Reduction of chilling injury in ‘Tommy Atkins’ mangoes during ripening

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Abstract

Studies were conducted to investigate how harvest maturity influence fruit ripening processes to alleviate chilling injury (CI) in mangoes (cv. Tommy Atkins). Fruit at three stages of maturity, immature (M1), half-mature (M2) and mature (M3) were stored for 18 days at 5 °C and then at 1 or 3 days at 20 °C. M1 fruit succumbed to CI after 18 days at 5 °C, with symptoms increasing in severity upon warming. Low C2H4 production, poor colour development, minor changes to fruit composition, insipid flavour and poor aroma revealed that fruit ripening was insufficient to reduce CI compared to M2 and M3 fruits. M2 and M3 fruits had higher C2H4 production rates than M1 fruit and ripened normally with acceptable flavour and aroma after 18 days at 5 °C and 3 days at 20 °C. While M3 fruit had no CI symptoms, they were overripe and fruit decay incidence was 26.6%, compared to M2 fruit which had no decay, a trace of CI symptoms and possessed the best overall quality.

Keywords: Chilling injury; Maturity; Ripening; Ethylene

1. Introduction

Increasing popularity and demand for high quality mangoes in international markets over the past two decades (Haines, 1991) have created a shift in transportation linkages away from air and toward marine shipments. Marine shipments of mangoes lower the cost and allow higher volumes, both of which could dictate potential expansion of the mango export industry (Medlicott et al., 1990). Sea transport is normally supplemented with low temperatures and may involve transit times of 2 weeks, followed by a period in the
wholesale and retail systems at various temperatures. Mangoes are reported to ripen satisfactorily (i.e. with acceptable eating quality) between 21 and 24 °C (Medlicott et al., 1990). About 12–13 °C is generally considered optimum for mango storage (Kader, 1992; Medlicott et al., 1990), although 10 °C (Thomas, 1975) and 5 °C (Abou-Aziz et al., 1976; Thompson, 1977) have also been reported to be suitable temperatures. The sensitivity of mangoes to temperatures below 10 °C varies with the maturity of the fruit, the cultivar, and the duration and temperature of exposure (Medlicott et al., 1990).

Storage of mangoes below 10 °C results in chilling injury (CI), which is manifested by greyish scald-like discoloration of the skin, skin pitting, uneven ripening, reductions in the level of carotenoids, aroma and flavour during ripening and susceptibility to fungal decay (Abou-Aziz et al., 1976; Hatton et al., 1965; Thomas and Oke, 1983; Wardlaw and Leonard, 1936). Previous reports have established that fruits at the pre-climacteric stage are generally more sensitive than those at post-climacteric stage to CI for avocado (Kosiya-chinda and Young, 1976), papaya (Chen and Paull, 1986), honeydew melon (Lipton and Mackey, 1984), tomato (Moline, 1976), and mango (Cheema et al., 1950). Data are also available to show that exogenous application of C₂H₄ results in more rapid and uniform ripening of the above-named fruits (Barmore, 1974; Fuchs et al., 1975; Jo-Feng and Paull, 1990; Pratt and Workman, 1962; Proctor and Caygill, 1985). We have previously observed that tree-ripe (climacteric) ‘Keitt’ and ‘Tommy Atkins’ mangoes may be stored for 2 weeks at 5 °C without CI development at that temperature or during a subsequent 5-day period at 20 °C (Bender, 1996; Bender et al., 1996).

How ripening or C₂H₄ treatment can alter fruit physiology and indirectly change the sensitivity of fruits to CI is still unclear. Published reports have indicated that C₂H₄ treatment can reduce, increase or have no effect at all on CI development (Wang, 1989). Kader and Morris (1975) and Ogura et al. (1976), for example, reported that exposing mature-green tomatoes to C₂H₄ before or after storage at a chilling temperature did not affect CI symptoms. A similar effect was obtained for cucumber seedlings (Wang, 1980).

This paper reports on studies aimed at determining the effects of harvest maturity on mango sensitivity to CI and quality development during subsequent ripening on transfer to a higher temperature.

2. Materials and methods

Freshly harvested ‘Tommy Atkins’ mangoes were obtained from J.R. Brooks Tropica1s, Homestead, FL. These fruits were previously hydrocooled at Brooks Tropica1s and stored in field bins at 12 °C for 1 day. Fruits were selected and categorised into three stages of maturity with M1 designated as immature, M2 as half-mature and M3 as mature based on morphological characteristics (Medlicott et al., 1987). Immature fruit (M1) had shoulders that were below the pedicel insertion, the half-mature (M2) fruit had shoulders in line with the stem, while the mature (M3) fruit were defined as having full, raised shoulders at the stem end, but remaining firm. M1, M2 and M3 fruits were packed in separate plastic crates and transported for 6 h at 26–28 °C on the same day by car to the Horticultural Sciences Department facilities at the University of Florida, Gainesville, USA.
Upon arrival, three lots of 20 fruits each (cv. Tommy Atkins) of M1, M2 and M3 were stored overnight in a flow-through system at 20 °C. Afterwards the fruits were individually placed and stored in 1.75 l glass jars and transferred to 5 °C, and 90–95% relative humidity (RH) for 18 days of storage. Readings were taken of epidermal ground colour, fresh mass and CO₂ and C₂H₄ production rates initially. At 3-day intervals for up to 18 days, readings were taken on half of the fruit from each maturity class for colour, percentage fresh mass losses, and C₂H₄ and CO₂ production rates. CI, aroma and flavour were subjectively evaluated and the percentage infected or decayed fruit calculated. After 18 days at 5 °C, and 90–95% RH, these fruit were used for destructive measurements by freezing the mesocarp tissue. Thereafter, measurements taken included pH, total soluble solids (TSS), total titratable acidity (TTA), and the TSS:TTA ratio. The other half of the fruit from each maturity class were transferred to 20 °C and 90–95% RH and evaluated for all the parameters mentioned above after 1 and 3 days. Three separate sets of 10 fruits from each maturity class were stored continuously at 20 °C and 90–95% RH in air up to 9 days in the flow-through system and used as the controls.

Whenever CO₂ and C₂H₄ production rates were measured, individual fruit in glass jars or plastic buckets were sealed for 1 h and 0.5 ml head space samples were retrieved from each container and injected into gas chromatographs. C₂H₄ production rates were determined by a photoionisation gas chromatograph at ambient temperature with a Photovac GC (Photovac 1OA10) equipped with a 76.2 × 0.3 mm² 60/80 mesh activated alumina column. Respiration rates were determined by a Gow-Mac Instrument, gas chromatograph, series 580, equipped with a 102 × 0.3 mm² 80/100 mesh Porapak Q column at 40 °C; thermal conductivity detector and injector temperatures were set at 90 °C.

The methods used to determine colour, compositional changes (pH, TSS, TTA, TSS:TTA) and CI were similar to that described by Bender and Brecht (1994), Medlicott et al. (1990) and Wild and Hood (1989), respectively.

Sensory evaluations of flavour and aroma were subjectively rated on a scale of 1–5, with 1 being excellent and 5 being poor for flavour, and 1 being very strong and 5 being non-detectable for aroma. These ratings were obtained from a research team of 10 trained postgraduate students and the score for each parameter was the average of individual ratings for all samples.

The experiment was carried out as a completely randomised design. Data were subjected to analysis of variance and LSD values calculated using the Minitab Statistical Program.

3. Results

3.1. CI

Only M1 fruit showed significant \( P < 0.05 \) evidence of CI after 18 days at 5 °C (Table 1). The pitted areas superimposed on slightly brown areas became more \( P < 0.05 \) obvious and widespread when M1 fruit were transferred to 20 °C after 18 days at 5 °C (Table 1). M3 fruit showed no visible CI symptoms throughout, but M2 fruit had slight pitting on the shoulders after 3 days at 20 °C following 18 days at 5 °C (Table 1).
3.2. Decay incidence

Low temperature storage proved extremely effective in reducing fruit decay. The M1 and M2 fruit benefited the most since no evidence of decay was apparent after 18 days at 5 °C, and even when the fruit were transferred to 20 °C for 1 or 3 days (Table 1). The incidence of decay in control fruit was 14.6, 66.8 and 100%, respectively, for the M1 and M2 and M3 classes after 9 days at 20 °C (Table 1). More than 25% of the M3 fruit were decayed after 3 days at 20 °C following 18 days at 5 °C (Table 1). In most cases decay was the result of multiple infections, often in the same lesion. Although positive identification of the causal agents was not made, symptoms of anthracnose (*Colleotrichum* sp.) and bacterial soft rot (*Erwinia* sp.) were more prevalent at 20 °C than at 5 °C.

3.3. Sensory evaluation

M2 fruit displayed superior flavour and aroma profiles (*P < 0.05* and *P < 0.01*) after 6 days at 20 °C compared to M1 and M3 fruit (Table 1). However while M3 fruit had slightly better flavour ratings at the time of transfer from 5 °C and after 18 days at 5 °C plus 1 day at 20 °C, the flavour of M2 and M3 fruits was after 18 days at 5 °C plus 3 days at 20 °C similar
and significantly \((P < 0.05)\) better than M1 fruit (Table 1). The presence of a fermented aroma accounted for the 3.60 rating in M3 fruit after 6 days at 20 °C and undoubtedly the inferior aroma ratings compared to M2 (1.50) and M1 (2.50) fruit, respectively (Table 1). While the aroma of the fruit proceeded from poor to worse after 18 days at 5 °C and after 18 days at 5 °C plus 1 or 3 days at 20 °C, the aroma of M2 and M3 fruits were good to excellent over the same storage intervals (Table 1).

3.4. Fresh mass losses

Progressive increases \((P < 0.05)\) in percentage fresh mass losses occurred for M1, M2 and M3 fruits throughout the 18 days exposure to 5 °C (Fig. 1). M3 fruit had the highest \((P < 0.05)\) fresh mass losses, although no visible shrivelling signs were evident.

Transferring fruit after 18 days at 5–20 °C for 1 or 3 days accelerated the rate of water loss for all fruit (Fig. 1). Mass loss in transferred fruit from the M3 category was significantly \((P < 0.05)\) higher than that of transferred M1 and M2 fruits.
3.5. Colour changes

Only the epidermal ground colour of M3 fruit changed appreciably after 18 days at 5 °C. Both M1 and M2 fruit maintained hue (H) values averaging above 100, chroma (C) in the upper thirties and ‘L’ values in the high fifties throughout storage at 5 °C, denoting a green ground colour while in contrast, M3 fruit had ‘L’, ‘C’ and ‘H’ values averaging about 60, 43 and 89 over the 18 days at 5 °C (Fig. 2A–C). Decreases in both ‘L’ and ‘C’ in M1 fruit between 1 and 3 days at 20 °C following 18 days at 5 °C corresponded to the development of CI symptoms in those fruit (Fig. 2A and B). Control fruit of all maturity classes generally showed more significant (P < 0.05) colour development after 3 days at 20 °C than the fruit stored at 5 °C when transferred to 20 °C (Fig. 2A–C).

Changes in ‘L’, ‘C’ and ‘H’ were generally greater (P < 0.05) for M1 and M2 fruit than M3 fruit after 18 days at 5 °C and when the fruit were transferred to 20 °C for 1 or 3 days (Fig. 2A–C). However, the final ‘L’ and ‘C’ values were the highest and ‘H’ was the lowest in M3 fruit after 18 days at 5 °C plus 3 days at 20 °C (Fig. 2A and B).

3.6. Compositional changes

There were increases in pH, TSS and the TSS:TTA ratio after 18 days at 5 °C as maturity stage increased from M1 to M2 and M3 (Table 2). While this order was maintained for pH through the subsequent 3 days at 20 °C, M1 fruit developed higher TSS and TSS:TTA ratio than M2 fruit at 20 °C. TTA in M1 fruit was higher than in M2 fruit, which had higher TTA than M3 fruit after 18 days at 5 °C (Table 2). However, the order was reversed after 3 days at 20 °C (Table 2). After 1 day at 20 °C, M2 fruit had the lowest TTA value while M1 fruit had the highest level (Table 2). The TSS:TTA ratio was the highest for M3 fruit and the lowest for M2 fruit after 18 days at 5 °C plus 1 and 3 days at 20 °C (Table 2).

3.7. Carbon dioxide production rate

Carbon dioxide production rates were altered according to fruit maturity and storage duration. M1, M2 and M3 fruits showed significant reductions in respiration rates from initial rates at 20 °C to those measured after 3 days at 5 °C (data not shown). Beyond 3 days at 5 °C all fruit showed increased respiration from 2–3.5 to 4–5 mg CO₂ kg⁻¹ h⁻¹ after 18 days at 5 °C, prior to transfer to 20 °C (data not shown). The pattern of CO₂ production in M3 fruit differed somewhat from that of M1 and M2 fruit, in that, after 3 days at 5 °C, the increase in CO₂ production was more or less continuous from day 3 to 18. While the CO₂ production rates of M1 and M2 fruit decreased between days 15 and 18 at 5 °C, by 3.31 and 1.93 mg CO₂ kg⁻¹ h⁻¹, respectively; M3 fruit on the other hand showed an increase of 0.31 mg CO₂ kg⁻¹ h⁻¹ over the same period (data not shown).

When the fruits were transferred to 20 °C for 1 or 3 days following 18 days at 5 °C, the increase in CO₂ production represented a 3–5-fold increase in some cases (Fig. 3). Meanwhile, the differences in CO₂ production between 1 and 3 days at the warmer temperature following prolonged storage at 5 °C represented minor changes for M1 and M2 fruit, i.e. only 1.21 and 2.08 mg CO₂ kg⁻¹ h⁻¹, respectively, compared to the dramatic reduction in M3 fruit, which measured 6.48 mg CO₂ kg⁻¹ h⁻¹ (Fig. 3).
Fig. 2. A–C. Effect of maturity on colour changes of ‘Tommy Atkins’ mangoes. At the times indicated by the arrows, samples of fruit were removed from 5 to 20 °C for 1 and 3 days, respectively.
3.8. Ethylene production rate

Unlike M2 and M3 fruits, M1 fruit showed a significant \((P < 0.05)\) increase in \(C_2H_4\) production after 3 days at 5 °C following overnight storage at 20 °C (data not shown). Thereafter, \(C_2H_4\) production declined to a minimum after 12 days for M2 and M3 fruits and likewise after 15 days for M1 fruit (data not shown).

Removal of M1 and M2 fruit after 18 days at 5 °C to 1 or 3 days at 20 °C accounted for a dramatic increase in \(C_2H_4\) production, representing CI and ripening, respectively (Fig. 4). M3 fruit showed no increase in \(C_2H_4\) production after 18 days at 5 °C plus 1 day at 20 °C and were apparently in the post-climacteric phase. A large increase in \(C_2H_4\) production for M3 fruit after 3 days at 20 °C following 18 days at 5 °C corresponded to decay development (Fig. 4).

4. Discussion

This investigation confirms the earlier findings of Medlicott et al. (1990) that successful storage of mangoes at chilling temperatures is related to physiological maturity. ‘Tommy Atkins’ mangoes harvested at the M2 and M3 stages were held for up to 18 days at 5 °C and then ripened normally at non-chilling temperature (20 °C), attaining superior flavour and aroma, both of which contributed significantly to acceptable eating quality. There was also no evidence of serious CI symptoms (Table 1), and the improved epidermal colour (Fig. 2A–C), and higher pH, TSS, TTA and TSS:TTA ratio (Table 2) of M2 and M3 fruits over M1 fruit persisted.
Evidence of abnormal fruit ripening processes in immature (M1) fruit was obtained for control fruit even at 20 °C. Ripening characteristics were limited to improved epidermal colour from 3 days onwards, but this was accompanied by only moderate flavour and aroma ratings (Table 1). M2 and M3 controls, on the other hand, ripened normally after 3 days, but beyond this period fruit decay became a major constraint, especially for M3 fruit. The M2 controls, with 25% decay after 6 days at 20 °C, had very high ratings for flavour and aroma, while M3 fruit, with 42.5% decay, were overripe, which inevitably influenced the lower ratings of 3.0 and 3.6, respectively, for flavour and aroma (Table 1).

Overall, M2 fruit possessed the best quality after storage at 5 °C. The absence of fruit decay for M2 fruit even after 18 days at 5 °C plus 3 days at 20 °C, coupled with aroma and flavour ratings reflecting highly acceptable eating quality, more than compensated for the occurrence of slight CI symptoms (Table 1). The M3 fruit displayed similar aroma and flavour profiles as M2 fruit when transferred from chilling to non-chilling conditions as stated before, but at the same time developed 26.6% decay (Table 1), even though CI symptoms were totally absent (Table 1). Thus, it would appear that decay control measures would be critical for successful storage and ripening of M3 fruit. Like M2 fruit, M1 fruit had no decay throughout the experiment, but CI ratings for M1 fruit were twice that of M2 fruit (Table 1). Furthermore, M1 fruit exhibited impaired ripening characteristics after

![Fig. 3. Effect of maturity on respiration rate of ‘Tommy Atkins’ mangoes after 18 days at 5 °C and during subsequent holding at 20 °C.](image-url)
storage at 5 °C undoubtedly due to CI. Inhibition of ripening processes of M1 fruit were verified by insignificant epidermal colour changes (Fig. 2A–C), low pH and TSS, and high TTA (Table 2). The reticence of M1 fruit to undergo acid loss could be related to disruption of acid metabolism due to CI, although according to Medlicott et al. (1986, 1990), acid changes in ripening mango have been known to be one of the slower processes. CI of M1 fruit could also account for unacceptable eating quality as indicated by the atypical flavour and aroma ratings of 4.4 and 4.0, similar to that reported by Thomas (1975) for ‘Alphonso’ mangoes suffering from CI.

The severity of CI in M1 fruit was indicated by the outburst of CO₂ at non-chilling temperature, which exhibited a more sustained pattern over 1 and 3 days compared to M2 and M3 fruits (Fig. 3). Such an outburst in post-chilling respiration could be used as an index of CI severity (Lyons and Breidenbach, 1989) and has been reported for zucchini squash (Mencarelli et al., 1983), citrus (Eaks, 1960), tomatoes (Cheng and Shewfelt, 1988), snap beans (Watada and Morris, 1966) and bananas (Murata, 1969). Also, the slight CI reported in Table 1 for M2 fruit after 3 days at 20 °C following 18 days at 5 °C could be reflected by the much smaller decrease of CO₂ production between 1 and 3 days compared
to M3 fruit (Fig. 3). The post-chilling ‘burst’ of respiration was reported by Kiener and Bramlage (1981) to be associated with the alternative pathway operating to a much greater extent during the ‘burst’ than it was either before or after.

C2H4 production which was the highest throughout for M3 fruit (Fig. 4), corresponded to the more rapid physiochemical changes associated with the enhanced ripening of those fruit compared to M1 and M2 fruits. Together, these processes may have suppressed CI, lending support to Saltveit and Morris’s (1989) hypothesis that CI alterations are probably inhibited in the already-accomplished process of ripening. It would therefore be argued that, while C2H4 production was adequate to initiate ripening and negate CI symptoms but not decay in M3 fruit, in M2 fruit C2H4 production was delayed, postponing decay but not CI symptoms altogether. M1 fruit, on the other hand, had C2H4 production levels below the minimum amount required to initiate ripening and attain protection against CI symptoms development. On the basis of these results, further studies are being undertaken to determine whether the ripening of immature fruit exposed to exogenous C2H4 could be initiated sufficiently to achieve alleviation of CI observed for M2 and M3 fruits.

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