoes are normally harvested as hard green preclimacteric fruit (Subramanyam *et al.* 1975). Once harvested, the fruit can be ripened artificially with ethylene or allowed to ripen naturally during storage. Temperature has a major influence on several biochemical pathways related to ripening (Medlicott and Jeger 1987), and each of these can have different temperature optima. Under natural conditions the fruit is exposed to a range of ripening temperatures, but artificial ripening is normally carried out at a single temperature. Optimum ripening temperatures for many mango cultivars have been reported in the range 18–24°C (Singh and Mathur 1952; Hatton *et al.* 1965), although optima outside this range are possible (Hatton *et al.* 1965; Medlicott *et al.* 1986). Cultivars ripened at <18°C are usually reported to be more acidic (Vazquez-Salinas and Lakshminarayana 1985), with reduced colour development (Thomas 1975) and, in some cases, a reduction in sugar development (Kapse *et al.* 1975; Thomas 1975; Veloz *et al.* 1977). At temperatures >24°C, many cultivars can develop mottled skin (Hatton *et al.* 1965; Medlicott *et al.* 1986) and produce strong flavours (Hatton *et al.* 1965). The effect of fluctuating temperatures during ripening of mangoes has not been reported.

Preliminary observations with cv. Kensington (the principal Australian cultivar) indicated that it can be too acidic to eat when ripened at ≤18°C, and that it maintains excessive green colour when ripened at >23°C (Jobin-Decor 1988). Current recommendations for ripening of this cultivar are based on these observations, together with field trials demonstrating effects of extreme temperatures on ripening (S. L. Ledger and J. S. Bagshaw pers. comm.).

This investigation measured the effect of temperature on several subcomponents of fruit quality and changes in compositional characteristics of cv. Kensington during ripening. The influence of fluctuating ripening temperatures was also assessed.

Materials and methods

Mango fruit (cv. Kensington) were assessed over 2 trials for their response to different ripening temperatures. In both trials, preclimacteric fruit were harvested at commercial maturity (14% dry matter) and transported to the laboratory within 24 h. Fruit were sorted for uniformity and dipped in a heated benomyl solution (0.5 g a.i./L, 52°C) for 5 min as a fungicide treatment. After drying, fruit were exposed to ethylene (200 μL/L) for 36 h to initiate ripening. Once initiated, fruit were randomly allocated to temperature treatments for ripening.

Experiment 1 (1990)

Fruit were ripened under 3 temperatures (13, 22 and 30°C) at 85–90% relative humidity (RH). Every 1–3 days over the experimental period (20 days), 4 fruit were withdrawn from each treatment and assessed for quality and composition. There were 8 withdrawals. Quality was divided into skin colour (SCQ), eating (EQ), and pulp colour (PCQ) and assessed by a 6-person panel (hedonic scale: 1, dislike extremely; 9, like extremely). Maximum scores and time to reach the maximum for each parameter were estimated from individual panellist data and analysed by analysis of variance for a randomised complete block design. Treatment means were compared by least significant differences (l.s.d.).

The pulp from each of the 4 fruit was analysed for total carotenoids, total soluble solids (TSS), and titratable acidity (TA), and the skin for chlorophyll concentration.

Total carotenoid determination was based on the method of Tomes (1963). Mango pulp (2 g) was excised and macerated before being extracted in 20 mL acetone:n-hexane (75:60 v/v). The extraction mixture was washed with distilled water to remove the acetone. The absorbance of the hexane extract was measured at 436 nm (Beadle and Zscheile 1942), and the total carotenoid concentration expressed as β-carotene equivalents, from a standard curve for β-carotene.

Total soluble solids (%) was determined on an Atago 3T Abbe refractometer corrected to 20°C. TA was determined by titration of 5 mL juice in 10 mL distilled water against standardised 0.1 mol NaOH/L to a pH 8.3 endpoint using a Metrohm autotitrator. Results were expressed as anhydrous citric acid (%).

Chlorophyll determination was based on the method of Compton and Boynton (1945) modified for fruit. Skin (2 g) was peeled from fruit so that the sample included a minimum of pulp. The resulting peel (about 1 mm thick) was macerated and extracted for 48 h in darkness in 20 mL 85% acetone. The absorbance of the extracted solution was measured at 642.5 and 660 nm, and the chlorophyll content (mg/g) calculated using the formula

$$\text{Total chlorophyll} = (7.12A_{660} + 16.8A_{642.5})(V/W),$$

where A is absorbance, V is volume (L), and W is weight of sample (g).

Experiment 2 (1991)

Fruit were ripened under a narrow temperature range (18, 22, 24°C; 85–90% RH). Two diurnal temperature regimes were also included: 12/12 h and 18/6 h cycles of 18 and 24°C. Sample size and experimental period were as in experiment 1.

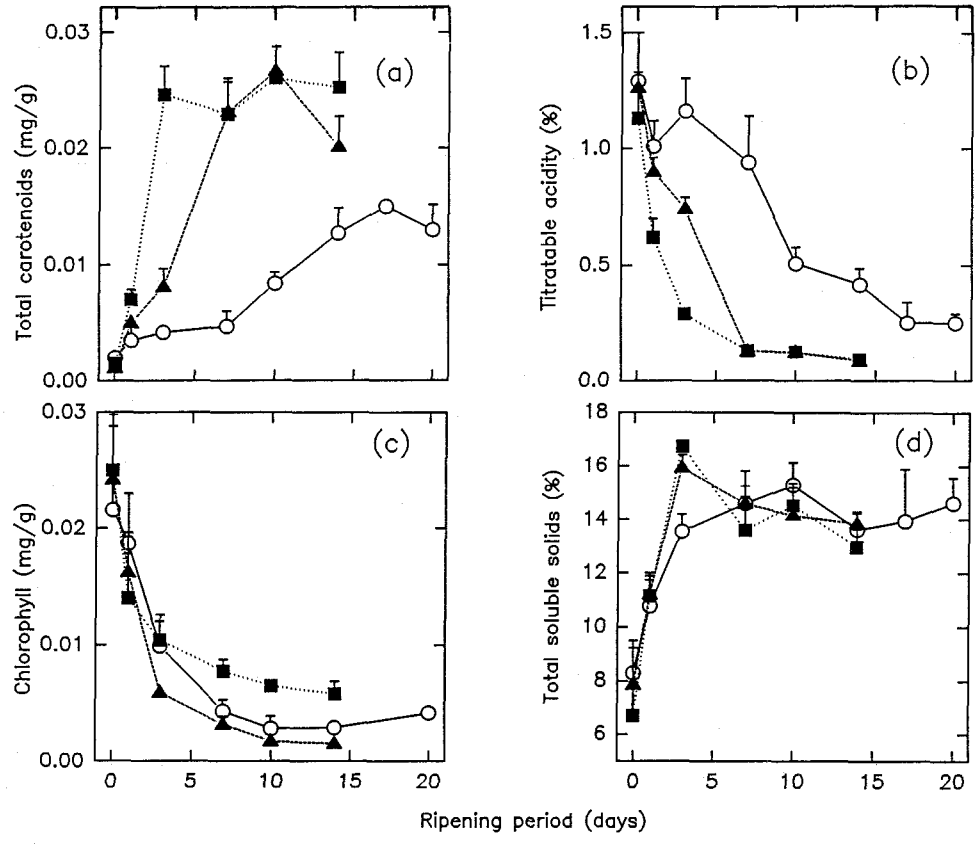

Figure 1. Effect of temperature (■ 30°C, ▲ 22°C, ○ 13°C) on (*a*) carotenoid concentration, (*b*) titratable acidity, (*c*) chlorophyll concentration, and (*d*) total soluble solids of mango during ripening. Standard errors are indicated as vertical bars.

Fruit quality (SCQ, EQ, PCQ) was determined hedonically at 1–3 day intervals over the experiment, and panel size was increased to 10 people. Results were analysed as in experiment 1.

Results

Experiment 1

Ripening temperature significantly affected the rate of mango ripening and the quality of the fruit. At 13°C, fruit ripened slowly, with low carotenoid development and a high TA even after 20 days (Fig. 1*a*, *b*). Maximum SCQ of the fruit at 13°C was reached at about the same time as minimum chlorophyll concentration, at 10 days (Table 1, Fig. 1*c*). Carotenoids continued to develop after this time (Fig. 1*a*), although concentrations were not as high as those attained at higher ripening temperatures. Skin blemishes became visible as fruit aged, and these detracted from the appearance. PCQ, which appeared to be closely related to carotenoid concentration, did not reach a maximum until about 16 days and was significantly lower than at higher ripening temperatures (Table 1). Maximum EQ at 13°C occurred at about the same time as minimum TA, at 16 days (Table 1, Fig. 1*b*). The higher minimum TA at 13°C than at higher ripening temperatures corresponded with a significantly lower EQ score at 13°C than at 22°C. By contrast, TSS peaked considerably earlier and reached a value (14–16%) similar to that attained at higher temperatures (Fig. 1*d*). At 13°C, quality parameters became unsynchronised, with SCQ peaking 4–5 days before PCQ and EQ (Table 1). Fruit approaching maximum SCQ at 11 days lacked colour internally and were still quite acidic (Fig. 1*a*, *b*). When EQ and PCQ reached their maxima (16 days), SCQ had declined because of blemish.

Fruit that were ripened at 22°C achieved a significantly higher SCQ than fruit ripened at 13 or 30°C (Table 1). Maximum SCQ coincided roughly with minimum chlorophyll concentration at 10 days (Fig. 1*c*).

Table 1. Experiment 1. Effect of ripening temperature on maximum quality scores and time from harvest to reach maxima

Quality parameters: SCQ, skin colour; EQ, eating; PCQ, pulp colour

	Ripening temperature (°C)			l.s.d.
	13	22	30	(P = 0.05)
	Maximum quality score (1–9)			
SCQ	7.0	8.4	7.2	0.38
EQ	7.1	8.0	7.3	0.78
PCQ	7.0	7.9	7.9	0.21
	Time to maximum score (days)			
SCQ	11.4	9.6	8.8	1.49
EQ	16.1	9.9	5.6	2.18
PCQ	15.8	7.8	6.8	2.92

Maximum PCQ also occurred soon after carotenoid concentration reached a maximum at 8 days (Fig. 1*a*). Skin blemishes were not obvious on the fruit and only became discernible towards the end of the trial. EQ peaked earlier at 22°C than at 13°C, at about 10 days (Table 1). Maximum EQ occurred 3 days after TA had reached a minimum (Fig. 1*b*). TSS peaked early in the trial, at 3 days after initiation (Fig. 1*d*). SCQ, EQ, and PCQ were synchronised at 22°C, all reaching a maximum score within 2 days of each other (Table 1).

At 30°C fruit ripened rapidly, although the time to reach maximum SCQ was limited by higher retention of chlorophyll (Fig. 1*c*), which gave fruit a mottled appearance. Skin chlorophyll concentration reached a minimum after about 8 days but remained higher than at 13 or 22°C. Maximum SCQ occurred at this time and was similar to that at 13°C (Table 1). Carotenoid development was not adversely affected by high temperature and reached a final concentration similar to that attained at 22°C (Fig. 1*a*). Maximum PCQ was also similar to that at 22°C and occurred at 6–7 days (Table 1). EQ peaked at 5–6 days (Table 1), corresponding to minimum TA (Fig. 1*b*). Although maximum EQ was not significantly lower than that recorded at 22°C, some taste panellists described fruit ripened at 30°C as less flavoursome. Peak TSS levels were comparable to those attained at 13 and 22°C (Fig. 1*d*) and occurred before TA had reached a minimum. SCQ, EQ, and PCQ maxima did not coincide, with EQ peaking 1 and 3 days before PCQ and SCQ, respectively, at 30°C (Table 1). Fruit that reached maximum EQ at 6 days still appeared moderately green due to higher chlorophyll concentration in the skin. When SCQ was at a maximum (about 9 days), EQ had begun to decline.

Experiment 2

Significant differences in EQ occurred between temperature treatments. Ripening fruit at 24°C resulted in lower EQ than 18 or 22°C. This contrasted with the previous experiment, in which, despite a trend, no significant (P>0.05) difference in EQ was recorded between 22 and 30°C. Ripening fruit at 18°C gave similar quality scores to ripening at 22°C in most respects, although the time to reach maximum SCQ was slightly longer at 18 than 22°C (Table 2).

Within each temperature treatment, SCQ, EQ, and PCQ peaked at about the same time. In contrast to fruit ripened at 13 or 30°C, quality parameters were well synchronised at 18, 22, and 24°C, peaking within a 1-day period (Table 2).

Ripening fruit under diurnally varied temperatures (18/24°C) provided no significant advantage over non-cycled temperatures (Table 2). In the 18/6 h cycle, maximum SCQ was similar to that attained at 24°C, with both treatments scoring significantly lower than either 18 or 22°C. All parameters remained synchronised under both cycled temperatures.

Table 2. Experiment 2. Effect of ripening temperature and diurnal temperature variation on maximum quality scores and time to reach maxima

Quality parameters: SCQ, skin colour; EQ, eating; PCQ, pulp colour

	Ripening temperature (°C)					l.s.d.
	18	22	24	18/24[A]	18/24[B]	(P = 0.05)
	Maximum quality score (1–9)					
SCQ	8.0	8.0	7.8	8.0	7.6	0.30
EQ	8.1	8.1	7.7	7.8	7.9	0.34
PCQ	7.6	7.8	7.9	7.9	7.6	n.s.
	Time to maximum score (days)					
SCQ	11.5	10.1	9.6	11.6	10.6	0.98
EQ	11.5	10.2	9.7	10.1	11.4	n.s.
PCQ	10.7	11.1	10.2	11.3	11.3	n.s.

[A] 12/12 h cycle. [B] 18/6 h cycle.

Discussion

Optimum quality scores for cv. Kensington were achieved by ripening fruit at 18–22°C. Although a preliminary study by Jobin-Decor (1988) reported that fruit of cv. Kensington were too acidic to eat when ripened at 18°C, this was not the case in the present trial. Similarly, fruit ripened at 13°C did not achieve the 'maximum colour characteristic of the cultivar' as described by Jobin-Decor (1988), due to the lower level of carotenoids produced at this temperature. Other mango cultivars have shown reduced carotenoid development at lower ripening temperatures (Thompson 1971; Veloz *et al.* 1977; Medlicott *et al.* 1986).

At 30°C, SCQ was adversely affected by higher chlorophyll retention in the skin. Jobin-Decor (1988) also reported 'green colour' retention of fruit (cv. Kensington) ripened at 28 or 33°C, and it is likely that the mottled appearance described in other cultivars ripened at high temperatures (Hatton *et al.* 1965; Medlicott *et al.* 1986) is due to increased chlorophyll retention.

Skin colour quality of fruit ripened at 13–30°C was influenced by a number of factors, although minimum chlorophyll concentration in the skin occurred around the time that SCQ reached a maximum. Carotenoid formation and the development of blemishes also affected SCQ, but at 22 and 30°C carotenoid formation had reached a maximum before chlorophyll had reached a minimum (Fig. 1*a*, *d*) and, consequently, was not a limiting factor to SCQ. At 13°C, however, carotenoid concentration remained low throughout the trial, giving fruit a dull yellow appearance. Although carotenoid concentration continued to increase slightly after the minimum chlorophyll concentration had been reached, SCQ did not improve. This appeared to be due to the development of light brown skin blemishes, which tended to offset any improvement in appearance associated with increased carotenoid concentration. At 22 and 30°C, blemishes occurred well after fruit had reached maximum carotenoid and minimum chlorophyll concentrations; consequently, blemishes did not affect maximum SCQ. In contrast to SCQ, PCQ was not affected by chlorophyll concentration or blemish and peaked not long after carotenoid concentration had reached a maximum.

Eating quality was significantly lower at 13 than 22°C, while at higher ripening temperatures there was evidence that flavour was adversely affected. At 13°C, EQ was strongly affected by high TA. High acidity in fruit ripened at low temperatures has been reported for other mango cultivars (Vazquez-Salinas and Lakshminarayana 1985; Medlicott *et al.* 1986). At high ripening temperatures (24, 30°C) fruit were less flavoursome, with fruit at 24°C having a lower EQ score. This did not appear to be related to TA or TSS, and may have been related to an alteration in either the range or quantity of mango volatiles at these temperatures. The EQ was not significantly lower at 30°C, but this may have been due to insufficient precision within the experimental design. In the second trial the precision was increased (i.e. more panellists, more treatments) to give a better indication of the error component (Cochran and Cox 1957).

Total soluble solids did not limit EQ at any temperature from 13 to 30°C, with values of 14–16% being reached at all temperatures. Temperatures within this range have also been reported to have little affect on TSS of cvv. Tommy Atkins (Medlicott *et al.* 1986) and Alphonso (Krishnamurthy and Subramanyam 1973), although other researchers have reported significant effects (cv. Totapuri, Kapse *et al.* 1975; cv. Alphonso, Thomas 1975; cv. Kent, Veloz *et al.* 1977).

Although maximisation of quality attributes (SCQ, EQ, PCQ) is important in determining the optimum ripening temperature for fruit, synchronisation is equally important. Quality optima became unsynchronised at 13 and 30°C, with peaks for SCQ and EQ occurring up to 4–5 days apart. Although panellists were not asked to rate the overall quality of a fruit (based on SCQ, PCQ, and EQ), this lack of synchronisation would be detrimental to overall quality, especially if a consumer eats the fruit when it looks most appealing. At 13°C, such a fruit would be acidic, and at 30°C it would be bland. By contrast, fruit ripened at temperatures within the range 18–24°C had well-synchronised quality parameters that would be acceptable to most consumers.

Fruit ripened under diurnally varied temperatures (18/24°C) had similar quality characteristics to fruit ripened at 18 or 24°C (Table 2). Jobin-Decor (1988) previously reported fruit ripened at 18°C to be acidic, and fruit ripened at 24°C to be poorly coloured but of

good flavour. In the present study, however, fruit ripened at 18°C had good quality characteristics, similar to those ripened at 24°C, with little apparent difference apart from the time to reach maximum scores and a slightly lower EQ at 24°C. Consequently, 18°C was not a suboptimal ripening temperature, and 24°C was only slightly suboptimal for EQ. Ambient temperatures within this range should provide ripening conditions close to optimum. At ambient temperatures outside this range, suboptimal ripening quality would become more common.

This study suggests that to achieve maximum SCQ, EQ, and PCQ at a synchronised time, cv. Kensington should be ripened in the temperature range 18–22°C. Maximum SCQ was limited by chlorophyll retention at high temperatures and carotenoid development at low temperatures, restricting possible ripening temperatures to 18–24°C. Maximum PCQ, which was only limited by carotenoid development at lower temperature, limited ripening to temperatures ≥18°C. Maximum EQ, however, further restricted ripening temperatures to 18–22°C. Fruit ripened below this temperature range were acidic, while fruit ripened above were less flavoursome. At these temperatures, maximum SCQ, EQ, and PCQ were well synchronised and occurred within a 2-day period. Temperature cycling of 18/24°C was not detrimental to fruit quality and produced fruit of quality similar to fruit ripened at 18 or 24°C. Ambient temperatures within this range would therefore provide conditions close to optimal for ripening.

Acknowledgments

This work was supported by the Australian Centre for International Agricultural Research as part of Project 8844. The author gratefully acknowledges the technical assistance of Mr A. Prasad and Mr C. D. Turner.

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Received 8 February 1994, accepted 27 October 1994