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Physiology and Quality Characteristics of Mango (*Mangifera indica* L.) Fruit Grown under Water Deficit Conditions

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Keywords: anthocyanin, β-carotene, ethylene, fruit firmness, fruit growth, respiration, starch

Abstract

This study aimed at understanding the quality characteristics of mango (*Mangifera indica* L. cv. 'Tommy Atkins') fruit from trees subjected to water stress (non-irrigated) during the first phase of growth (up to 42 days after bloom). Selected physico-chemical and physiological parameters were monitored at two weeks interval from fruit set up to 168 days after bloom. Fruit weight and starch content increased steadily with time and slowed down towards fruit maturity with starch content being higher in fruit from non-irrigated trees. Total soluble solids and total titratable acidity increased initially and decreased to constant low levels. No ethylene was detected, although respiration rate decreased towards maturity to the climacteric minimum. Fruit from non-irrigated trees were significantly ($p<0.05$) firmer than those from irrigated trees. β-Carotene and anthocyanin contents increased with fruit maturity and the latter was higher in fruit from non-irrigated trees. There was a high correlation between the increase in firmness and starch, r^2= 0.86 and 0.96 for fruit from irrigated and non-irrigated trees, respectively. The abscission rate was also higher among fruit in the irrigated trees, probably due to excess weight. Fruit from irrigated trees did not develop the characteristic colour associated with this variety. These results indicate that although irrigation results in slightly bigger fruit, it affects colour development due to increased canopy cover and fruit are less firmer.

INTRODUCTION

Mango (*Mangifera indica* L.*)* is one of the most important fruit crops in Kenya and its production has increased from 500 ha in 1970 to approximately 15,000 ha in 2005 (Mumero, 2005) partly due to increased land under cultivation and improved varieties. Despite this, 40-60% of the crop is lost due to preharvest factors, poor harvesting methods and postharvest handling systems (HCDA, 2003). Mango fruit are harvested commercially within a range of maturities including immature green, mature green and tree ripe stages that have different but significant impact on eating quality (Mitra and Baldwin, 1997). With increasing production and the fact that this commodity is one of the fruits that form the bulk of fruits for local and export markets in Kenya, it is important to understand the preharvest cultural practices that affect its quality.

The influence of preharvest factors, such as water supply has been reported to have an effect on maturity and quality of several fruits at harvest. Indeed a number of farmers in the arid and semi-arid lands of Kenya irrigate their mango trees and retail traders have indicated that the quality and postharvest behaviour of fruit from irrigated trees is somehow different from that of fruit from non-irrigated trees. In order to understand the scientific basis of this argument, we monitored selected physico-chemical and physiological parameters in mango fruit from irrigated and non-irrigated trees.

MATERIALS AND METHODS

Mango (*Mangifera indica* L. cv. 'Tommy Atkins') fruit were sampled from a commercial farm in Yatta District, a semi-arid region in Kenya. One set of trees was

subjected to water stress until 42 days after bloom (DAB) and another set of trees was irrigated throughout the year. Three trees were randomly labeled per plot and six fruit per tree were sampled for analysis from each set of trees at 14 day intervals.

Fruit weight was measured using a scientific balance (model Libror AEG-220, Shimadzu Corp., Kyoto, Japan). Flesh firmness along the equatorial region of the fruit was determined using a rheometer (model NRM-2010J-CW, Fudoh, Tokyo, Japan) fitted with an 8 mm probe and expressed in Newtons (N). Starch staining was done by taking a slice from the equatorial region of the fruit, dipping in I/KI (2 g/10 g) solution and rated as a percentage based on the Cornell Starch Chart. Total soluble solids (TSS) content was determined using an Atago hand refractometer (Type 500, Atago, Tokyo, Japan). Total titratable acidity (TTA) was determined by titration with 0.1 N NaOH and results expressed as % citric acid. β-carotene content was determined by a modified chromatographic method (Heionen, 1990) using HPLC (model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with a UV detector and operated at oven temperature of 35°C. Anthocyanin content was determined by the pH differential method (Ngo et al., 2007) by measuring the absorbance of extract in pH 1.0 and pH 4.5 buffers at 510 nm and 700 nm using a UV-Vis spectrophotometer (model UV mini 1240, Kyoto Shimadzu). For determination of respiration rate, fruit were placed in plastic jars ranging in volume from 100 ml to12 L fitted with a self-sealing rubber septum for gas sampling. The fruit were incubated for 1h at room temperature. Gas samples from the headspace gas were removed using an airtight syringe and injected into a gas chromatograph (Model GC-8A, Shimadzu Corp., Kyoto, Japan) fitted with a thermal conductivity detector and a Poropak Q column.

Values for the treatment and control were compared using t-test; paired two samples for means using Genstat (13th version) statistical method of analysis.

RESULTS AND DISCUSSION

Weight and Starch Content

The change in fruit weight during growth followed the typical sigmoid curve and reached a peak at 168 DAB (Fig. 1A). There was minimal change in fruit weight between 0-42 DAB for both treatments. Flesh weight of mango fruit increases almost linearly until 100 DAB and then tends to slow down (Lechaudel et al., 2005). The increase in fruit weight towards maturity is probably due to an increase in both cell size and intercellular spacing, thus allowing the maximum possible accumulation of assimilates. Fruit from non-irrigated trees had lower weight than those from irrigated trees as has previously been reported under irrigation (Halil et al., 2001; Lechaudel et al., 2005). The reduced weight in the non-irrigated treatment is brought about by a decrease in water supply which greatly decreases growth (Tezara et al., 2002). In the long term, water deficits decrease growth by slowing down the rate of cell division and expansion due to loss of turgor and increased synthesis of abscisic acid (Lawlor and Cornic, 2002). A deficit in water supply affects key metabolic and physiological processes in plants, although the mechanisms are still unclear (Tezara et al., 2002).

Carbohydrate metabolism plays an important role during mango fruit development, particularly changes in starch content. Fruit from the non-irrigated trees had significantly ($p<0.05$) higher starch content. At 154 DAB the starch content began to decrease and this could have been caused by the reduction in the synthesis of the storage reservoir and the increase of the catabolic reactions that resulted in increased sugar content (data not shown) as the fruit began to ripe. Mango fruit starch hydrolysis has been reported during ripening (Lima et al., 2001; Tasneem, 2004).

Total Soluble Solids Content and Total Titratable Acidity

The highest total soluble solids (TSS) content found in the fruit from irrigated trees was 2°Brix while for fruit from the non-irrigated trees was 3°Brix at 28 DAB (Fig. 2A). The TSS content was high initially and thereafter decreased to a low constant level. There was a significant difference ($p<0.05$) in TSS content in fruit from both treatments

before termination of water stress. The low TSS content during the latter phase of growth and development may be attributed to channeling of carbohydrates into starch synthesis as observed in breadfruits (Worrell et al., 1998). The increase in the TSS content towards maturity corresponded with decrease in starch content (Fig. 1B).

Total tritratable acidity (TTA) increased during the initial stage of growth and development and decreased to a constant level (1%) at the later stages of development (Fig. 2B). A similar trend has previously been reported in mango fruit (Lechaudel et al., 2005). Fruit from non-irrigated trees had significantly ($p<0.05$) higher levels of TTA than those from irrigated trees prior to termination of water stress. The seasonal parabolic trends for TTA observed in mango flesh are similar to those observed for other fruits such as peach (Wu, 2002). In other mango cultivars, increase in TTA during the early period of fruit development followed by a decline towards the end of their growth have been reported (Lechaudel et al., 2005). The rapid decline in TTA as fruit approach maturity may be due to acids being used in respiration or their transformation to other metabolites such as sugars and amino acids.

Respiration and Fruit Firmness

The respiration rate rose early between 14 and 28 DAB for fruit from both non-irrigated and irrigated trees (Fig. 3A). Thereafter, the respiration rates decreased with increased fruit development, to reach a climacteric minimum of 5.1 ml per kg per hour for the fruit from irrigated trees and 3.4 ml per kg per hour for fruit from non-irrigated trees. There was no significant difference at ($p<0.05$) in respiration rates between the fruit from irrigated and non-irrigated trees. The high respiration rates during the early stages of fruit development is attributed to intense cellular activity, particularly high rates of cell division, enlargement and differentiation in the tissues as observed in other fruits (Graham et al., 2004). The respiratory pattern was similar to that of TSS content and TTA. Interestingly, no ethylene production was detected during the period of growth and development (data not shown). Passion fruit produces the most CO_2 in the early stages of growth that is attributed to intense cellular division although no ethylene is detected (Gillaspy et al., 1993). No ethylene was detected during the growth and development of other climacteric fruits such as miniature apple fruit (Graham et al., 2004).

Firmness for fruit from the irrigated and non-irrigated trees was significantly different ($p< 0.05$) with the latter being firmer (Fig. 3B). There was a high correlation between the increase in firmness and starch, $r^2= 0.86$ and 0.96 for fruit from irrigated and non-irrigated trees, respectively. When fruit approach maturity, the flesh softens as water-soluble pectin is solubilized and cell wall integrity is lost.

Pulp β-Carotene and Peel Anthocyanin Contents

The β-carotene content increased as fruit developed reaching a peak of 0.26 mg/100 g in fruit from irrigated trees and 0.14 mg/100 g in fruit from non-irrigated trees (Fig. 4A). The β-carotene content increased faster in fruit from irrigated trees than those from non-irrigated trees. Lewallen (2000) reported that carotene synthesis (yellow color) is not light dependent and corresponds to firmness and maturity, although Tasneem (2004) reported a variance in the increase of carotenoid during ripening among mango cultivars.

β-Carotene content increased with a gradual decrease in anthocyanin towards maturity in fruit from both sets of trees (Fig. 4B). The fruit from non-irrigated trees had higher anthocyanin content compared to fruit from the irrigated trees throughout the growth and development period. This may be attributed to increased light exposure of fruit from the non- irrigated fields due to reduced vegetative growth and thus producing more of the light protecting pigments. Fruit from irrigated trees had high chlorophyll content (data not shown) due to increased canopy cover. Anthocyanin synthesis is light-dependent and influenced by solar radiation and not related to firmness or maturity (Lewallen, 2000).

CONCLUSION

Water deficit seems not to have a negative effect on all fruit quality parameters and indeed effect on some aspects such as TSS content and TTA can be reversed during growth by supplying water. Fruit from irrigated trees did not fully develop the characteristic colour associated with mature 'Tommy Atkins' due to enhanced canopy cover resulting from intense vegetative growth hence less appealing to consumers at harvest. This may be addressed through pruning, thereby increasing the cost of production. Irrigation has negative effect on fruit firmness that is bound to affect postharvest handling practices.

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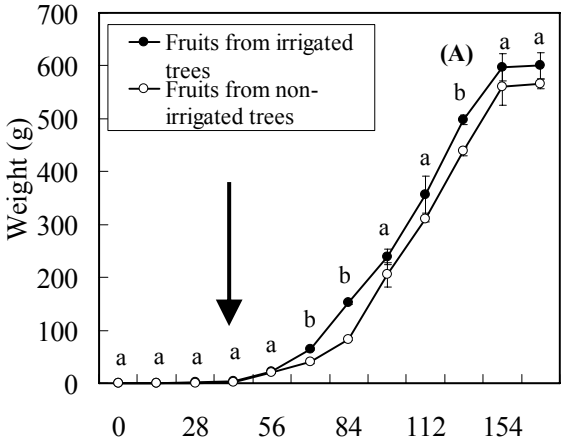
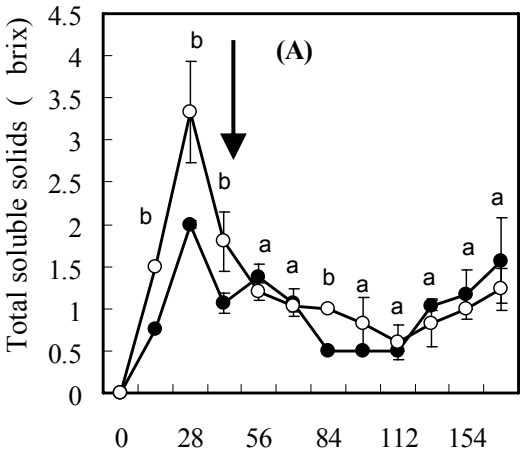
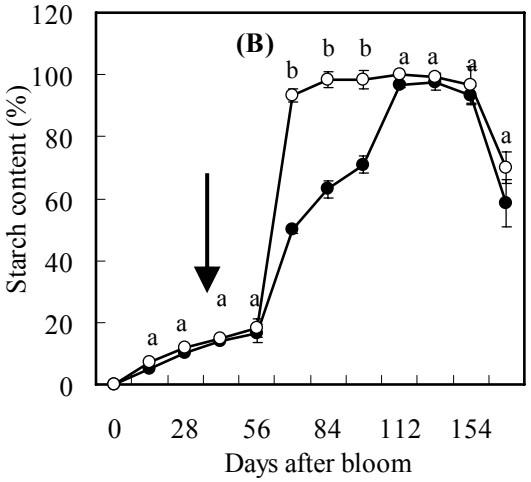
Figures







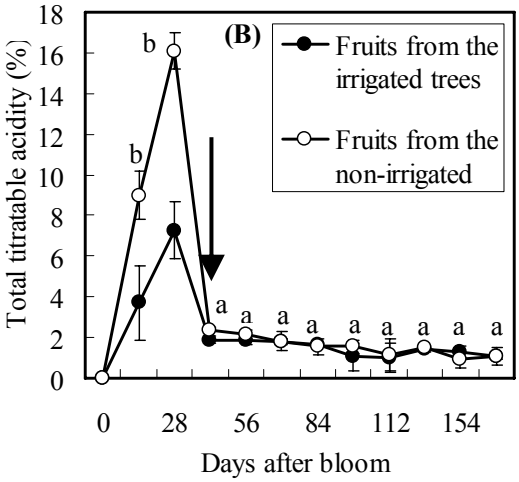
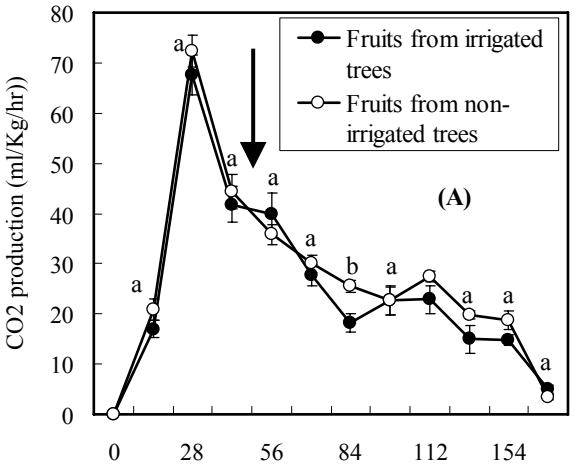
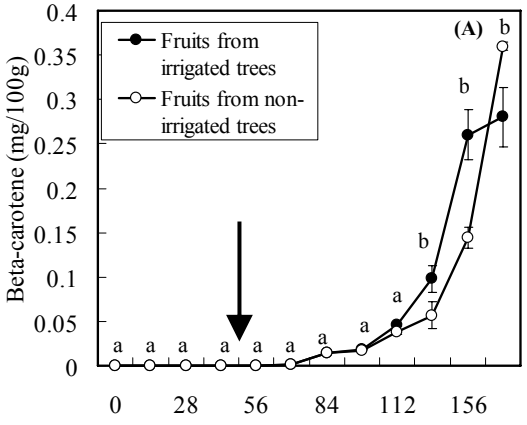
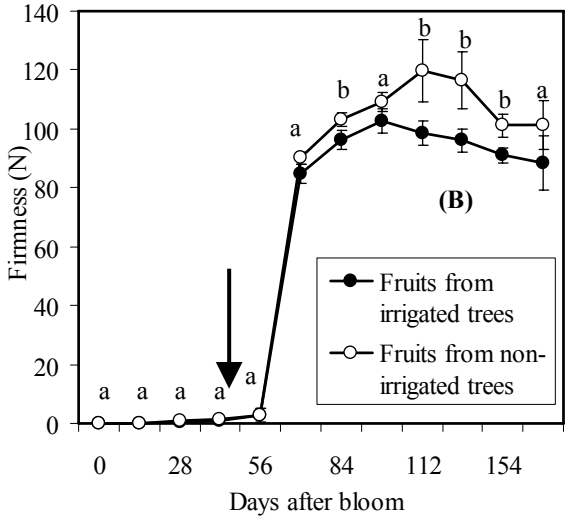


Fig. 1. Changes in weight (A) and starch content (B) during growth and development of mango fruit from irrigated and non-irrigated trees. The arrow indicates the end of water stress period (42 DAB). Vertical bars represent SE of the mean of six replications. When absent, the SE fall within the dimensions of the symbol. 'a' denotes a period of no significance difference while 'b' denotes a period of difference between the fruit from irrigated and non-irrigated trees ($p<0.05$).

Fig. 2. Total soluble solids (A) and total titratable acidity (B) during growth and development of fruit from irrigated and non-irrigated mango trees. The arrow indicates the end of water stress period (42 DAB). Vertical bars represent SE of the mean of three replications. 'a' denotes a period of no significance difference while 'b' denotes a period of difference between the fruit from irrigated and non-irrigated trees ($p<0.05$).







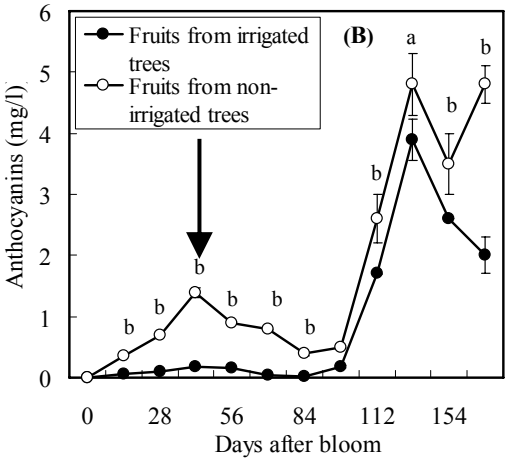


Fig. 3. Respiration rate (A) and fruit firmness (B) during growth and development of fruit from irrigated and non-irrigated mango tree. The arrow indicates the end of water stress period (42 DAB). Vertical bars represent SE of the mean of six replications. 'a' denotes a period of no significance difference while 'b' denotes a period of difference between the fruit from irrigated and non-irrigated trees ($P<0.05$).

Fig. 4. Pulp β-carotene (A) and peel anthocyanins (B) content during growth and development of fruit from irrigated and non-irrigated mango trees. The arrow indicates the end of water stress period (42 DAB). Vertical bars represent SE of the mean of three replications. 'a' denotes a period of no significance difference while 'b' denotes a period of difference between the fruit from irrigated and non-irrigated trees ($p<0.05$).

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