PHYSIOLOGY AND POSTHARVEST BEHAVIOUR OF MANGO (*Mangifera indica* L. cv. TOMMY ATKINS) FRUIT GROWN UNDER WATER STRESS

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(Food Science and Postharvest Technology)

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

2007

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A thesis submitted in partial fulfillment for the Degree of Master of Science in Food Science and Postharvest Technology in the Jomo Kenyatta University of Agriculture and Technology

2007

DECLARATION

This thesis is my own original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as University supervisors

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DEDICATION

I dedicate this work to my father Joseph Madigu, my mother Ann Madigu, my fiancée Osborn, my brothers Godfrey and Allan and my sisters, Margaret, Lydia and Evelyn for their persistent support and encouragement as I pursued this task.

ACKNOWLEDGEMENTS

I express my sincere gratitude to my supervisors, Professor Francis Mutiso Mathooko for his guidance and dedicated support, to Dr. Christine Onyango and Dr. Wills Owino for continuing academic advice. Thanks for believing in me. I am grateful to Mr. Paul Karanja and Mr. David Votha for assisting me with the running of the equipment especially the high performance liquid chromatography and the atomic absorption spectrophotometer. I thank my father for his financial support throughout my study, Jomo Kenyatta University of Agriculture and Technology for sponsoring the research work through a research grant to Prof. F.M Mathooko, Prof. E.M. Kahangi and Dr. C.A Onyango and the Mangusa's, Yatta for allowing me to use their farm as an experimental field. It was not possible to mention by name all the organisations or individuals who helped to make this study a success but to all of you I say ''Asante Sana''

Finally, I thank the almighty God for giving me strength and determination in pursuing this course.

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ABSTRACT

The study mainly aims to establish proper maturity indices and postharvest behavior of mango fruit of Tommy Akins variety, the effects of irrigated and water-stress on the development, maturity indices and posthavest behavior of this fruits. The fruits were sampled from a farm in Yatta Division, Machakos district.

Changes in various physical, physiological and biochemical were monitored during fruit development from fruit set to maturity. Among the measured parameters include changes in size and weight, sugar, titratable acidity, total soluble solids, and β-carotene pulp content, anthocyanin and chlorophyll peel content, mineral peel and pulp content, respiration and ethylene production rates. In addition, postharvest changes in these parameters were determined. Fruit weight, diameter, length, sugars (sucrose, fructose and glucose), starch showed a steady increase with time declining towards fruit maturity. Total titratable acidity increased just before maturity and decreased at maturity. Total soluble solids increased as the fruit approached maturity irrespective of the treatment. β-carotene content increased with growth of the mango fruit. Anthocyanins content showed a variance but later decreased towards fruit maturity, no ethylene was detected although respiration rates showed a true climacteric curve. There was a high correlation observed between the increase in firmness and starch r^2= 0.86 and 0.96 for fruits from irrigated and non-irrigated, respectively. Vitamin C content varied at different stages of growth and development.

Fruits from irrigated and non-irrigated were harvested at 168 DAB (Days after bloom). Fruits from non-irrigated trees had higher percentage weight loss than those from irrigated trees. Individual sugars (sucrose, fructose and glucose) might have increased steady with fruit ripening while starch content, total titratable acidity all decreased with increase in storage days. Total soluble solids increased in both treatments. Respiration rates showed a true climacteric curve. β-carotene increased steadily decreasing at 9 days in storage while the anthocyanin content, firmness and ascorbic acid content decreased with time.

A high correlation was observed between the increase in length and diameter r^2= 0.992 and 0.996 in the fruits from irrigated and non-irrigated trees, respectively. The formula of the equation can be calculated and therefore used by farmers. This is accompanied by an increase in glucose, total soluble solids and a decrease in starch content and firmness. Fruits from irrigated trees matured earlier than those from non-irrigated trees. The mango fruits from non-irrigated trees had a longer shelf life than those from irrigated trees most probably due to a late maximum climacteric peak and higher degree of firmness, a characteristic that makes them good for dessert and export market. The fruit from irrigated trees were higher in total soluble content and β-carotene but had a short shelf life and reduced firmness that makes them suitable for juice production industry and local market.

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Introduction

Mango (*Mangifera indica L.)* is one of the most important fruit crops in the tropical and subtropical lowlands. It is native to India, Bangladesh, Myanmar and Malaysia, but can be found growing in more than 60 other countries throughout the world (Salim et al., 2002).

The mango is best adapted to a warm tropical monsoon climate with a pronounced dry season (>3 months) followed by rains. However, information from other countries indicates that crops cultivated for a long time over an extended area show a high degree of diversity due to varied environmental influences. This characteristic is likely also true for mango seedlings first introduced in Kenya which were all polyembryonic (Griesbach, 2003).

Over, 20 cultivars of mangoes are grown in Kenya, among them are: Alphonso, Apple, Carabao, Dodo, Haden, Heart, Irwin, Kent, Keit, Kensington, Ngowe, Nimrod, Peach, Sensation, Tommy Atkins and Van Dyke. Of these, a few have steadily lost ground to a generation of cultivars introduced in the 1970s and 1980s like Tommy Atkins. Tommy Atkins originated from Florida and belongs to the Anacardiaceae family a member of *Mangifera indica L.* (Griesbach, 2003). Tommy Atkins is distinguished by greater resistance to diseases such as

anthracnose (caused by *Colletotrichum spp)* and powdery mildew (caused by *Oidium spp),* very attractive colour, excellent shipping and shelf-life qualities.

Worldwide mango cultivation now covers approximately 2.9 million hectares (FAO, 2001) and earns nearly US$ 500 million in export revenues. The production has increased partly due to increased land under cultivation and improved varieties. In Kenya the area under mango cultivation rose from 500 ha in 1970 to approximately 15,000 ha in 2005 (Mumero, 2005). Despite the increase in production of mangoes, 40-60% of this crop is lost through poor postharvest handling systems (HCDA) (Horticulture Crop Development Authority, 2003).

Depending on cultivars and environmental conditions it takes 90 to 160 days after flowering for Kenyan mangos to reach maturity. Not all fruits on one tree ripen at the same time. A major problem is to determine precisely the stage at which the fruit is ripe for picking. Fruits harvested too early will be of inferior quality after storage and will shrivel during postharvest storage; however, fruits picked when too ripe cannot be stored for any length of time and may give rise to problems such as jelly seed (Griesbach, 2003). The fruit will have its best flavour if allowed to ripen on the tree. The tests currently used to determine ripeness of mango, such as acid, sugar content or specific gravity are not fully reliable (Griesbach, 2003). For farmers to produce fruits that are of good quality both for export and local markets they need a maturity index that are affordable and that can be easily determined in the field.

Irrigation has been reported to affect the fruit composition and quality in various climacteric fruits such as grapes (Williams and Matthews, 1990), braeburn apples (Mills et al., 1996), stone fruits (Crisostol et al., 1997), mango cv. 'Lirfa', grafted on 'Maison Rouge' (Lechaudel et al., 2005), but little has been done on mango fruit. This project aimed at establishing maturity index and quality of Tommy Atkins subjected to irrigation and water stress during growth and development and its effect at postharvest storage.

1.2. Problem Statement

In Kenya, the bulk of mangoes are produced by small-scale farmers. These fruits experience seasonal gluts leading to a high percentage of postharvest wastage. This is because of senescent deterioration, pests and diseases, poor handling practices and lack of storage facilities (Joseph and Aworh, 1991).

Advanced cultural practices coupled with improved fruit cultivars, have in recent years contributed to superior quality of mango at harvest and increased yields. Unfortunately, the impact of these horticultural and technological improvements have not fully been realised as a high percentage of this commodity is lost after harvest due to poor postharvest handling practices (Mathooko, 1995), thereby affecting food security. The problem is made worse by lack of proper harvestable maturity indices. Mango fruits are harvested commercially within a range of maturities including immature green, mature green and tree ripe (Mitra and Baldwin, 1997) stages that have different impact

on fruit quality. When the fruits are harvested immature they tend to have inferior quality, shrivelling on storage. On other hand when the fruits are picked when too ripe, the fruits develop the best flavour but they do not store for a considerable length of time. This means the stage of harvest is very important because postharvest characteristics are affected by stage of maturity at harvest. With increasing production, and the fact that this commodity forms the bulk of fruits for local and export markets, then proper postharvest handling is important in order to expand market opportunities. This will increase generated income and hence alleviate poverty.

1.3. Rationale and Justification

Mangoes are the most popular and choicest of the commercial fruits produced in the tropics due to their extremely excellent flavor, attractive fragrance, beautiful colour, delicious taste and health-giving properties (Tasneem, 2004). However, these fruits are delicate and many cultivars cannot withstand long distance transportation, often reaching the market in a mushy, overripe state. Storage and maturity indices of mangoes continue to be challenging problems that need more attention. Indeed poor postharvest handling has been identified as one of the constraints in the mango industry in Kenya. Therefore, development of maturity indices for harvesting mangoes will result in a sound mango industry in Kenya especially during marketing and distribution.

A number of farmers in the arid and semi-arid lands irrigate their mango trees. The influence of this on fruit development, quality and postharvest behaviour has not been well documented. Harvest time represents a compromise between leaving the fruit on the tree long enough to maximize yield (quality) but harvesting early enough when it still has sufficient green life is best for effective marketing. It is, therefore, important to harvest the fruit at an optimum mature stage, which can only be achieved by the determination of proper maturity indices. Furthermore, mango growing can become more viable when one is able to predict the harvestable maturity, because this helps to seek markets before hand, thus reducing the postharvest losses while maintaining product quality during retail/export distribution. This will reduce mangoes price fluctuations thereby enabling farmers to obtain better profits.

1.4. Research Objectives

The main objective of this study was to establish the proper harvestable maturity indices and postharvest behaviour of mango *(Mangifera indica* L.) fruit.

The specific objectives of this study were to:

a) Establish fruit growth and development patterns of mango (*Mangifera indica* L. cv. Tommy Atkins) fruit in irrigated and non-irrigated trees.
b) Identify physical, physiological and biochemical parameters that correlate well with harvestable maturity and quality, and therefore, establish optimum harvestable maturity indices for mango fruit.

c) Determine the effects of irrigation and water stress on the growth and development and their effect on potential harvestable maturity indices.

d) Study the postharvest behavior of the fruits from irrigated and non-irrigated trees after harvesting at potential harvestable maturity indices.

1.5. Hypothesis

(a) Establishment of clear maturity indices will improve postharvest fruit quality and reduce postharvest loss.

(b) Pre-harvest water stress affects the quality and postharvest behavior of mango fruit.

CHAPTER TWO

LITERATURE REVIEW

2.1. Fruit growth and Development

Plants and plant parts progress through a dynamic series of genetically controlled developmental processes terminating in their eventual senescence and death. Their development is the combination of both growth (an irreversible increase in size) or volume (accompanied by the biosynthesis of new protoplasmic constituents) and differentiation (qualitative changes in the cells) and can be viewed at either the whole plant or individual organ level. During the developmental period, plants display a remarkable degree of variability in form that is strongly influenced by the environment in which they are grown (Kays, 1991). Environment has pronounced influence on the development of plants and plant parts, and this influence carries over into the postharvest period. Variations in composition and structure can significantly alter the way a product responds after harvest and as a consequence how it must be handled. If the physical and chemical changes occurring during the postharvest period are to be understood, it is essential that first there is an understanding of how the postharvest period fits in to the entire developmental cycle of the plant (Kays, 1991).

The ability to reproduce is a unifying and essential characteristic of all organisms. In the plant kingdom, sexual reproduction by way of flower and seed production is one of the most common (Kays, 1991). Flowering represents

a distinct stage in the overall developmental cycle of most plants. Flowering in mango trees can be induced by water/drought stress. Dry weather preceding and during the bloom period is considered optimum for good fruit production (Crane et al., 1994). Older trees respond better than young ones (Griesbach, 2003). For optimum growth and productivity, 20-26°C is believed to be ideal temperature during flowering and ripening. Temperatures exceeding 40°C may, especially in hot/dry areas, lead to sunburn of fruits and stunting of tree growth.

Different authors have found the developmental pattern of mangoes to vary. For instance, Subhadra and Subramanyam, (1970) found Alphonso mango to take about 16 weeks to reach complete development with the physical increase in size and weight slacking between 9-14 weeks after fruit set. Leley et al. (1943) and Mukerjee (1959) found the mango fruit to take 21 weeks to maturity while the increase in size and weight stopped 4-5 weeks before harvest.

A respiratory climacteric during the early stages of fruit development has also been reported in mango (Singh et al., 1937), peaches and plums (Roux, 1940) and apples (Kidd and West, 1945). Ascorbic acid and acidity reached a peak around the 5^{th} and 7^{th} week, respectively but decreased towards fruit maturity. Sugar content declined throughout the period of growth while starch continued to increase with growth and development (Subhadra and Subramanyam, 1970). The wide variation in physical, physiological and biochemical developmental

patterns necessitates more systematic studies to obtain a clear understanding. It is also important to correlate the physical, physiological and biochemical parameters if reliable results are to be found.

2.2. Fruit Maturation

Maturity describes the stage of internal fruit development. Maturity may be defined in terms of either physiological or horticultural maturity and is based on the measurements of various qualitative and quantitative factors. Maturity is a stage of development superimposed on the plant or plant part relative to human needs. The fruit is considered mature when it meets the requirements for harvest (harvestable maturity) (Kays, 1991). Maturity at harvest is the most important factor that determines storage-life and final fruit quality (Kader, 2002). Immature fruits are more subject to shriveling and mechanical damage and are of inferior quality when ripe. Overripe fruits are likely to become soft and mealy with insipid flavor soon after harvest. Any fruit picked either too early or too late in its season is more susceptible to physiological disorders and has a short-life than fruit picked at proper maturity (Kader, 1999). Fruits have to be picked mature but unripe so that they can withstand the posthavest handling system when shipped long-distance (Kader, 2002).

During on-tree maturation of mangoes, neither firmness nor the sugar-acid ratio changes significantly (Nagle et al., 2005). As described for other mango cultivars (Leshem et al., 1986), a respiratory rise is stimulated by detachment from the parent tree, thus inducing postharvest ripening. Fruit softening and

parallel increase in the sugar-acid ratio, characteristic of acid degradation and initial sugar accumulation occurs at fruit ripening. Hence, the post-harvest ripening index (RPI) that specifies fruit ripeness based on these changes (Vasquez-Caicedo et al., 2005) cannot be used in detection of picking maturity. Thus there is need for a suitable method that can be easily adopted by small scale farmers in Kenya. This will increase income earned by the farmers thus eradicating poverty.

2.3. Determination of Maturity Stage

Many methods exist for determining the harvest time of mango that require a set of maturity-related physiological or quality attributes. Most currently used maturity indices are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide the needed flexibility in marketing (Kader, 2002). Producers and traders commonly use destructive methods that are inexpensive for determination of harvest time. Such methods are based on pit hardening and the mesocarp color change around endocarp (Crane and Campbell, 1994). Thresholds of acidity and contents of soluble solids, carbohydrates and phenolics have also been used (Lakshminarayana, 1980). However, differences exist between mango varieties. In some cases, access to technological resources, such as a laboratory, and considerable expertise are needed. Most producers are ill-equipped to accurately determine the best time for harvest and remain using unsophisticated methods based on experience with no real standardization.

Maturity indices for various horticultural crops have relied on different features of the commodity, such as duration of development, size, density, starch or sugar content, color and firmness (Shewfelt, 1993). Firmness and color are good indices used to determine overripe peaches during processing (Tyson et al., 1975; Horton, 1992).

Fruit showing some yellow colour on the tree has a shelf life of only a few days and must be sold in the local market. For export market, the fruit are picked when firm and at the mature-green colour stage. A fruit harvested at the mature green stage ripen quite rapidly after harvest and begin to turn yellow within 3 to 5 days at ambient temperature. A fruit harvested immature green does not ripen properly, taste poorly, and shrivels (Medlicott et al., 1986). Although color changes when the mango matures, it is an unreliable maturity index more so because it varies with variety and light exposure (Haller, 1952; Lott, 1965). Color measurements can also be affected by the condition of the fruit surface and the amount of trichomes. Moisture on the fruit surface can decrease the L* value (Delwiche and Baumgardner, 1983).

Pectic substances are structural polysaccharides responsible for the firmness of fruits. Softening of fruit occurs when these polymers become less tightly bound in the cell walls during ripening. Therefore, firmness could also be used as an index for fixing optimum stage of maturity for harvest (Kudachikar et al., 2001). Reduction in firmness may also be due to accelerated ripening process in free atmospheric conditions of storage temperature. Similar findings have

been reported in mangoes of other varieties (Doreyappa-Gowda and Huddar, 2001; Opara et al., 2000). Since firmness is affected by many conditions, it is important to use firmness together with other maturity indices in order to get reliable results.

Some technologies like near-infrared (NIR) spectroscopy offer a reliable tool to specify postharvest ripeness of mangoes (Mahayothee et al., 2004) or their fruit quality (Schmilovitch et al., 2000). Near-infrared quantification of starch and dry matter contents has been suggested to determine picking maturity of mangoes (Saranwong et al., 2003). Although NIR measurements have been integrated in large-scale automated sorting of various fruits (Schmilovitch et al., 1999), such technologies are still not widely available for use in the mango orchard. Moreover, they require comprehensive calibration based on precise knowledge of the maturation kinetics, of suitable thresholds for picking maturity and are expensive for a developing country like Kenya.

2.4. Fruit Ripening

Fruit ripening is the composite of the processes that occur from the latter stages of growth and development through the early stages of senescence. Ripening results in characteristic aesthetic and /or food quality, as evidenced by changes in composition, colour, texture or other sensory attributes (Kader, 2002). The ripening process of fruit involves a series of biochemical reactions or metabolic activities. The changes cause chemical changes, increased respiration, ethylene production, change in structural polysaccharides causing softening, changes in

carbohydrates or starch conversion into sugars, organic acids, lipids, phenolics and volatile compounds. Others includes degradation of chlorophyll and unmasking of preexisting pigments such as anthocyanins and carotenoids, thus leading to ripening of fruit with softening of texture to acceptable quality (Herianus et al., 2003).

Softening is one of the most significant quality alterations consistently associated with the ripening of fleshy fruits. Alterations in texture affect both the edibility of the fruit and the length of time the fruit may be held. Once the softening process is initiated, the rate of textural change is a function of the type of fruit and the conditions under which the product is held. Often acceptable flesh texture represents a very narrow range that can be rapidly exceeded, diminishing the quality of the product (Kays, 1991).

During ripening, the taste of many fruits changes due to alterations in sugars that enhance palatability of the fruit. With fruits that must ripen while attached to the parent plant, sugars increase via translocation of sucrose from the leaves. For instance, upon arrival, sucrose in grapes is hydrolyzed by invertase, forming glucose and fructose. In some climacteric fruits such as mangoes, changes in internal sugars represent products derived from hydrolysis of starch reserves by α- amylase and β- amylase and/or starch phosphorylase. The activity of these enzymes increases markedly during the ripening of many fruits (Kays, 1991).

Changes in acidity are also important in the development of the characteristic taste in many fruits. During ripening, there is a decrease in organic acids in most fruits. This loss is due largely to the utilization of these compounds as respiratory substrates and as carbon skeletons for the synthesis of new compounds during ripening. The decrease in total acidity in the grapes tends to coincide with the onset of ripening and the accumulation of sugars. The concentration of organic acids does not, however, decline in all fruit during ripening. In the bananas, there is a significant increase in the concentration of malic acid and a decrease in pH (Kays, 1991).

Aroma of a fruit is extremely important quality criterion and as fruits ripen there is an increase in the rate of synthesis of these volatile compounds. Over 200 different compounds have been identified in a variety of other fruits (Nursten, 1970). Only relatively a small number of the total complement of volatile compounds, however, tends to make up the characteristic aroma perceived for a specific fruit (Kays, 1991).

Changes in fruit colour may or may not coincide with the development of the other quality criteria associated with ripening. With apples, colour development does not closely parallel the respiratory climacteric. Colour, therefore, is not generally an acceptable means of assessing ripeness of this fruit. There is, however, a relatively close association between colour changes and ripening in climacteric fruits such as the banana and bitter melon and non-

climacteric fruits such as the cherry, blue cherry (Vaccinium spp.), and strawberry (Kays, 1991).

Mangoes exhibit climacteric ripening behavior characterized by decrease fruit respiration during development (preclimacteric minimum) followed by a rise in respiration levels (the climacteric peak) until full ripeness and a subsequent respiratory decline (postclimateric) during fruit senescence (Biale and Young, 1980). The climacteric rise is associated with a sharp increase in ethylene production in fruit like mangoes which induces ripening. Ethylene levels at harvest influence the magnitude of the climacteric curve, and therefore, the final product quality (Lalel et al., 2003). Fruits harvested too early do not undergo the desired ripening changes and a late harvest will lead to off-flavor and reduced shelf life.

Fruit softening occurs very rapidly and is one of the main causes of quality deterioration during postharvest handling. This includes changes in ascorbic acid content, loss of volatile aroma components and textural properties (Sablani et al., 2006). This poses a big challenge during transportation and distribution, and results in considerable postharvest loss. For mangoes, in order to avoid the excessive damage of fully ripe fruits, the fruits are harvested at earlier stages, resulting in firmer fruits but with inevitable negative effects on final fruit quality. In the absence of clear harvest indices, this problem will continue to persist.

Light exposure affects fruits quality and storage period. For example large differences in soluble solid concentration, acidity, and fruit size were detected between fruit obtained from the outside and inside canopy positions of open vase trained peaches trees (Marini, 1991; Saenz, 1991). During the season it was observed that fruit grown under a high-light environment (outside canopy) has a longer shelf life (storage and market) than fruit grown under a low-light environment (inside canopy). Investigation that are based on improving the quality of mango at preharvest are of importance more so because most preharvest factors affect post harvest storage of fruits.

2.5. Postharvest Changes in Mangoes

The shelf life of mango varies among its varieties depending on storage conditions. It ranges from 4 to 8 days at room temperature and 2-3 weeks in cold storage at 13°C (Carrillo et al., 2000). A difference among varieties exhibits 4 days of shelf life for Baneshan, Tommy Atkins and Kit (Narayana et al., 1996; Rodov et al., 1997) as compared to 8-9 days of Alphonso (Raje et al., 1997; Srinivasa et al., 2002). Usually after harvest the ripening process in mature green mango takes between 9-12 days (Herianus et al., 2003) or 12-14 days (Manzano et al., 1997) with good flavor, texture and colour characteristic at ambient conditions.

Spoilage of mango due to stem end rot and anthracnose limits its storage potential and the shelf life is decided on the basis of spoilage (10%) during storage (Narayana et al., 1996). Most postharvest pathogens are present on the

fruit surface at harvest and cause decay where the tissues are wounded or soften sufficiently in storage to permit pathogen penetration and infection (William and Whitaker, 1997). The stage at harvest affects the quality of mangoes and their postharvest life. Fruits harvested too early will be immature with inferior quality after storage; however, fruits picked when too ripe cannot be stored for any length of time and may give rise to problems such as jelly seed. Shriveling of immature fruit occurs at room temperature due to excessive loss of water from fruit due to skin evaporation (transpiration) and to some extent respiration. This makes the fruit appearance to deteriorate thus reducing its market value. Reduction of post harvest losses increases food availability to the growing human population, decreases area needed for production and conserves natural resources (Kader, 2003).

Many methods exist for extending fruits shelf life of mangoes such as Modified atmosphere packaging (MAP) and the use of low-temperature storage. MAP has been suggested but it requires careful handling to prevent damage to bags and loss of the modified atmosphere. The main factor, that maintain mango quality in various film packaging are increased CO_2 and decreased O_2 levels, which reduce respiration rates and prevent water loss (Chaplin et al., 1982; Miller et al., 1983; Yuen et al., 1993; Rodov et al., 1997). However despite its success at the laboratory level (Chaplin et al., 1982; Miller et al., 1983; Yuen et al., 1993; Rodov et al., 1997), MAP is still not a commercial technique.

The low-temperature storage has been use in an attempt to prolong storage life (Medlicott et al., 1990). In practice, the minimum temperature for storage of most tropical fruits is determined by their susceptibility to chilling injury (CI). Between 12 and 13°C generally is considered as optimum for mango storage (Kalra and Tandon, 1983 and Medlicott et al., 1987) although suitable temperature has been given as 10°C (Thomas, 1975) and 5°C (Abou Aziz et al., 1976; Thomson, 1977). The variation in reported optimum temperature may be a cultivar's effect, and may also be related to the stage of harvest maturity and ripeness of the mangos when placed in storage (Medlicott, 1990). The technology is not widely spread in Kenya because of the difference that exists between cultivars, lack of proper harvestable maturity indices and high cost of refrigerators.

2.6. Preharvest Water Deficit

Water stress is a universal problem in the production of agricultural plant products. Severe water stress results in increased sunburns of fruits, irregular ripening of pears, tough leathery texture in peaches and incomplete kernel development in nuts (Kader, 2002). Excess water results to cracking of fruits (such as cherries and prunes), excessive turgidity leading to increased susceptibility to physical damage, reduced firmness, delayed maturity and reduced soluble solids content (Kader, 2002).

Water deficits have been found to enhance red color development at preharvest and increases total soluble solids (TSS) and total titritable acidity (TTA) in

braeburn apples during postharvest storage (Mills et al., 1996). This, improved consumers' acceptance of the fruits. Water deficits also has been found to modify tree nutrition that in turn influences market life, quality and internal breakdown of fruits like apples (Bramlage, 1993) and stone fruits (Crisostol et al., 1997). It is, therefore, important to establish the effects of water deficit and irrigation with the aim of improving market value of mango (*Mangifera indica* L. cv. Tommy Atkins) fruit.

Despite the important role of water in fruit growth and development, no specific studies have been done on the influence of the amount of water applied on mango quality at harvest and post harvest performance. Therefore, this study seeks to understand the postharvest behavior of Tommy Akins, an important Kenyan mango cultivar.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Plant material

Mango (*Mangifera indica* L. cv. Tommy Atkins) fruit were sampled of growth, development and postharvest storage data. The fruits were sampled from a farm in Yatta Division, Machakos district. One set of trees was irrigated throughout the experiment while the other set was subjected to water stress until 42 days after bloom (DAB). This is because of the rainfall that was experienced in this region. Fruits were sampled for laboratory analysis from both sets of trees at intervals of 1 day for postharvest storage and 14 days for growth development data. For postharvest storage fruits were kept at ambient temperature. Data was analyzed using Genstat (13^{th} version) package (t-test; paired two samples for means).

3.2. Analyses and Physical Measurements

3.2.1. Fruit Harvestable Maturity-Length, Weight and Diameter

Changes in fruit weight were determined using a scientific balance (Model Libror AEG-220, Shimadzu Kyoto, Japan). Flowers were tagged and the time taken to develop to harvestable maturity determined. During the same period, the changes in length and diameter were determined using a caliper (Model Mitutoyo, Japan).

3.2.2. Pulp Sucrose, Fructose and Glucose Contents

Ten grams of fruit pulp was refluxed in ethanol for one hour. The sample was then concentrated by rotary evaporation and diluted with 75% acetonitrile. These individual sugars were analyzed using a high performance liquid chromatograph (HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) using a refractive index (RI) detector. The conditions were: oven temperature, 35^{o}C, recorder speed: 3, attenuation: 4, range: 4 flow rate: 0.5 ml/min, column: Reverse phase, NH_2P 250 X 4.6 mm, 5µm and 75% acetonitrile as an elution solvent.

3.2.3. Starch Content

This was done by the Starch staining method. A slice from the equatorial region of the fruit was dipped in I/KI (2g/10g) solution and rating was reported as a percentage using the Cornell Starch Chart, whereby 100% flesh coloration is equivalent to 3 while 0% is equivalent to no color change. This chart has a scale of 1-8 with 1, all starch and 8, no starch.

3.2.4. Pulp Total Soluble Solids Content and Total Titratable Acidity

Total soluble solids (TSS) content was determined using an Atago hand refractometer (Type 500, Atago, Tokyo, Japan) and expressed as ^{o}Brix while total titratable acidity (TTA) was determined by titration with 0.1N NaOH in the presence of phenolphthalein indicator. TTA results were expressed as % citric acid.

3.2.5. Ethylene Production and Respiration

Depending on the size of determined weight, mango fruits were placed in plastic jars ranging in volume from 100ml to12lt whose covers was fitted with a self-sealing rubber septum for gas sampling. The fruits were incubated for one hour 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). The gas chromatograph for carbon dioxide determination was fitted with a thermal conductivity detector and a Poropak Q and that for ethylene determination fitted with an activated alumina column and a flame ionization detector. Rates of carbon dioxide production were calculated as ml per kg per hr at standard atmospheric pressure while, the rates of ethylene production calculated as ήl per kg per hr.

3.2.6. Pulp β-Carotene Content

β-carotene content was determined by modified chromatographic procedure (Heionen, 1990). Twenty grams of fruit pulp was crushed in a pestle with a mortar after adding a spatula of hydroflorosupercel. The sample was extracted with 50ml acetone until the residue was white. Partitioning was done using 25ml of petroleum ether in a separating funnel to obtain the β-carotene rich upper layer. Saponification was carried out by adding an equal amount of upper layer extract in to 3ml of 10% KOH in methanol, and a few drops of 0.1% butyratehydrotoluene in petroleum ether. The mixture was kept in the dark for 16 hours after which it washed with water in a separating funnel until

it was clear. Sodium sulphate (anhydrous) was added to remove water and further concentration was done using a rotary evaporator. β-carotene content was determined using HPLC (Model LC-10AS, Shimadzu Corp., Kyoto, Japan). The conditions were as follows: the mobile phase was acetonitrile: methanol: dichloromethane in the ratio of 70: 10: 20, flow rate: 1.0 ml/min, column: ODS150, injection volume: 10µl, oven temperature, 35°C and UV-Visible detector.

3.2.7. Total Peel Anthocyanin Content

Three grams of the peel was ground and diluted with 100ml of distilled water. Sediment was removed by centrifugation. The sample was diluted with the same amount of buffers pH 1.0 (0.2M KCL and 0.2M HCL) and pH 4.5 (1M of sodium acetate and HCL) and the absorbance measured at 510nm and 700nm using a UV-Vis spectrophotometer (Model UV mini 1240, Kyoto Shimadzu). Samples diluted with the pH 1.0 buffer were left at rest for 15 minutes before measurements, whereas the samples diluted with the pH 4.5 buffer were ready for measurement after 5 minutes. The corresponding pure buffer solution was used as reference sample in the spectrophotometer. To correct for turbidity (haze) the absorbance at 700nm is subtracted from the absorbance at 510nm (the wavelength of maximum absorption). To calculate the difference in absorbance between the samples the following formula was used:

$$\Delta\text{Absorbance} = (A_{510\text{nm pH 1.0}} - A_{700\text{nm pH 1.0}}) - (A_{510\text{nm pH 4.5}} - A_{700\text{nm pH 4.5}})$$

Determination of anthocyanin content was based on Lambert- Beer's Law:

$A = \varepsilon CL$

A is the absorbance, which is measured with a spectrophotometer.

L is the path length in cm of the spectrophotometer cell.

ε is the molar absorbance, a physical constant for a molecular species in a given solvent system at a given wavelength. Molar absorbance values for purified pigments taken from the literature can be used, making it unnecessary to determine them. Molar absorbance is also referred to as the molar extinction coefficient.

C is the molar concentration and rearranging the Lambert- Beer's Law equation and multiplying by the molecular weight (m) of the pigment, the concentration in milligrams per liter is determined by:

$C\ (mg/l) = \Delta A/\varepsilon L \times M \times 10^3 \times D$

Where D is the dilution factor, and ΔA is the difference in absorbance of the sample at maximum absorption (510nm) in the pH 1.0 and pH 4.5 buffers.

3.2.8. Chlorophyll Content

Chlorophyll content was determined using the method of Arnon (1949) using a UV-Vis spectrophotometer (Model UV mini 1240, Shimadzu corp, Kyoto, Japan). Total chlorophyll was extracted with 80% acetone, and total chlorophyll, chlorophyll a and b contents were calculated using MacKinney's coefficients after measuring absorbance at 645nm and 663 nm in which:

$\text{Total chlorophyll content } (\mu g/g) = 20.2A_{645} + 8.02A_{663}$

Chlorophyll a content (μg/g) = $12.7A_{663}$ - $2.69A_{645}$ and

Chlorophyll b content (μg/g) = $22.9A_{645}$ – $4.48A_{663}$

3.2.9. Color Assessment

Color of both the pulp and peel were measured using a Minolta color difference meter (Model CR-200, Osaka, Japan) that was calibrated with a white and black standard tile. The L*, a* and b* coordinates were recorded and, a* and b* values converted to hue angle (H°), where $H^\circ = [(\tan^{-1} b^*/a^*)]$ (McGuire, 1992; Mclellan et al., 1995).

3.2.10. Mineral Content

Three grams of the pulp and peel were each dried in the oven, ashed in the muffle furnace and diluted with 1% HCL. The minerals determined included Mg, K and Ca. Analysis was done by atomic absorption spectrophotometry (AOAC (Association of Official Analytical Chemists)., 1996) method. Phosphorus content was determined using ascorbic acid method with the UV-Vis spectrophotometer (Model UV mini 1240, Kyoto Shimadzu).

3.2.11. Fruit Firmness

The firmness along the equatorial region of the fruit was determined using a rheometer (Model NRM-2010J-CW, Japan) fitted with an 8 mm probe. Firmness was expressed as Newton (N) (Joyce et al., 1993; Jiang et al., 1999).

3.2.12. Ascorbic Acid Content

Five grams of the pulp was ground and diluted to 100ml using 10% trichloroacetic acid (TCA). The indicator (2, 6-Dichlophenolindophenol) was titrated to 10ml of the fruit pulp filtrate till color changed. Ascorbic acid content was determined by visual titration according to AOAC methods (1996).

3.2.13. Statistical Analysis

Values for the various treatments were compared using t-test; paired two samples for means. Genstat (13^{th}version) statistical analysis was used.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Influence of Water Deficit on the Physiology and Physico-Chemical Characteristics of Mango Fruit during Growth and Development

The irrigated mangoes trees flowered one week earlier than non-irrigated ones. This suggests that water stress suppresses flowering in mangoes. Non-irrigated trees were supplied with water at 42 DAB.

4.1.1. Length, Diameter and Weight

Changes in the size (length and diameter) during the growth and development of fruits from irrigated and non-irrigated trees are shown in Fig.1. The length increased almost linearly and was proportional to DAB till 112 DAB when the relationship was broken in both fruits from irrigated and non-irrigated trees. After the termination of the water stress in 42 DAB, the fruits increased in length to 110 mm at 112 DAB, the length being greater than the length of 107 mm observed in the fruits from irrigated trees during the same period. The length and diameter of the fruit growth measured displayed single sigmoid curve and reached a maximum at 140 DAB for both the fruits from non-irrigated and irrigated trees. Single sigmoid curve were also reported during growth and development of Alphonso mango (Subhadra and Subramanyam, 1970) and bread fruit (Worrell et al., 1998).

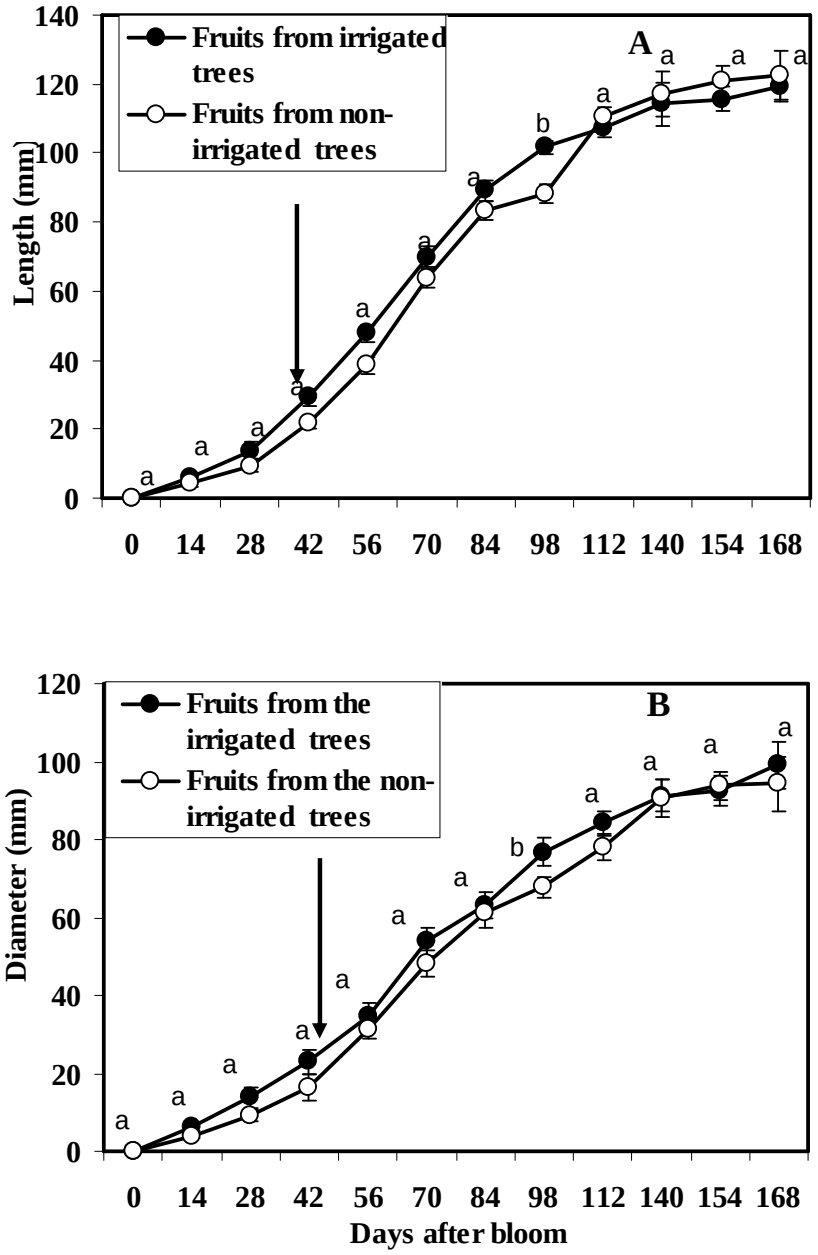

Figure 1. Length (A) and diameter (B) during growth and development of mango fruits from irrigated and non-irrigated trees. The arrows indicate the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The change in fruit weight during growth followed the typical sigmoid curve (Fig. 2). The weight changes of the fruits were minimal between 0 - 42 DAB. A similar trend has been reported during the early stages of growth and development of other fruits like Alphonso mango (Subhadra and Subramanyam, 1970), breadfruit (Worrell et al., 1998) and pear (Mwaniki et al., 2005). After 42 DAB there was a steady increase in weights that was almost linear to the increase in DAB, and the changes occurred in both fruits from irrigated and non-irrigated trees. A similar experiment carried out on fresh weight of mango fruit cv. "Lirfa," showed that weight increased almost linearly until 100 DAB and then tended to slow down (Lechaudel et al., 2005). Bollard (1970) reported that the major increase in fruit fresh weight towards maturity may be due to an increase in both cell size and intercellular spacing, thus allowing the maximum possible accumulation of assimilates.

Mango fruits from non-irrigated trees had less weight than mango fruits from irrigated trees. Lechaudel et al. (2005) found similar results when they studied irrigation management on 'Kensington' fruit. 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 decreases growth by slowing down the rates of cell division and expansion due to loss of turgor and increased synthesis of abscisic acid (Lawlor and Cornic, 2002).

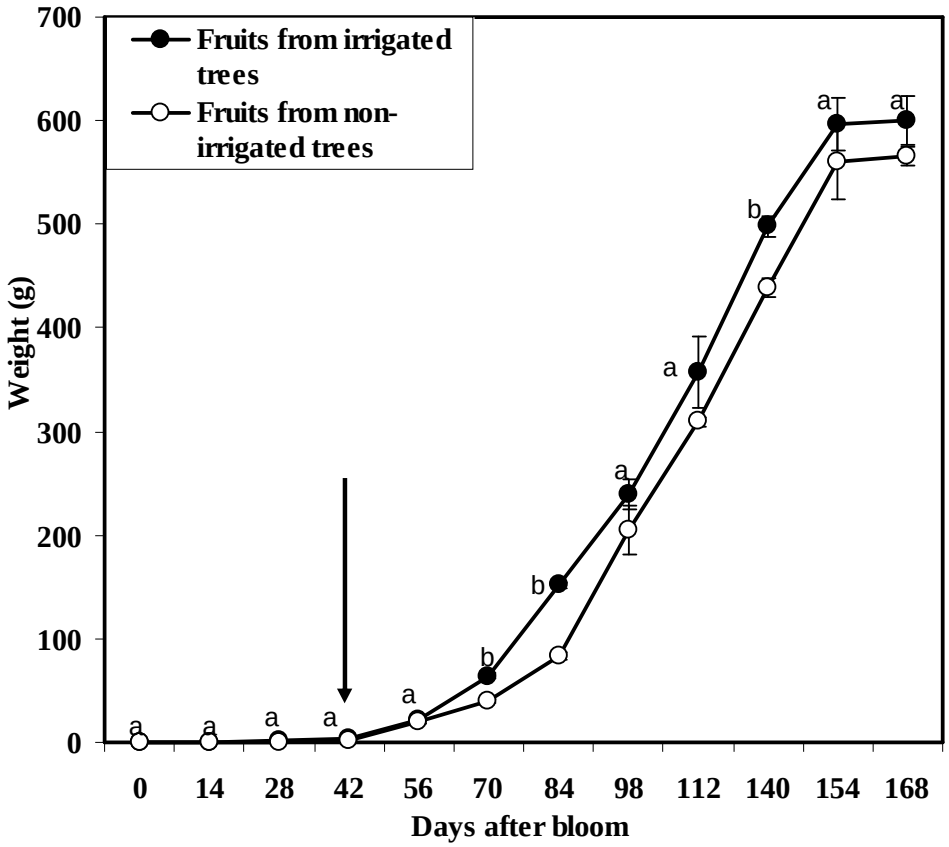

Figure 2. Weight during growth and development of mango fruits from irrigated and non-irrigated trees. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

A deficit in water supply affects many key metabolic and physiological processes in plants, the mechanisms which are still unclear (Tezara et al., 2002).

In general, there was a significant reduction in fruit size and weight under water stress (Halil et al., 2001). The termination of water stress had very little effect on the weight and size of the fruits. A high correlation was observed between the increase in length and diameter r^2= 0.992 and 0.996 in the fruits from irrigated and non-irrigated trees, respectively (Fig. 3). The length correlated to the rise of shoulders while the diameter correlated to swelling of the cheeks. The correlation shows the fruits attained harvestable maturity at 140 to 154 DAB for the fruits from the irrigated trees and 154 to 168 DAB for the fruits from the non-irrigated trees (Fig 3). This means that the fruits are ready for harvest at a length of 107- 115mm and a diameter of 85 to 95 mm for the fruits from the irrigated and a length of 118-122 mm and a diameter of 92 to 94 mm for the fruits from the non-irrigated. Length and diameter are maturity indices mostly used to assess maturity of mangoes by farmers. The formula of the equation can be easily calculated and therefore used by farmers in determining harvestable maturity of the mango fruit. This is a definite good maturity index because it is easily carried out, cheap and nondestructive.

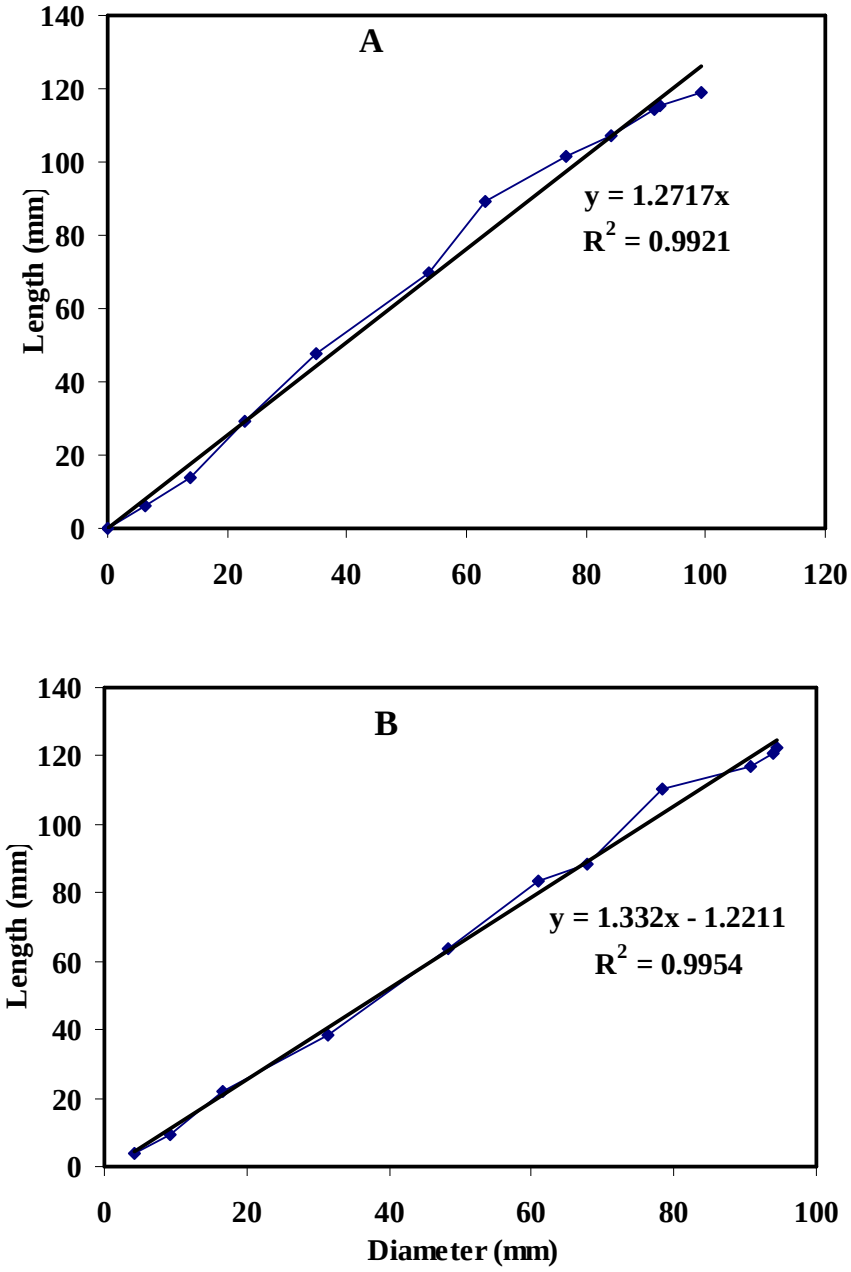

Figure 3. The correlation of length verses diameter of mango fruits from irrigated (A) and non-irrigated (B) trees during the growth and development period.

4.1.2. Pulp sugar content

The changes in the reducing sugars (glucose and fructose) and sucrose during the growth and development of fruits from irrigated and non-irrigated trees is shown in Fig. 4 and 5. Glucose decreased between 70 to 140 DAB but later increased as the fruits approached maturity. The initial decline in glucose may reflect the high sugar requirements for metabolism during the early developmental phase or the channelling of carbohydrates into starch, as has been found to occur in breadfruit (Worrell et al., 1998). Similar results were observed in Alphonso mangoes, with the glucose content reaching a maximum at about 21 days after fruit set with a slight fall being observed afterwards during fruit growth (Subhadra and Subramanyam, 1970). The beginning of starch hydrolysis at the latter stages of fruit development could also explain the high glucose concentration observed in larger fruit (Lechaudel et al., 2005). A sudden increase in glucose corresponds to the attainment of harvestable maturity in these mangoes.

Fructose increased throughout the growth and development period with a significant difference between the fruits from irrigated and non-irrigated being observed at 140 DAB. A maximum fructose content (52 and 54mg/100g) was observed as the fruits from irrigated and non-irrigated trees approached maturity where as a maximum glucose content of 14 mg/100g was found for the former and 16 mg/100g for the latter.

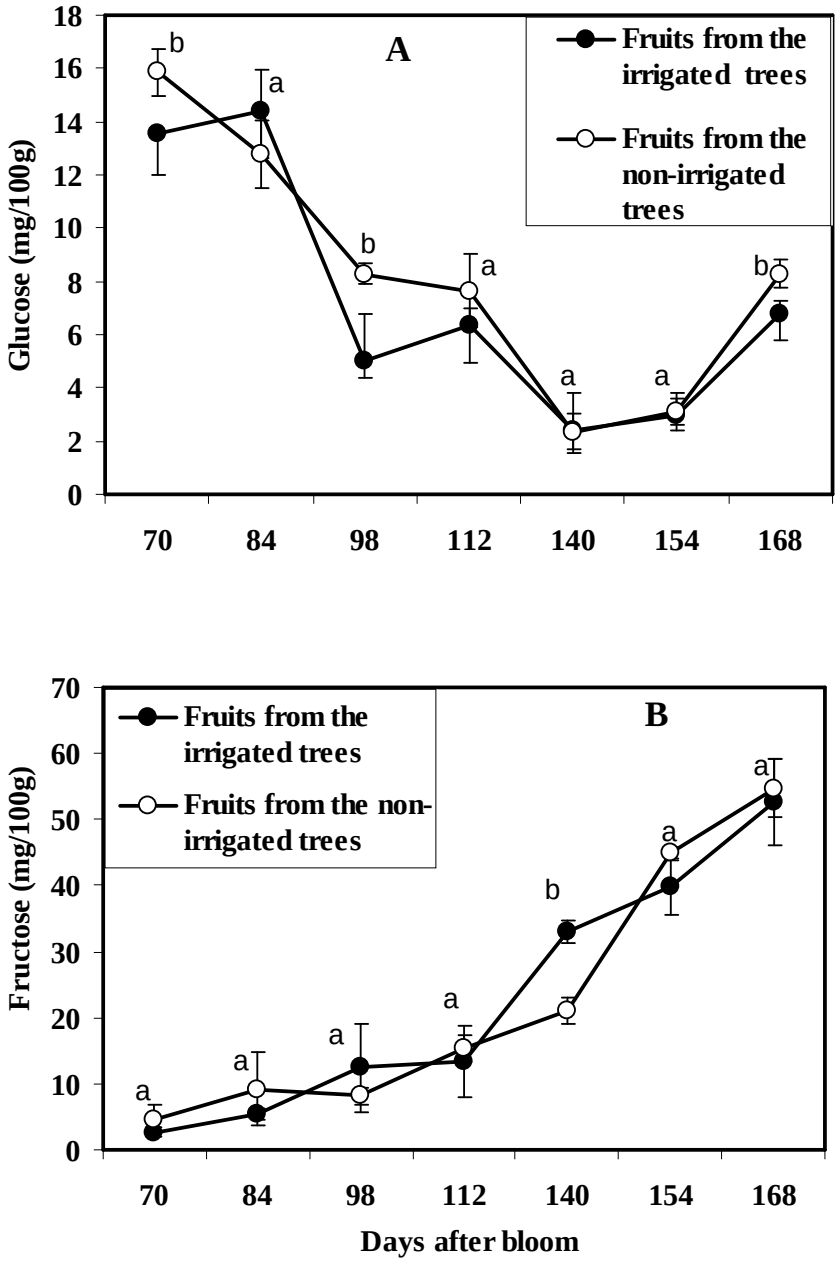

Figure 4. Glucose (A) and fructose (B) content during growth and development of fruits from irrigated and non-irrigated mango trees. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

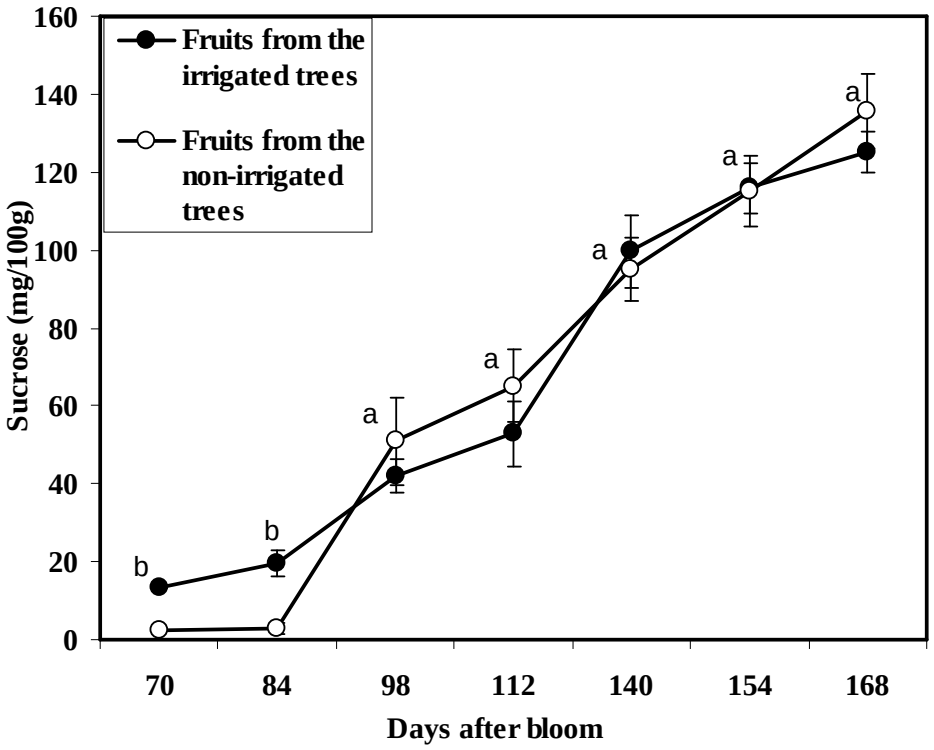

Figure 5. Sucrose content during growth and development of fruits from irrigated and non-irrigated mango trees. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b is a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The fructose content which was higher than glucose content agrees with results obtained by Lechaudel et al. (2005) who suggested that fructose represented about 20-30% of the total sugars during fruit growth and development and may be considered as a storage sugar.

Carbohydrate metabolism plays an important role during mango fruit development, particularly changes in starch content (Lechaudel et al., 2005). Fructose and glucose come from sucrose hydrolysis, glucose also being produced by starch hydrolysis. These hexoses fuel respiration and fruit growth. A high correlation was observed between the increase in sucrose and fructose r^2= 0.97 and 0.81 in the fruits from irrigated and non-irrigated trees, respectively. In the case of a shortage of assimilate supply, the role of higher fructose concentrations during fruit development in the osmotic adjustment has not been studied but may be a strategy to contribute to sustaining growth during periods of low assimilate supply (water stress) as reported in apple (Lechaudel et al., 2005).

There was a marked increase in sucrose content in both the fruits from irrigated and non-irrigated trees. Lechaudel et al. (2005) observed an increase in sucrose during growth and development of mango cv. 'Lirfa', grafted on 'Maison Rouge' in fruits from both the irrigated and non-irrigated trees.

In our study, the concentration of fructose and sucrose were higher than that of glucose. The sweet taste of mango fruit relies upon the storage of large

amounts of sucrose and fructose. Indeed, fructose and sucrose are 2.3 and 1.4 times sweeter than glucose, respectively (Lechaudel et al., 2005). Sweetness, however, is also affected by acid composition. Citric acid may decrease sucrose sweetness, (Bonnans and Noble, 1993) while malic acid may decrease that of fructose (Fabian and Blum, 1943). The decline of citric acid might enhance the sweetness of sucrose at ripening, although there was low correlation between the sucrose content and citric acid during growth and development period.

4.1.3. Pulp starch content

Starch content increased with time (Fig. 6). The fruits from the non-irrigated mango trees had higher starch content on the Cornell Starch Chart index. The lowest and highest content corresponded to 7.8, (0%) and 3, (100%), respectively. There was increase in starch content among fruit from irrigated trees the highest (96%) being observed at 112 DAB that corresponded to 3.8 on the Cornell Starch Chart index.

This finding agrees with results found by Subramanian et al. (1976) and Mattoo et al. (1975) who indicated that starch is the main carbohydrate present in mature green mango fruit. 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 catabolism reactions that resulted in to simple sugars as the fruit began to ripe. Reports of mango fruit starch hydrolysis have been reported during ripening (Lima et al., 2001; Tasneem, 2004).

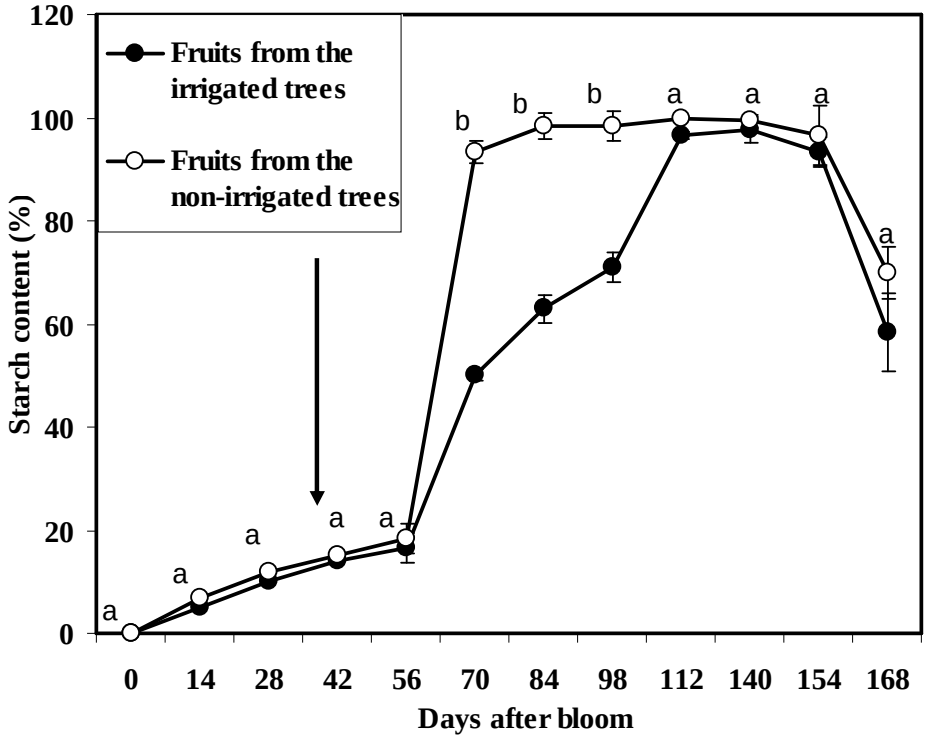

Figure 6. Starch content during growth and development of fruits from irrigated and non-irrigated mango trees. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The main monosaccharide include glucose and fructose and sucrose, a disaccharide is a predominant sugar that contributed to 57 % of total sugar in ripe mangoes cv. Keitt while fructose and glucose are present at 28 and 15%, respectively (Medlicott and Thompson, 1985).

Carbohydrate metabolism plays an important role during mango fruit development, particularly changes in starch content (Lakshimnarayana et al., 1970). Fruit maturation, which is another feature of fruit quality, may be evaluated by the patterns of different biochemical compounds such as starch or sucrose (Krishnamurthy and Subramanyam, 1970; Akamine and Goo, 1973; Mendoza and Wills, 1984).

4.1.4. Pulp total soluble solids and total titratable acidity

The mangoes had low TSS content during the period of growth and development (Fig. 7). The highest TSS content found in the fruits from irrigated trees was 2° Brix while the fruit from the non-irrigated trees was a 3°Brix at 28 DAB. The TSS content decreased as weight, size, firmness and starch content increased. Reducing water supply has been reported to decrease harvest weight but increase soluble sugar concentrations in pear (Ramos et al., 1994), apple (Kilili et al., 1996; Mills et al., 1996), citrus (Gonzalez-Altozano and Castel, 1999) and kiwi (Miller, 1998) fruits.

There was no significant difference ($p = 0.05$) in total soluble solids in fruits from both irrigated and non-irrigated treatments especially after termination of

water stress in the non-irrigated trees. Low TSS content during growth and development has also been reported in climacteric fruits like Jujube (*Ziziphus mauritiana* Lamk (Abbas and Fandi, 2002). The Low TSS content during the latter phase of growth and development could be caused by conversion of soluble carbohydrates into starch synthesis as observed by Worrell et al. (1998) in breadfruit or synthesis of alcohol-insoluble materials as reported in Alphonso mangos (Subhadra and Subramanyam, 1970).

In both treatments, at 112 DAB the TSS content began to increase most probably because the stored starch was being mobilized and broken down as the mango fruit approached harvestable maturity. The rise in total soluble solids could was also be attributed to partial breakdown of pectins, celluloses (Roe and Bruemmer, 1981).

The total tritratable acidity (TTA) increased during the initial stage of growth and development and decreased to a constant level (Fig. 7). The decrease occurred in fruits from both irrigated and non-irrigated trees. These findings are similar to those of (Lechaudel et al. 2005) who reported that as fruit maturity increases there is a decrease in acidity of flesh. The decrease in TTA content observed during growth and development has also been reported to occur in miniature golden apples in which a major decline was recorded 133 days after fruit set (Graham et al., 2004)

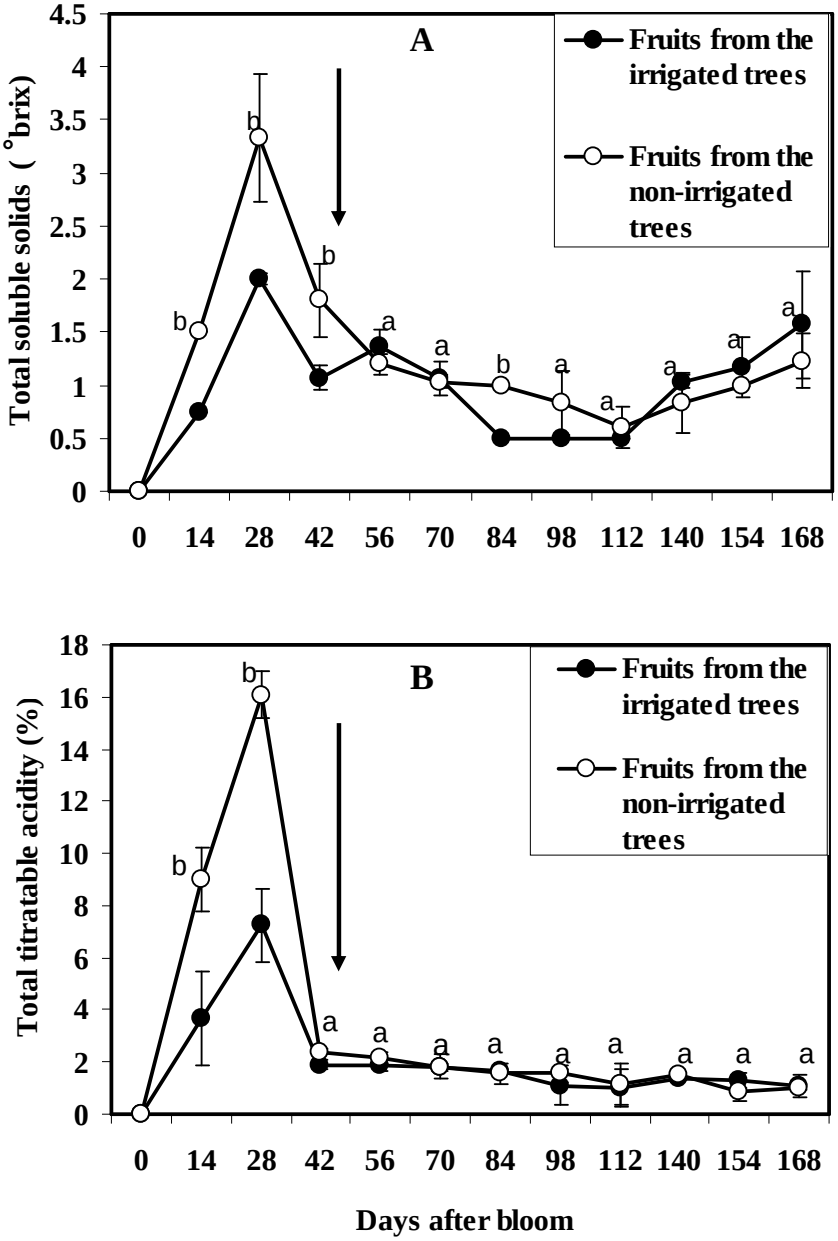

Figure 7. Total soluble solids (A) and total titratable acidity (B) during growth and development of fruits from irrigated and non-irrigated mango trees. The arrows indicate the end of water stress period. Vertical bars represent SE of the mean of three replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The fruits from non-irrigated trees recorded higher levels of TTA than those from irrigated trees and reached a peak of 16% at 28 DAB. The seasonal parabolic trends of TTA concentration described in mango flesh are similar to those observed for other fruits such as peach (Wu, 2002) and grapevine (Esteban, 1999). In various mango cultivars like 'Nam Dok Mai', 'Langra' or 'Dashehari', a rise in TTA has been reported during the early period of fruit development, followed by a decline until the end of their growth (Mendoza and Wills, 1984; Mukerjee, 1959).

Burton, (1982) suggested that the rapid decline in TTA may be due to acids being used in respiration or their transformation to other metabolites such as sugars and amino acids.

Our results showed no correlation between TSS and TTA during growth and development of mangoes fruits, although a certain drop in TTA with a gradual increase in TSS occurred especially from 112-168 DAB. Such changes are expected in order to enhance the sweetness that occurs at full maturity of mangoes.

4.1.5. Respiration and ethylene production rates

The respiration rates rose early between 14 and 28 DAB for fruits from both irrigated and non-irrigated trees, reaching a maximum of 72.4 ml/Kg/hr and 67.6 ml/Kg/hr respectively (Fig. 8).

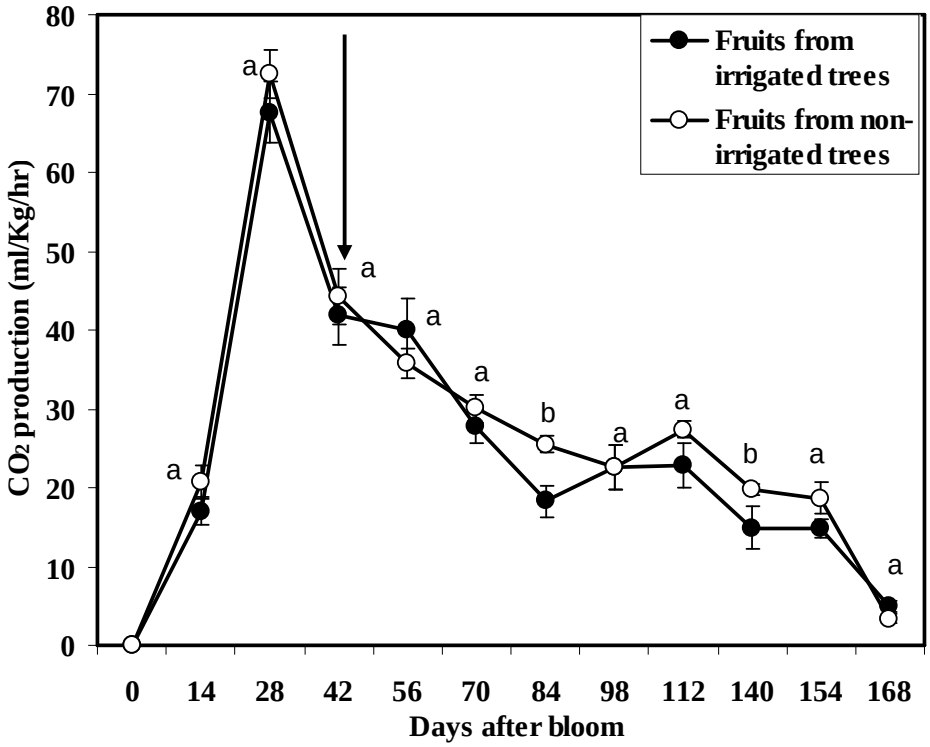

Figure 8. Respiration rates (CO_2 production) during growth and development of fruits from irrigated and non-irrigated mango tree. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

Thereafter the respiration rates (CO_2 production) decreased with increased fruit development, to reach climacteric minimum at 5.1 ml per kg per hr for the fruits from irrigated trees and 3.4 ml per kg per hr for fruits from non-irrigated trees. The high rates of CO_2 production detected during the very early stages of fruit development was likely to be related to intense cellular activity, particularly high rates of cell division, cell enlargement and cell differentiation in the tissues of the developing fruits as observed in Alphonso variety of mango (Subhadra and Subramanyam, 1970) and fleshy fruit (Graham et al., 2004).

Gillaspy et al. (1993) reported that passion fruit produced the most CO_2 in the earliest stages of growth, and this was attributed to intense cellular division, with no ethylene being detected.

There was no ethylene emission during this period of growth and development. Indeed no ethylene was detected during the growth and development of other climacteric fruits like miniature apple fruit (Graham et al., 2004), jujube (*Ziziphus mauritiana* Lamk) (Abbas and Fandi, 2002), apple (Reid et al., 1973).

4.1.6. Pulp carotenoid and peel anthocyanins content

The initial levels of β-carotene content were low (0.018mg/100g) for both fruits from irrigated and non-irrigated trees (Fig. 9). The β-carotene content increased as the fruit grew reaching a peak of 0.28 mg/100g in fruits from irrigated trees and 0.36mg/100g in the fruits from non-irrigated trees. The β-

carotene content increased faster in fruits from irrigated trees than in fruits from non-irrigated trees. The reason for this could be that mango fruits from irrigated trees grew faster and thus achieved maturity faster than fruits from non-irrigated trees.

At 168 DAB the β-carotene content in fruits from non-irrigated trees was higher than in fruits from irrigated trees. Lewallen et al. (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 carotenoids during ripening among mango cultivars.

The levels of carotenoids increased with a gradual decrease of anthocyanins in mangoes cv. Tommy Atkins. Anthocyanins content decreased from 0.17 to 0.023 mg/l between 42 and 84 DAB in fruits from irrigated trees and 1.4 to 0.39 mg/l in fruits from non-irrigated trees (Fig. 9). Medlicott et al. (1986) reported similar results during growth of mangoes cv. Tommy Atkins. At 98 DAB the anthocyanins content increased in fruits from both irrigated and non-irrigated trees with the highest (4.8 mg/l) being shown in the fruit from non-irrigated trees. The fruits from non-irrigated trees had higher anthocyanins content compared to fruits from the irrigated trees throughout the growth and development period. This may be attributed to reduced light penetration in the irrigated trees due to high canopy formed during this time.

Lewallen et al. (2000) reported that anthocyanins (red pigments) are light dependent and are not related to firmness or maturity in peaches.

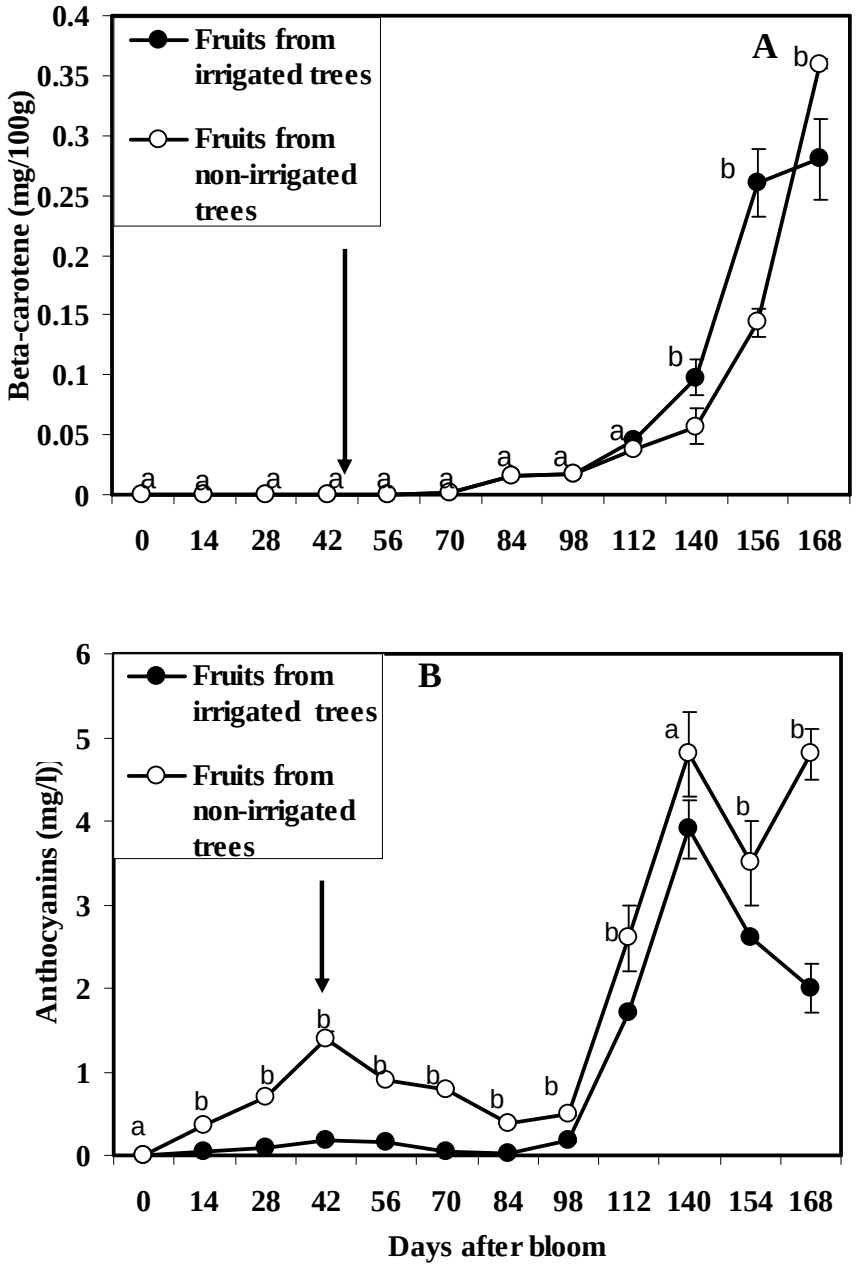

Figure 9. Pulp β-carotene (A) and peel anthocyanins (B) content during growth and development of fruits from irrigated and non-irrigated mango trees. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of three replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

Loreti et al. (1993) reported that development of anthocyanins, the pigment responsible for red colour development in the skin of peach fruit was influenced by solar radiation.

Anthocyanins began to decrease after 140 DAB in the fruits from irrigated; the time the fruits were approaching maturity. Anthocyanins are thought to accumulate during ripening when degradation of chlorophyll occurs in climacteric fruits like mangoes (Medlicott et al., 1986) and mangosteen as cited by Ratanamarno et al., (2004).

4.1.7. Peel chlorophyll content

Chlorophyll a and b content decreased as the fruit increased in size (Fig. 10). Total chlorophyll content decreased as the fruit grew in both treatments between 28 and168 DAB. The reduction being from 201 to 10µg/g for fruits from non-irrigated trees and (152 to 12µg/g) for fruits from irrigated trees (Fig. 11). During the early period of growth and development, total chlorophyll content in the fruits from the non-irrigated trees was higher than in those from irrigated trees (P= 0.01). There is a possibly that the fruits from non-irrigated trees were lagging behind in maturity compared to mango fruits from the irrigated treatment.

Chlorophyll concentrations in the fruit skin were initially low, but increased between 14 and 28 DAB falling off afterwards as full maturation approached.

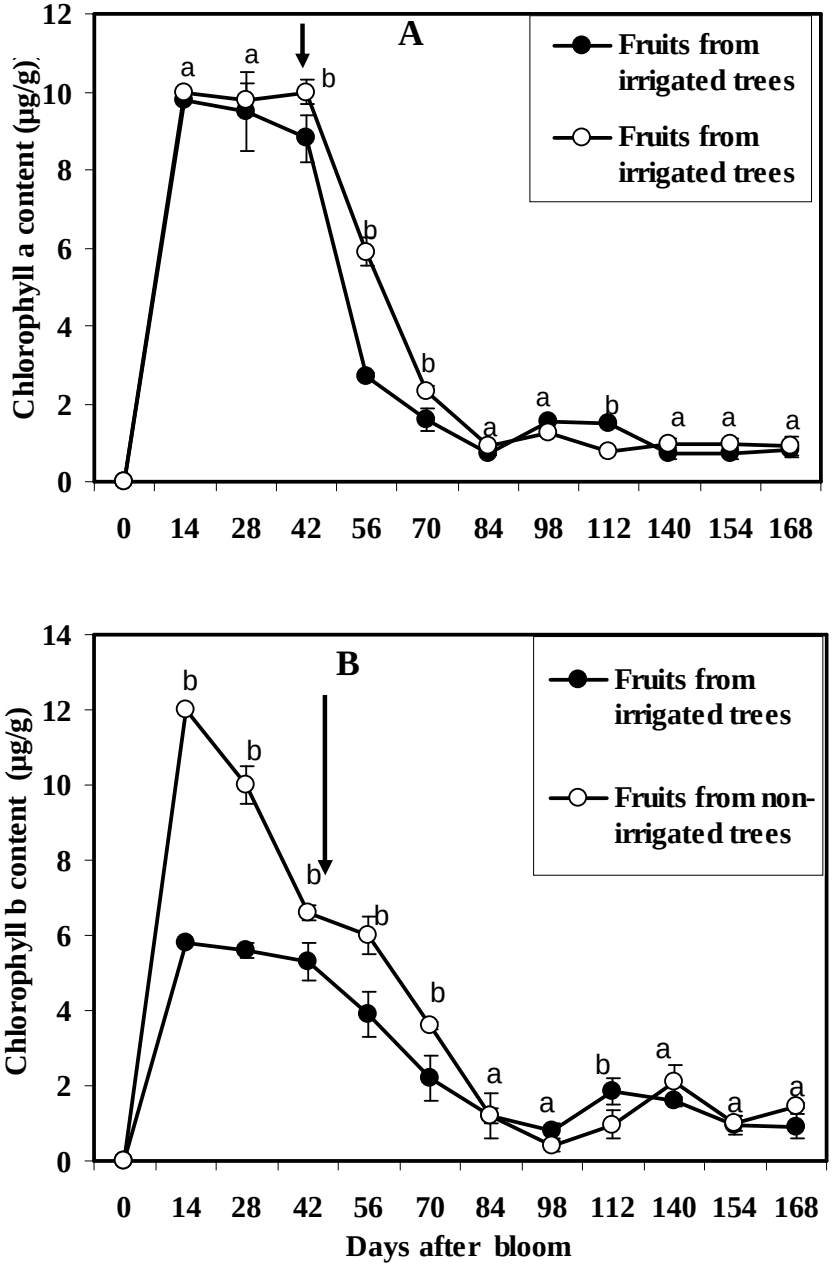

Figure 10. Chlorophyll a (A) and chlorophyll b (B) content during growth and development of fruits from irrigated and non-irrigated mango tree. The arrows indicate the end of water stress period. Vertical bars represent SE of the mean of 18 replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

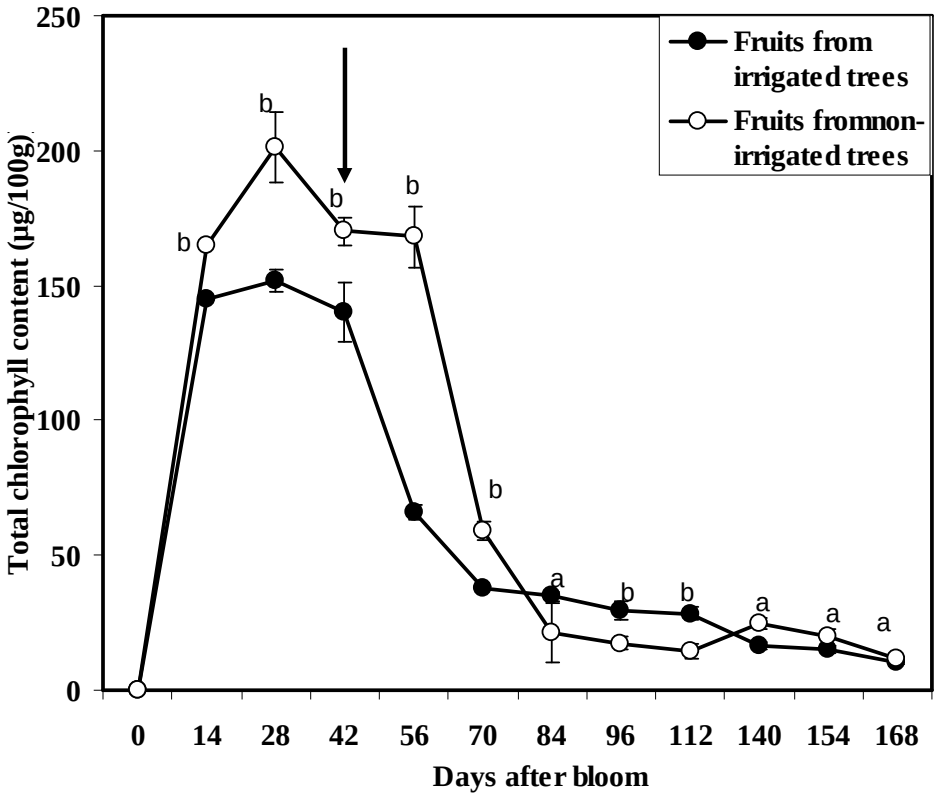

Figure 11. Total chlorophyll content during growth and development of fruits from irrigated and non-irrigated mango tree. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

This matched the observations found in breadfruit that showed skin color was initially light, darkened during early maturity and finally paled to a light green (Worrell et al., 1998).

Towards the end the of the development period, the fruits from non-irrigated treatment had higher chlorophyll content than those from irrigated treatment. The canopy formed in the fruits from irrigated trees may have interfered with light penetration that led to reduced chlorophyll synthesis in this fruits.

The decrease in chlorophyll could be attributed to peel color change of the fruit during ripening. The mango fruit from irrigated trees has chloroplast in the peel being converted into chromoplast, which has red or yellow pigments, while some remain green (Lizada, 1993). Medlicott et al. (1986) reported a decrease in chlorophyll during ripening when chlorophyll is degraded.

4.1.8. Colour

The colour changes in L* value and hue angle in both the peel and the pulp are shown in the Tables 1 and 2. The L* value increased with the increase in size until 112 DAB for fruits from non-irrigated and irrigated trees. Degreening in fruit was very apparent and was supported by changes in L* value which increased significantly in the range of 35 to 50 with the color changing from green to red -green to red yellow.

Table 1. L value of the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees.

	L value					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	ND	ND		ND	ND	
14	ND [b]	ND		ND	ND	
28	ND	ND		ND	ND	
42	35.5±5.50[c]	37.0±0.60	NS [e]	ND	ND	
56	41.0±4.40	37.0±2.50	NS	ND	ND	
70	44.2±4.10	38.9±2.50	NS	ND	ND	
84	46.0±0.90	39.2±1.90	** [d]	ND	ND	
96	50.5±2.00	40.0±0.20	**	ND	ND	
112	41.4±0.80	40.9±2.30	NS	77.5±0.90	78.4+0.80	NS
140	42.7±4.00	36.3±3.30	*	75.6±1.50	75.5±0.90	NS
154	43.3±3.30	34.9±2.20	*	77.3±0.70	76.8±0.70	NS
168	49.5±3.30	39.8±4.24	*	49.5±3.3	39.8±4.24	**

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different (P≤ 0.05) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant.

Table. 2. Hue angle of the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees.

	Hue angle					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	ND	ND[b]		ND	ND	
14	ND	ND		ND	ND	
28	ND	ND		ND	ND	
42	112.7±2.60[c]	114.1±3.90	NS	ND	ND	
56	113.5±2.80	116.8±6.30	NS	ND	ND	
70	110.3±4.00	111.0±8.40	NS	ND	ND	
84	111.3±2.20	112.0±3.00	NS	ND	ND	
96	110.4±2.70	110.2±1.60	NS[e]	ND	ND	
112	61.0±3.70	54.0±1.90	*	111.0±4.40	110.0±4.00	NS
140	56.3±4.40	38.6±5.00	**[d]	101.4±5.30	104.5±5.30	NS
154	53.3±7.50	36.0±4.80	**	99.8±0.87	99.2±2.30	NS
168	31.4±0.80	35.8±3.00	*	100.1±4.50	99.1±6.50	NS

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant.

The colour of the fruit peel changes during ripening as chloroplasts in the peel are converted into chromoplasts. These have red or yellow pigments, while some cultivars show reddish bluish colour because of anthocyanins, with some remaining green (Lizada, 1993). A wide change in the L* value in fruits from irrigated trees could be caused by excess irrigation that contributed to increased canopy density and thus shading of mangoes as has been observed in grape clusters (Smart and Coombe, 1983; Kriedemann, et al., 1977; Neja et al., 1977; McCarthy et al., 1983).

Iland, (1984) observed that improving light conditions heightened cluster colour, and examined the possible positive correlation between colour parameters and berry exposure levels. Several researchers Kliewer (1970); Crippen and Morrison, (1983); Roubelakis-Angelakis and Kliewer (1986) have considered solar radiation to be a critical factor in colour development in the berries of many grape cultivars, and shading of clusters has been shown to lower the total anthocyanins content in red grape varieties (Crippen and Morrison, 1983; Rojas-Lara and Morrison, 1989; Gao and Cahoon, 1994). Both light intensity and temperature are factors affecting berry colour.

The red colour could be due to high sugar deposition due to high photosynthesis in the fruits from the non-irrigated than in the fruits from irrigated trees. The red colour development acts as a protective mechanism that reduces the amount of light absorbed by the fruits.

There was no significant difference ($p = 0.05$) in the L* value and hue angle of the pulp for fruits from irrigated and non-irrigated trees that was first measured at 112 DAB. The hue angle in the peel increased steadily, decreasing at full maturity of the mangoes. The L* value decreased between 154 and 168 DAB most probably because degradation of chlorophyll and unmasking of chromoplast. The change shows a shift in colours from green to red and finally yellow at full maturity. Peel colour is a good indicator of maturity and is mostly used by farmers as a maturity index.

4.1.9. Mineral content

Changes in calcium, magnesium, potassium and phosphorus contents during growth and development are illustrated on Tables. 3, 4, 5 and 6, respectively. The mineral levels were initially high at 70 DAB decreased at 84 DAB in both the pulp and peel of fruits from non-irrigated and irrigated trees. Ferguson and Boyd, (2002) reported the mineral nutrient flow in to developing fruit over time not to be linear. The rapid uptake phase was associated with the early period of cell division.

Calcium and magnesium content rose in both the pulp and peel in fruits from both irrigated and non-irrigated trees, while potassium showed an increasing trend decreasing towards fruit maturity. Similar results reported by Ferguson and Boyd, (2002) who worked on various tropical fruits. A decrease in calcium in the peel and pulp was noted as the fruits approached maturity in both irrigated and non-irrigated trees.

Table 3. Calcium content in the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees

	Calcium content (mg/100g dry weight)					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	ND	ND		ND	ND	
14	ND[b]	ND		ND	ND	
28	ND	ND		ND	ND	
42	ND	ND		ND	ND	
56	ND	ND		ND	ND	
70	6.8±0.05[c]	5.4±0.05	***[d]	5.3±0.05	2.2±0.02	NS
84	2.2±0.04	2.2±0.06	NS[e]	2.2±0.06	2.5±0.06	**
96	4.9±0.03	3.3±0.04	***	3.3±0.04	3.1±0.03	***
112	6.6±0.01	6.9±0.04	***	6.9±0.03	5.7±0.05	*
140	5.0±0.12	3.4±0.07	***	2.6±0.26	2.7±0.09	NS
154	2.1±0.38	1.7±0.21	NS	2.7±0.39	3.7±0.01	*
168	2.2±0.70	2.1±0.50	NS	0.7±0.10	2.2±0.10	NS

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant.

Table 4. Magnesium content in the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees.

	Magnesium content (mg/100g dry weight)					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	ND	ND		ND	ND	
14	ND[b]	ND		ND	ND	
28	ND	ND		ND	ND	
42	ND	ND		ND	ND	
56	ND	ND		ND	ND	
70	2.5±0.02[c]	2.1±0.03	*** [d]	7.4±0.08	7.1±0.01	NS
84	2.0±0.05	1.6±0.01	***	2.2±0.02	2.5±0.04	***
96	17.2±0.03	9.9±0.07	***	8.0±0.03	7.6±0.01	***
112	18.1±0.04	14.9±0.09	***	10.0±0.02	6.0±0.07	***
140	19.8±0.64	16.5±0.20	***	4.6±0.14	5.6±0.06	***
154	11.4±2.18	6.5±0.38	NS [e]	4.1±0.84	4.0±0.57	NS
168	7.8±0.17	5.6±0.41	***	3.8±0.48	4.1±1.40	NS

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant.

Table 5. Potassium content in the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees.

	Potassium content (mg/100g dry weight)					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	0	0		0	0	
14	ND[b]	ND		ND	ND	
28	ND	ND		ND	ND	
42	ND	ND		ND	ND	
56	ND	ND		ND	ND	
70	83.2±0.49[c]	78.8±1.10	**	77.8±0.14	79.8±0.14	***
84	17.9±0.11	13.0±0.15	***[d]	70.0±0.24	38.2±0.15	***
96	29.7±0.29	20.0±0.27	***	84.6±0.38	79.5±0.23	***
112	33.4±0.58	22.0±0.24	***	98.3±0.30	85.0±0.18	***
140	39.3±0.38	25.2±0.63	***	48.9±0.76	57.4±0.64	***
154	70.2±3.90	44.8±3.80	***	50.0±3.00	58.0±3.00	***
168	72.1±6.52	39.2±9.40	***	51.5±11.5	54.2±8.45	NS[e]

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant

Table 6. Phosphorus content in the peel and pulp during growth and development of mango fruits from irrigated and non-irrigated trees.

	Phosphorus content (mg/100g dry weight)					
	Peel			Pulp		
DAB	Irrigated	Non-irrigated[a]	Significance	Irrigated	Non-irrigated	Significance
0	ND	ND		ND	ND	
14	ND[b]	ND		ND	ND	
28	ND	ND		ND	ND	
42	ND	ND		ND	ND	
56	ND	ND		ND	ND	
70	296.9±2.90[c]	270.1±2.10	*** [d]	247.0±3.70	275.3±4.30	***
84	352.5±4.50	346.8±1.20	NS [e]	294.2±2.10	303.7±50.00	NS
96	45.8±1.30	47.8±2.10	NS	26.4±1.70	24.5±20.00	NS
112	0.6±0.12	0.5±0.06	NS	0.1±0.00	1.22±0.07	***
140	0	0		0	0	
154	0	0		0	0	
168	0	0		0	0	

[a] The non-irrigated trees were subjected to water stress until 42 DAB.

[b] ND denotes not determined. The data was not collected because the peel could not be separated from the pulp.

[c] Data are means± SD of 18 replications.

[d] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[e] NS denotes not significant.

Potassium and magnesium showed a reverse trend. Ferguson and Boyd, (2002) reported similar results with the movement of a relatively immobile cation such as calcium into the fruit ceasing at the later stages of development, although the pattern is not found in every season.

The pattern of uptake depended on the nature of the mineral and transport pathway. A more mobile cation such as potassium continued to flow in to the fruit over the season. These uptake patterns are believed to result in decreasing concentrations of minerals such as calcium (Raymond et al., 1998).

Our result contrasts those of Lechaudel et al. (2005) who reported initial slight increase in calcium and a decrease in magnesium during fruit growth and development. The decline in minerals may be due to difference in cultural practices, location of study or the variation in minerals distribution as seen in the avocado. The sides of the avocado fruit exposed to the sunlight are found to have greater water loss that leads to higher minerals concentration such as calcium; the mineral that are dependent on water flow.

The potassium content was the highest (498 and 515 mg/100g) at 112 DAB in the pulp of the fruit from irrigated and non-irrigated trees, respectively. This was in agreement with (Lechaudel et al., 2005) who reported K^+ to represent more than 80% of the cation pool in mango fruit flesh. The relative importance of minerals (i.e. $K>Ca^{2+} > Mg^{2+)}$ in mango fruit flesh is similar to that found in apple (Jones et al.,1983) and in Asian pear (Behboudian et al., 1994).

Potassium uptake continues throughout growth, being an essential constituent of the buffer system in the vacuole. Calcium uptake falls off appreciably after the initial period of cell division. It is suggested that the initial supply or availability of calcium in the tree may be of importance in determining the later development of physiological disorders (Wilkinson and Perring, 1963). Calcium is reported to be essential in delaying ripening and senescence, (Ferguson, 1984) and to reducing storage disorders (Lechaudel et al., 2005) probably because of its role in stabilizing pectin thereby influencing the degree of firmness.

The phosphorus content decreased with growth and development of the fruit (Table 6). For example, the level of phosphorus declined from 296 to 0.58mg/100g in the peel of fruit from irrigated trees. The peel had higher phosphorus content than the pulp in fruits from both treatments. Phosphorus is an essential element for plants and it increases CO_2 assimilation in leaf photosynthesis (Fredeen et al., 1989; Jacob and Lawlor, 1992) enhancing the making of biomass in the sources. This promotes growth of the plant and its organs (Fujita et al., 2003). Towards maturity of the mango fruit there was no phosphorus detected irrespective of the treatment. This might be because the organs had reached full maturity thus no biomass synthesis was needed.

4.1.10. Firmness

Firmness increased as the fruit developed until 112 DAB (Fig. 12).

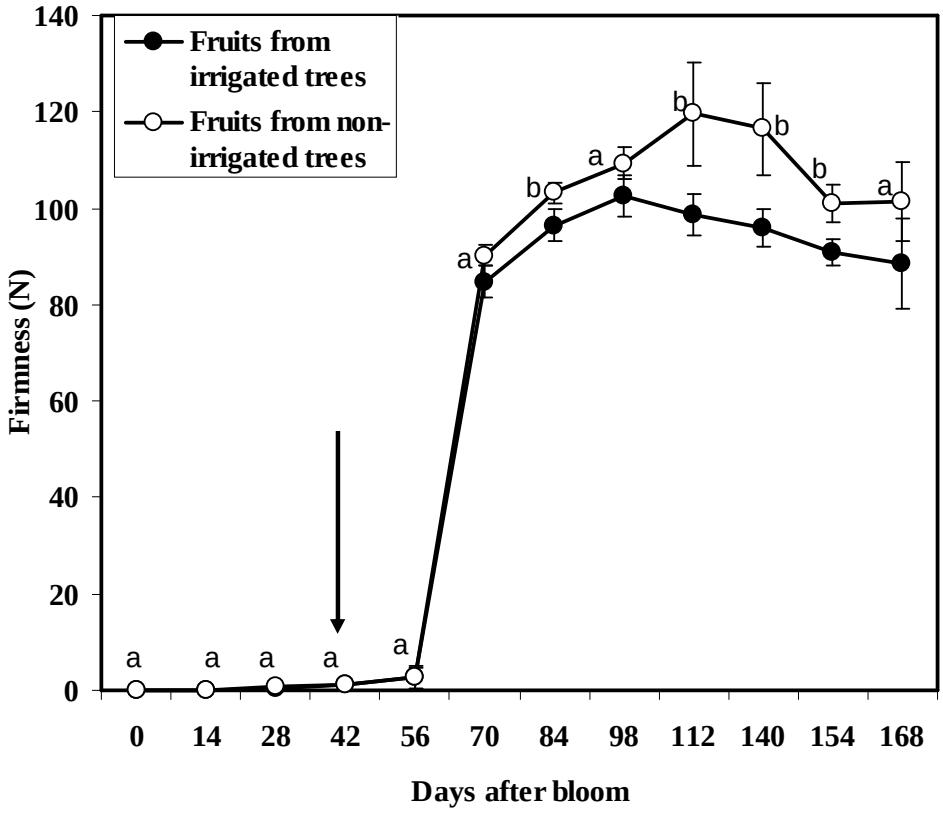

Figure 12. Firmness during growth and development of fruits from irrigated and non-irrigated mango tree. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

Firmness for fruits from the irrigated and non-irrigated trees was significant different (p= 0.05) with the latter being firmer. A high correlation was observed between the increase in firmness and starch r^2= 0.86 and 0.96 for fruits from irrigated and non-irrigated trees, respectively. Decline in firmness most likely resulted from flesh softening due to the initiation of ripening as starch was converted into sugars.

Higher starch content in fruits from non-irrigated trees might have formed densely packed polymers that increased firmness of fruits from these trees. After 112 DAB the fruits from both irrigated and non-irrigated trees showed a reduction in firmness. This is because when mangoes approach maturity, the flesh softens as water-soluble pectin is solubilized (Pressy and Avants, 1973) and cell wall integrity is lost (Fishman et al., 1993). Firmness is therefore a good indicator of maturity because the reduction symbolizes mangoes harvestable maturity. A similar pattern of changes in firmness was observed during ripening of tree mango cultivars (Abu-Goukh and Abu-Sarra, 1993), bananas (Abu –Goukh et al., 1995), dates (Barrevelled, 1993), pears (Luton and Holland, 1986), apples, peaches, and apricots (Salunkhe and Wu, 1973), peaches (Lewallen et al., 2000).

4.1.11. Vitamin C content

During the early period of growth and development vitamin C (ascorbic acid) content showed a gradual increase (Fig. 13).

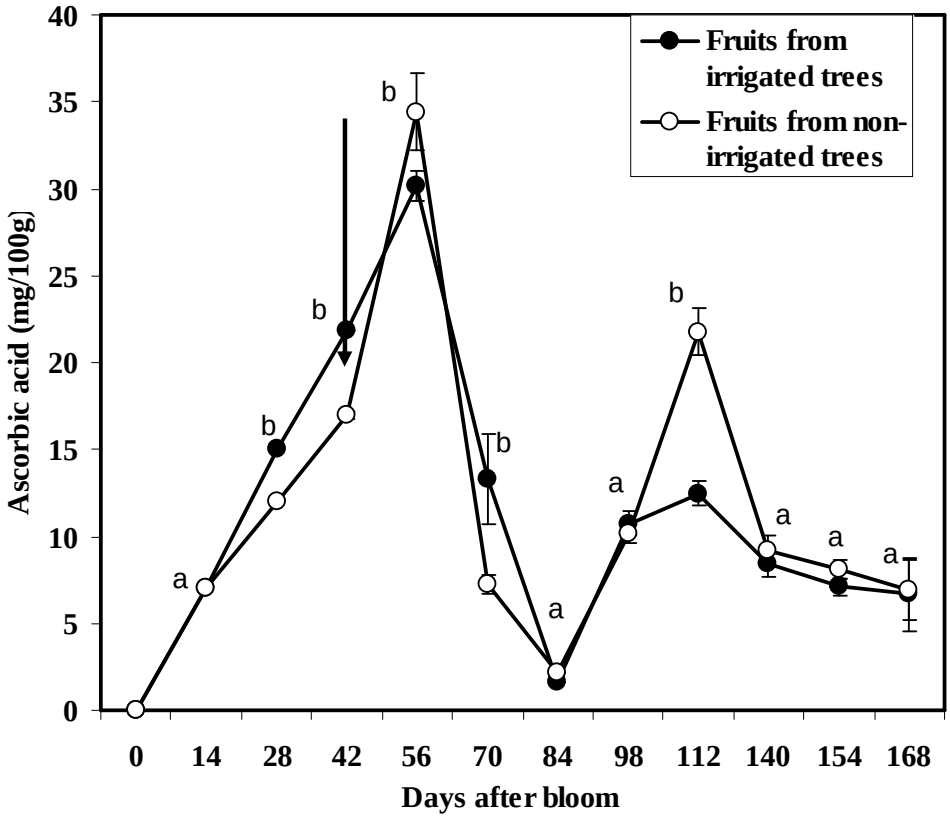

Figure 13. Vitamin C (ascorbic acid) during growth and development of fruits from irrigated and non-irrigated mango tree. The arrow indicates the end of water stress period. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The highest content of ascorbic acid (34 mg/ 100g) was found in the fruits from non-irrigated trees. Ascorbic acid content in fruits from irrigated and non-irrigated trees began to decrease abruptly after 56 DAB and the levels were very low by 84 DAB.

A decrease in ascorbic acid as the fruit approaches maturity has been reported in many fruits of the Anacardiaceae family, including mangoes more so occurring at color-break (Graham et al., 2004). Similar observations were reported in Alphonso variety (Subhadra and Subramanyam, 1970). Such declines may be due to oxidative processes as has been reported in mangoes (Graham et al., 2004). The onset of rains could have provided alternative sources of substrates to be used in the oxidative process thus the increase in ascorbic acid at 98 DAB for mango fruits from irrigated and non-irrigated mango trees.

As the fruits approached maturity the ascorbic acid content was almost constant (10 and 7mg/100g) from fruits from both irrigated and non-irrigated trees, respectively. There was no significant difference (P= 0.05) during this period, although fruits from non-irrigated trees had higher ascorbic acid content at 112 DAB.

4.2. Influence of Water Deficit on the Physiology and Biochemistry of Mango (*Mangifera indica L.*) Fruit during Postharvest Handling

4.2.1. Weight loss

The weight loss (%) significantly ($p<0.05$) increased following an ascending order of ranking throughout the storage period (Fig.14). The reduction in weight in mangoes is attributed to physiological loss in weight (PLW) due to respiration, transpiration of water through peel and other biological changes taking place in the fruit (Rathore et al., 2007; Hulme, 1971). Fruits from non-irrigated trees lost water faster compared to those from irrigated trees although there are no data to substantiate this. This lowered their water activity preventing the growth of microorganism that promotes fruit spoilage. As a result the fruits from non-irrigated trees were able to keep longer than fruits from irrigated trees although the mangoes shriveled with increase in storage time, most probably due to high storage temperatures (27°C) that increased rates of respiration and transpiration from the fruits. The fruits from irrigated trees had higher water content that changed very little throughout the ripening period. This may be due to moisture condensation resulting from hydrolysis of polymeric components such as starch and pectin (Aina, 1990). The latter fruit could not last for long; they began to rot at 11 days in storage bringing the experiment to an end.

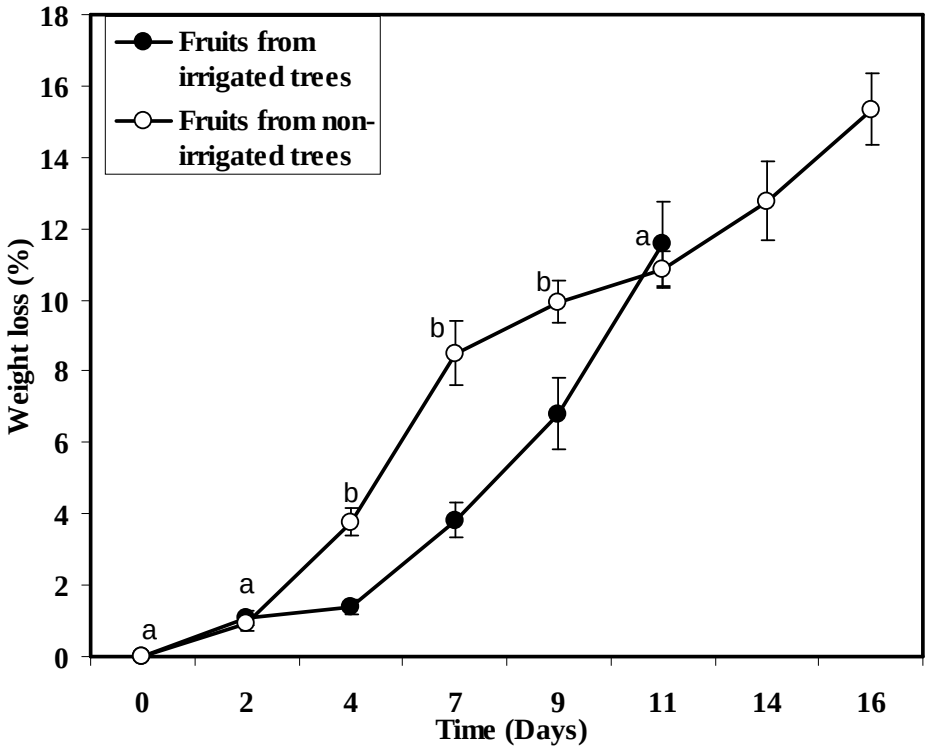

Figure 14. Percentage weight loss in fruits from the irrigated and non-irrigated trees during postharvest storage. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

4.2.2. Pulp sugar content

Changes in reducing sugar (glucose and fructose) content in fruits from irrigated and non-irrigated trees during postharvest storage are shown in (Table 7). Glucose and fructose might have increased during storage to each a maximum of 20 and 21 mg/100g for glucose and 86 and 90 mg/100g for fructose in the fruit from the irrigated and non-irrigated trees, respectively. There might have been a gradual increase in fructose especially the first 7 days in storage after which the levels were almost constant. At 11 days after storage the maximum fructose content was 4 times that of glucose. Vazquez-Salinas and Lakshminarayana, (1985) reported glucose to be lower than fructose during the whole period of ripening. Our findings of gradual increase of reducing sugars are similar to those of Medlicott and Thompson (1985) who worked on keitt mangoes. The increase in reducing sugars is brought about by the hydrolysis of starch sand sucrose (Lechaudel et al., 2005). Fructose and glucose come from sucrose hydrolysis, glucose also being produced by starch hydrolysis. The decrease in the glucose content at the later stage is caused by its use in the respiration processes.

There was a marked increase in the conversion of sucrose to fructose and glucose at day 9 of storage in the fruits from non-irrigated trees as the reducing sugars level recorded at this period was higher than in the fruits from irrigated trees (Fig. 16). Similar results were reported for apples (Mills, et al., 1996).

Table 7. Pulp sugar content during postharvest storage at ambient temperature of mango fruits from irrigated and non-irrigated trees.

	Sugar Content (Mg/100g)								
	Glucose			Fructose			Sucrose		
DAB	Irrigated	Non-irrigated	Significance	Irrigated	Non-irrigated	Significance	Irrigated	Non-irrigated	Significance
0	6.8+0.94	8.3+0.53	NS	52.7+6.50	52.7+4.40	NS	85.1+5.48	90.8+3.62	NS
2	8.6+1.35	9.1+1.23	NS	59.5+0.50	60.3+4.29	NS	125.6+6.90	135.9+5.00	NS
4	ND	ND		ND	ND		ND	ND	
7	ND	ND		ND	ND		ND	ND	
9	20.5+1.09	21.6+1.22	NS	82.8+4.10	88.9+2.46	NS	126.3+3.20	140.8+2.70	***
11	20.2+1.05	21.5+1.07	NS	86.0+8.54	90.1+4.93	NS	118.3+13.1	125.8+9.30	NS

[a] Data are means$\pm$ SD of18 replications.

[b] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[c] NS denotes not significant

[d] ND denotes not determined. The data was not collected.

Plants can regulate their solute potential in tissues and organs to compensate for water stress, a process called osmotic adjustment. In this process, water potential is decreased without an accompanying decrease in turgor or decrease in cell volume. The osmotic adjustment results in a net increase in the concentration of a variety of solutes but primarily sugars. The osmotic adjustment could have resulted in the increased sugar accumulation in the mango fruits from non-irrigated trees. A high sugar deposition due to high photosynthesis in these fruits could have resulted in to the predominant red colour that is a protection mechanism imposed by sunlight exposure.

There is also a possibility of monomeric sugars such as glucose and fructose being released from polymeric forms (starch and sucrose) in response to water stress. Similar results were reported by Landsberg and Jones (1981) who indicated an increase in the conversion of starch to sugars under deficit irrigation.

At the second day in storage, sucrose content was higher than glucose and fructose content (Table 7). Sucrose was reported to be higher than glucose and fructose corresponding to 75% of total sugars thus contributing most for the increase in sweetness in mangos (Vazquez-Salinas and Lakshminarayana 1985). At 4th to the 9th day after storage, the sucrose concentration was higher in the fruits from non-irrigated trees than in the fruits from irrigated trees. A greater increase in sucrose level during storage in the fruits from the non-irrigated trees compared to those from irrigated trees may indicate a higher

level of starch to sucrose conversion probably due to increase in sucrose synthase activity in these fruit although there are no data to substantiate this.

The decline of glucose and sucrose content between at 9 and 11 days after storage could indicate the disappearance of metabolism in the synthesis of new materials and the beginning of senescence for the mango fruits. The metabolism pattern shifts to the manufacturing of new compounds that are to be used in the next season. The decline in glucose content during post harvest storage also indicates its usefulness in respiration and the inability of a fruit to store glucose at post harvest. There was high mobilization of glucose for respiration and was not being replenished from the parent plant.

4.2.3. Starch content

The starch content decreased rapidly during the first 7 days of storage from 58% in fruits from irrigated trees and 70% in the fruits from non-irrigated trees to almost zero in both cases (Fig. 17). Lima et al. (2001) found traces of starch in over ripe mango fruits pulp Cv. Tommy Atkins with the amylase activity reduced. A similar trend was reported during the storage of 'Dashehari' mango variety (Kalra and Tandon 1983); 'Haden' (Fuchs et al., 1980) and other mango cultivars (Mattoo and Modi 1969).

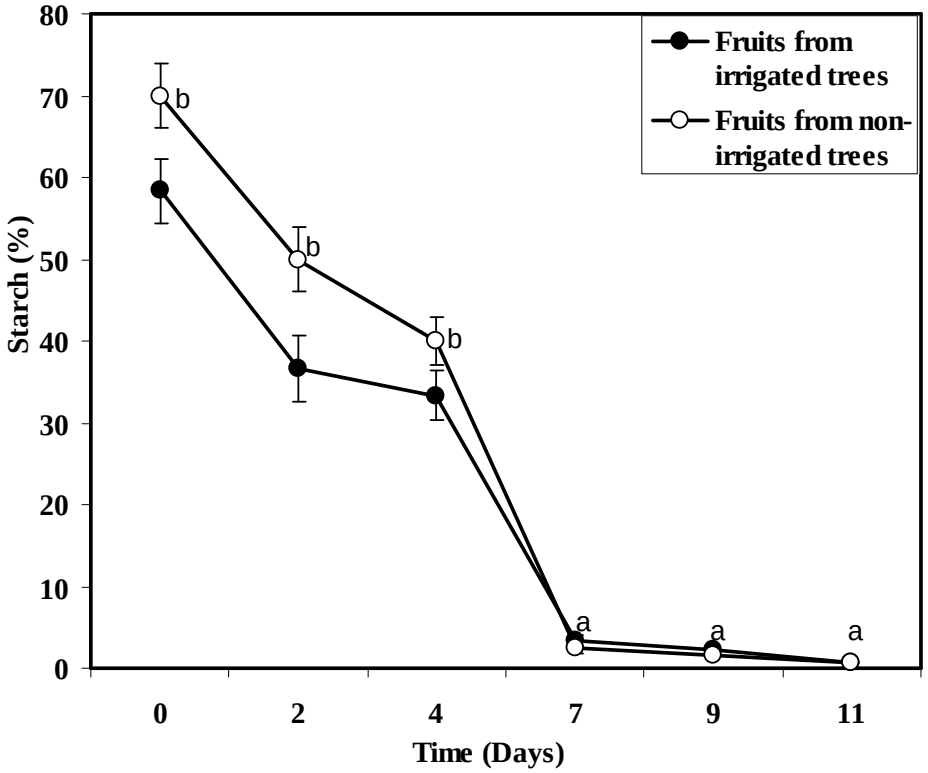

Figure 17. Starch in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperature. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The decrease in starch between 9 and 11 days during storage and the increase of fructose and glucose during the same period, could imply that starch was hydrolyzed to simple sugars that were most probably used up in the climacteric respiration peak. The catabolism of carbohydrates or starch may also lead to various metabolites among them, sugars, organic acids, lipids, phenolics and volatile compounds that lead to ripening of fruit with softening of texture to acceptable quality (Herianus et al., 2003).

Jain et al. (2005) found decreased activities of α-amylase and β-amylase with ripening of guavas. This was because starch is being broken down into sugars and other related compounds that are substrates for respiration. Jain et al. (2005) reported that starch content decreased with concomitant increase in alcohol-soluble sugars in guavas. Decrease in starch due to starch hydrolysis could have led to increase in soluble substances such as sugars and total soluble solids with the former being used up in respiration processes. Starch hydrolysis might have led to substantial total soluble solids that increased with committal decrease with starch.

4.2.4. Total soluble solids and total titritable acidity

Total soluble solids content was initially low until 4 days after storage when the content increased to reach a peak of 14 and 12° Brix for the fruits from irrigated and non-irrigated trees, respectively (Fig. 18). Rathore et al. (2007) who worked on Dosehari variety of mango found total soluble solids to increase due to the alteration in cell wall structure and breakdown of complex

carbohydrates into simple sugars during storage. The rise in total soluble solids was also attributed to partial breakdown of pectins, celluloses (Roe and Bruemmer, 1981).

This increase in total soluble solids is directly correlated with hydrolytic changes in starch and conversion of starch to sugar being an important index of ripening process in mango and other climacteric fruits. Similar pattern of increase in total soluble solids was observed in green mature Alphonso and seven other varieties of mango fruits stored at 18-34°C. During ripening mangoes underwent a series of physico-chemical changes that included an increase in total soluble solids content (Doreyappa- Gowda and Huddar, 2001). Similar views were expressed by Manzano et al. (1997) who observed that the temperature of storage also affects the total soluble solids contents. At low temperature the TSS were high (14 -15%) than at high temperature (25°C) during 20 days of storage.

Total titratable acidity decreased with increase in days of storage to a minimum of 0.2% in the fruits from irrigated trees and 0.11% in the fruits from non-irrigated trees (Fig. 18). There was no significant difference ($p=0.05$) in total titritable acidity in the fruits from irrigated and non-irrigated trees. Similar results were found by (Rathore et al., 2007) who worked on Dosehari mango. Percent titratable acidity of Dosehari mango ranged from 0.5% to 0.094% with an average means of 0.28% during storage.

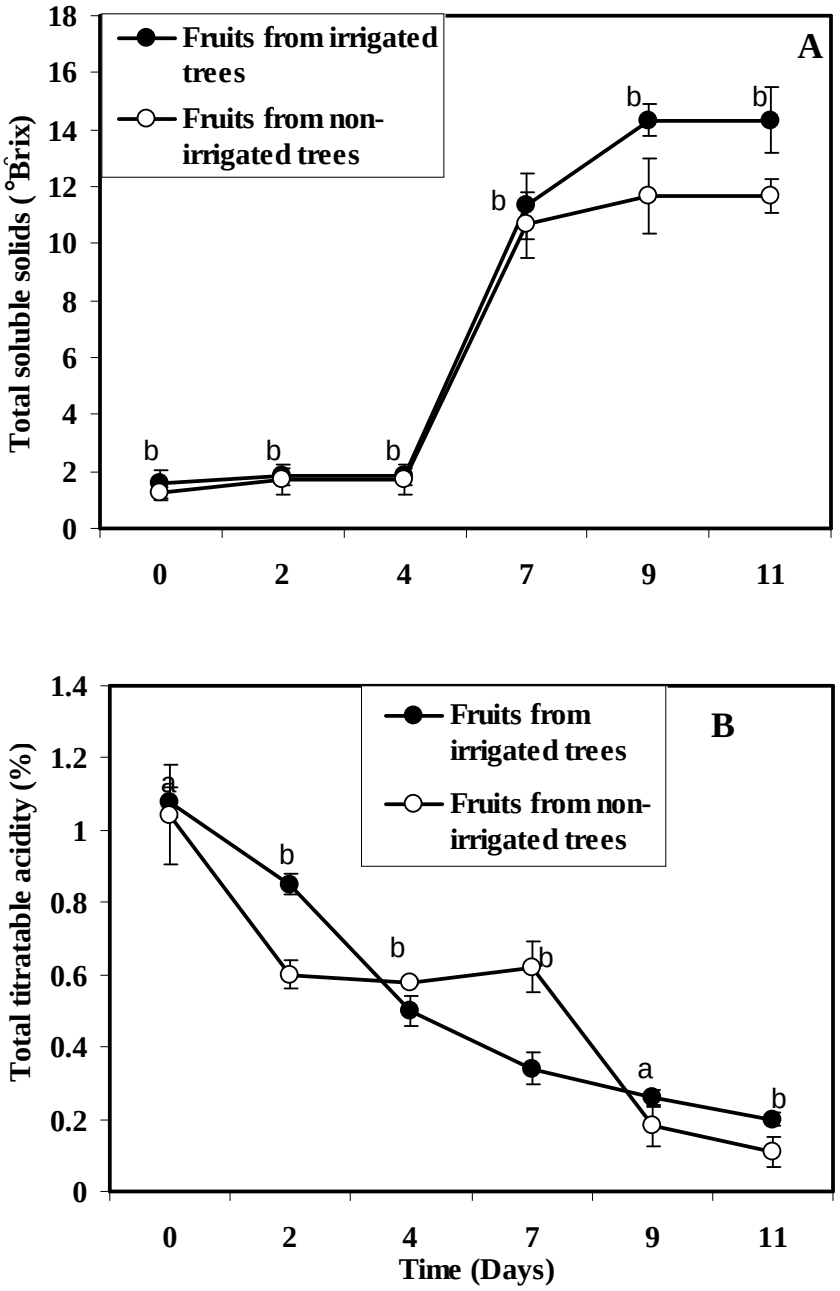

Figure 18. Total soluble solids (A) and total titratable acidity (B) content in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperature. Vertical bars represent SE of the mean of 18 replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

Rathore et al. (2007) also observed percent titratable acidity decrease during 15 days of storage. The reduction of titratable acidity was due to the degradation of citric acid which is attributed to increased activity of citric acid glyoxylase during ripening. The reduction in acidity could also be attributed to its conversion to sugars and their further utilization in metabolic process like respiratory climacteric in the fruit. Our results further coincide with those of Doreyappa-Gowda and Huddar, (2001). They found a similar pattern in different varieties of mango fruits stored at 18-34 ^{0}C in which the acidity decrease from 2.71 to 0.04% during ripening.

These results further agree with those of Srinivasa et al. (2002) who found that titratable acidity values of Alphonso mango showed a decreasing trend from 2.17% to 0.08% on the 12th day when stored at ambient temperature 27±1 ^{0}C and 65% RH. Similar changes were also noted by Kudachikar et al. (2001) in Neelum mango.

4.2.5. Respiration and ethylene production

The fruits reached a climacteric maximum of 19 ml per Kg per hr and 17.2 ml per Kg per hour in the fruits from irrigated and non-irrigated trees, respectively (Fig.19). Ethylene was detected 11 days after harvest with the fruits from irrigated trees (6.5ήl per gram per hour) having a lower ethylene production rate than the fruits from non-irrigated trees (13.3ήl per gram per hour).

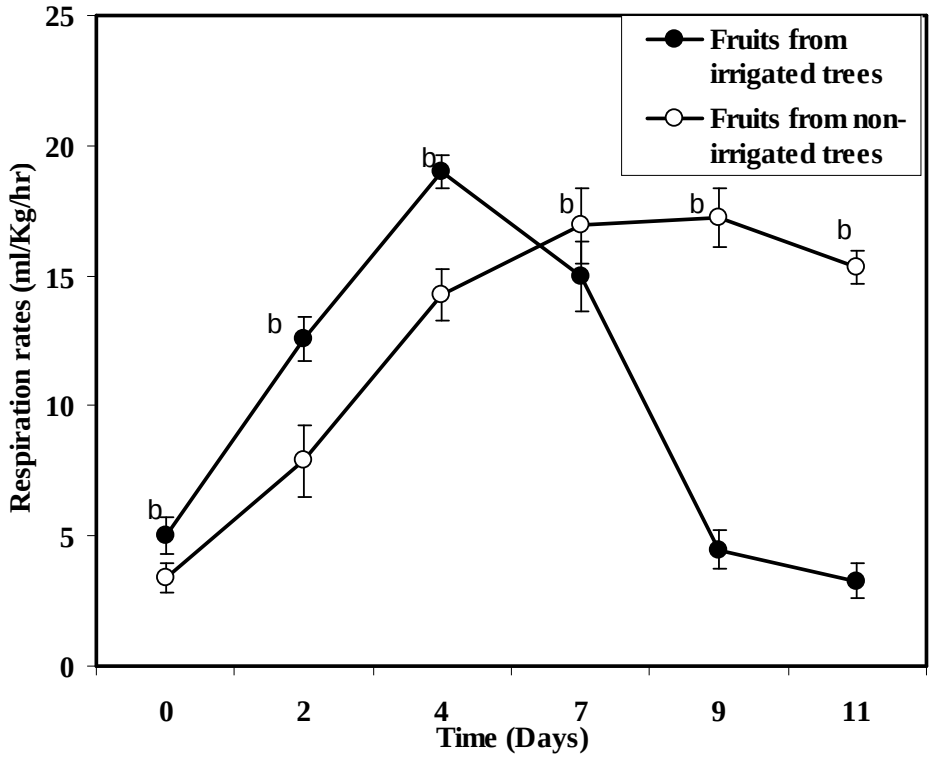

Figure 19. Respiration rates in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperature. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The fruit emitted very low ethylene peaks although mango fruits have high perishability. The fruits that have a similar behavior include the breadfruit Artocarpus altilis *(Par)* (Worrell et al., 1998), raspberry and vegetables such as cauliflower (Kader, 1985). Mango's high perishability and low ethylene production rate reiterate the observation that there is no inviolate relationship between the ethylene production capacity of a given fruit and its perishability. Earlier climacteric peak, could have led to short shelf-life and the delay in irrigated trees peak could result in delay of the deteriorative processes because climacteric peak is synchronized with ethylene production.

The fruits from irrigated trees reached a climacteric maximum earlier than the fruit from non-irrigated trees. This could be the reason why they had a shorter shelf life than the fruits from non-irrigated trees. This is supported with the fact that the fruits from irrigated trees spoiled (began to rot) at 11 days after storage while those from non-irrigated trees spoiled at 16 days on storage. The latter can therefore store for longer period of time a characteristic that is a plus in the postharvest handling of mangoes especially for export market. Mangoes being a climacteric fruit possess a very short shelf life and reach respiration peak 3 or 4 days after harvesting at ambient temperature (Narayana et al., 1996).

4.2.6. β-carotene and anthocyanins

The β-carotene content of the pulp increased with increased in storage days reaching a high of 1.26mg/100 and 1mg/100g in the fruits from irrigated and non-irrigated trees respectively at 9 days in storage (Fig.20). The level of β-

carotenes have also been reported to increase in Dosehari (Rathore et al., 2007) and 'Haden', 'Irwin', 'Keitt' and 'Kent' (Vazquez-salinas and Lakshminarayana 1985) varieties of mango. Thereafter the levels decreased to 0.67 and 0.51mg/100g on 11 days in storage in the fruits from irrigated and non-irrigated trees, respectively. Rodriguez-Amaya, (1999) reported that β-carotene is highly unsaturated and, therefore, susceptible to isomerization and oxidation during storage of foods.

β-carotene in one of the carotenoids found in nature. Collectively, the major cause of carotenoid loss, is enzymatic and non-enzymatic oxidation, which depends on the availability of oxygen and the carotenoid structure. Data on percentage losses of carotenoids during food storage are somewhat conflicting, but carotenoid degradation is known to increase with the destruction of the food cellular structure, increase of surface area or porosity, length of storage time and transmission of light and permeability to O_2 of the packaging (Rodriguez-Amaya, 1999).

The anthocyanins content in the peel decreased to 0.7 and 1.03 mg/l in the fruits from irrigated and non-irrigated trees, respectively (Fig. 20). The fruits from non-irrigated trees had higher anthocyanins content than the fruit from irrigated trees. The decreased canopy in the fruit from non-irrigated trees may have contributed increased anthocyanins concentration.

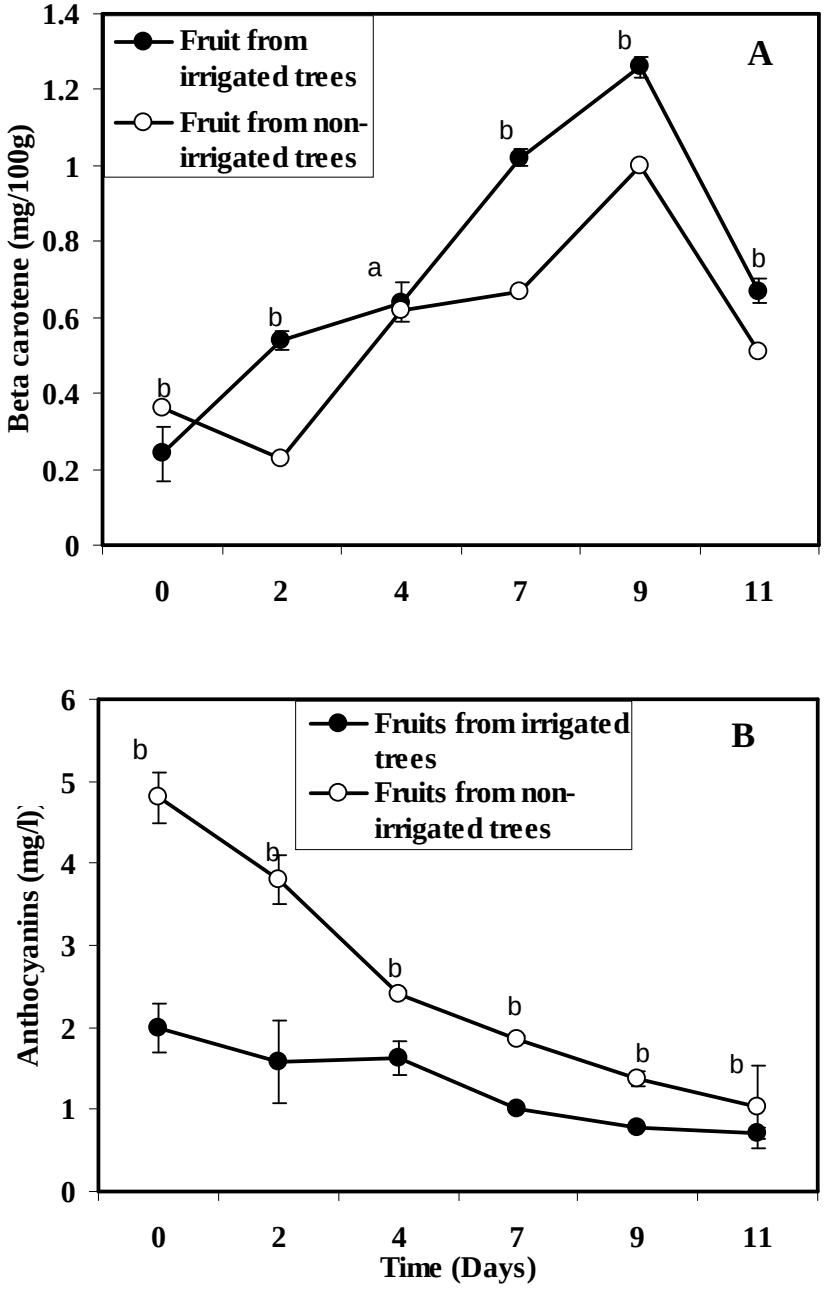

Figure 20. β-carotene (A) and anthocyanins (B) in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperatures. Vertical bars represent SE of the mean of 18 replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The anthocyanins content also depends on factors like maturity index, seasonal conditions, or storage conditions of food (Gil, 2000; Costa, 2000; Holcroft, 1998). Westwood, (1988) indicated that preharvest factors resulting in high levels of carbohydrates in the fruit during growth tend to increase anthocyanins pigments.

Although Ratanamarno et al. (1999) reported total anthocyanin content increased continuously during maturation and reaching a maximum value at fully ripe stage in mangosteen, environmental conditions like temperature and light (Saure, 1990) and cultural factors are thought to influence fruit colour development in many fruits including apple fruit cv. Jonathan (Chalmers and Faragher, 1977); Pinot noir berries and table grapes varieties (Kliewer, 1970), peaches (Lewallen et al., 2000) and on skin of bagged mango fruit cv. Kent (Hofman et al., 1977; Saengnil et al., 1997).

4.2.7. Chlorophyll content

An initial increase in the a, b and total chlorophyll content was observed at 2 days of storage (Fig. 21), that was later followed by a decline in a and b chlorophyll content while the total chlorophyll was almost constant before decreasing at 9 days in storage in both the fruits from irrigated and non-irrigated trees (Fig. 22).

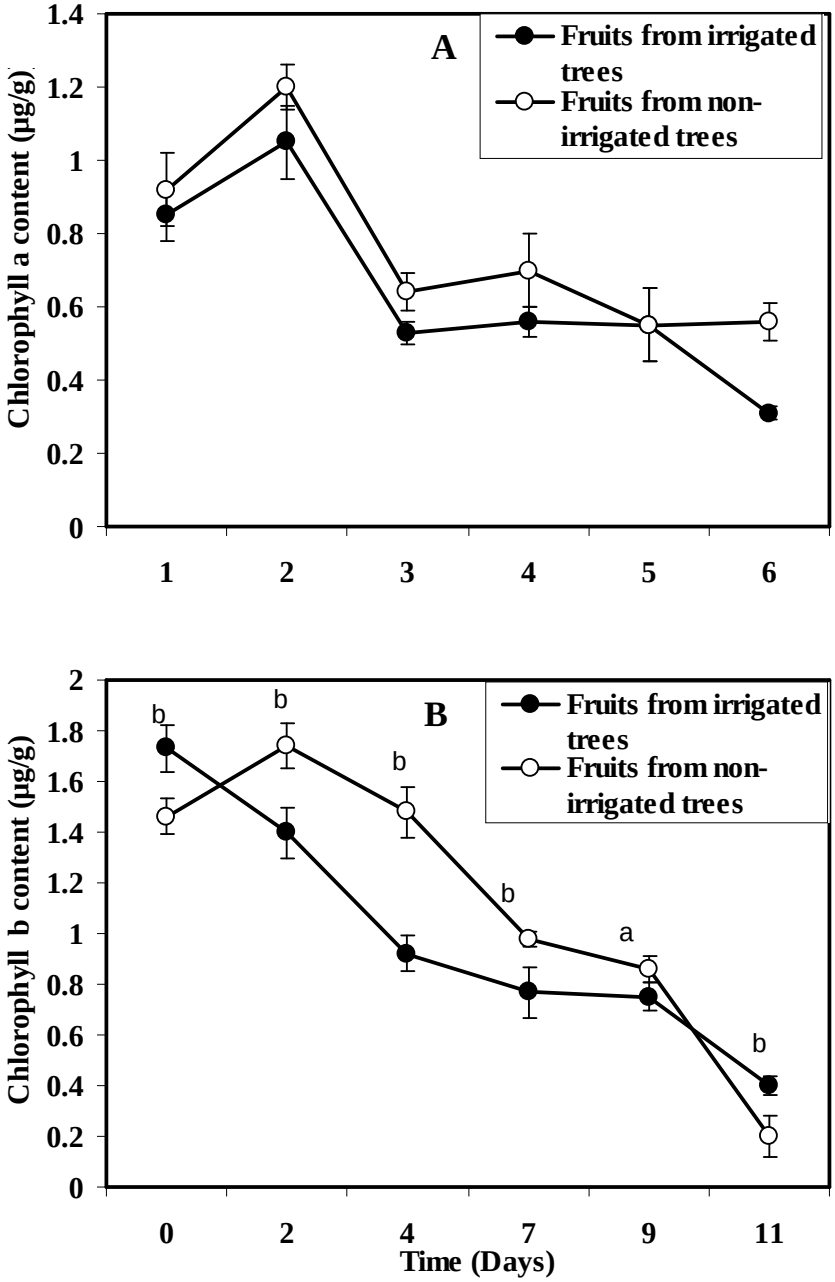

Figure 21. Chlorophyll a (A) and chlorophyll (B) content in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperature. Vertical bars represent SE of the mean of 18 replications. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

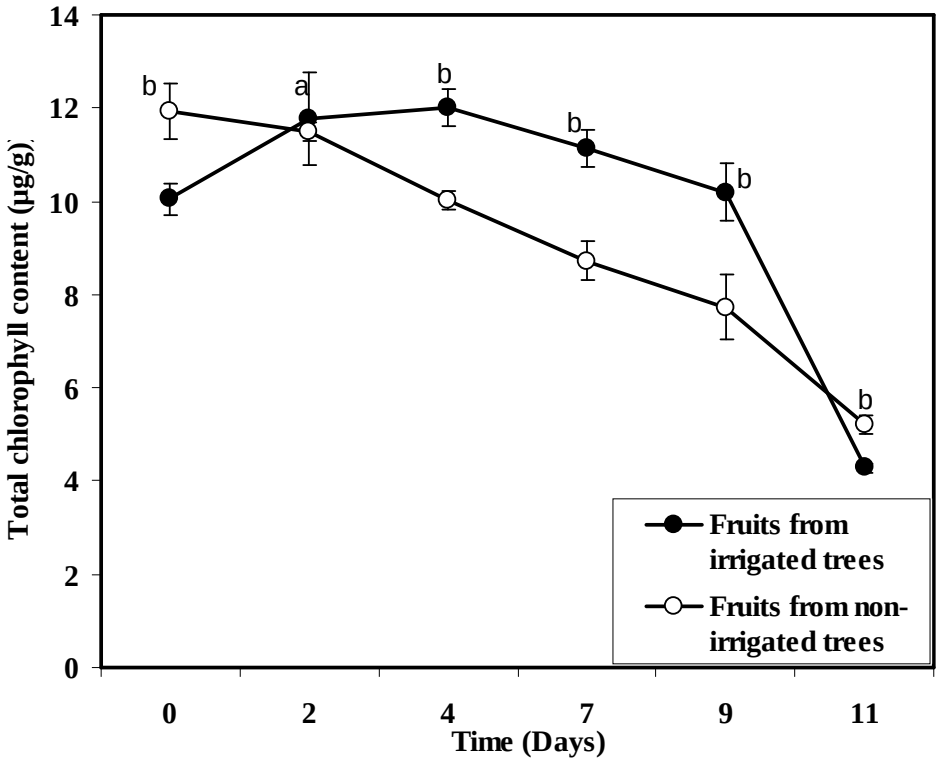

Figure 22. Total chlorophyll in fruits from the irrigated and non-irrigated trees during postharvest storage at ambient temperature. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The decline could be caused by degradation of chlorophyll due to ripening (color break) as thought to occur in many climacteric fruits. Eilati et al. (1975) reported that the gradual disintegration of chloroplasts was due to disappearance of chlorophylls. Rathore et al. (2007) also cited degradation of chlorophyll in Dosehari mango to be attributed to the physico-chemical changes on degradation of the chlorophyll structure and increase in carotenoid pigments during storage.

The principal agents thought to be responsible for this degradation might be the oxidative system, pH change and enzymes like chlorophyllases (Wills et al., 1982). Kalra and Tandon, (1983) also found chlorophyll a and b to decrease in 'Dashehari' mango.

4.2.8. Color

Colour is the most important first impression by a consumer of any food product. Hue describes a visual sensation according to which an area appears to be similar to one or proportions of two of the perceived colours, red, yellow, green and blue. The hue angle is thus actual colour. L* is a measure of lightness on a scale from zero to 100. Zero represents black and 100 equals white (McGuire, 1992).

The colour of the peel and pulp varied both in terms of L value and hue angle with increase in storage time (Table 7 and 8), respectively.

Table 8. L value of the peel and pulp during postharvest storage at ambient temperature of mango fruits from irrigated and non-irrigated trees.

	L value					
	Peel			Pulp		
Time (Days)	Irrigated	Non-irrigated	Significance	Irrigated	Non-irrigated	Significance
0	43.3±3.63[a]	37.3±3.63	NS[c]	72.5±1.03	73.6±9.13	NS
2	42.2±3.70	38.2±3.70	NS	71.5±3.13	74.2±2.04	NS
4	42.2±3.80	39.1±3.80	NS	70.2±0.40	73.5±3.70	NS
7	42.0±4.50	35.8±4.50	NS	61.4±7.30	67.0±3.72	NS
9	43.9±8.40	37.3±8.40	NS	60.0±6.20	69.1±6.70	NS
11	46.8±3.40	36.8±3.40	NS	59.8±1.90	60.1±1.00	NS

[a] Data are means± SD of18 replications.

[b] *** denotes highly significantly different ($P \leq 0.05$) between fruits from irrigated and non-irrigated trees.

[c] NS denotes not significant

Table 9. Hue angle of the peel and pulp during postharvest storage at ambient temperatures of mango fruits from irrigated and non-irrigated trees.

	Hue angle					
	Peel			Pulp		
Time (Days)	Irrigated	Non-irrigated	Significance	Irrigated	Non-irrigated	Significance
0	31.4±0.80[a]	35.8±3.30	*	100.1±4.50	99.1±6.50	NS[c]
2	40.3±3.90	24.8±4.30	***[b]	91.2±1.40	95.9±6.20	NS
4	40.3±2.60	25.5±4.50	***	91.1±0.97	93.7±3.30	NS
7	47.8±2.40	27.4±5.70	***	92.9±0.90	92.8±1.70	NS
9	48.3±3.40	32.5±2.40	***	93.4±2.80	90.5±0.35	NS
11	49.8±2.33	41.3±6.10	*	93.5±2.10	91.3±0.55	NS

[a] Data are means± SD of18 replications.

[b] *** denotes highly significantly different (P≤ 0.05) between fruits from irrigated and non-irrigated trees.

[c] NS denotes not significant

The peel colour in the fruits from irrigated trees increased in L value (42 to 46) while fruits from non-irrigated trees showed a variation in peel L value ranging between 36 and 39. The latter L values were lower compared to those of former. The fruits from irrigated changed from green red to green yellow while non-irrigated trees changed colour from green red to green yellow or red and finally to red yellow. There was no significance difference (P=0.05) in the L value between fruits from irrigated and non-irrigated trees.

The peel hue angle increased in both the fruits from irrigated and non-irrigated trees with increase in storage time, with the latter having a lower hue angle than the former. Similar observations have been reported in braeburn apples (Mills et al., 1994; Mills et al., 1996).

The pulp L value decreased with storage time while the hue angle increased then decreased with storage time in both the fruits from irrigated and non-irrigated trees. There was no significance difference (P=0.05) both in the terms of pulp L value and hue angle between fruit from irrigated and non-irrigated trees. The pulp changed from pale yellow to yellow and then to yellow orange. The L value ranged from 59 – 74. The change was due to series of physico-chemical changes like the breakdown of chlorophyll and increase in carotenoid pigments of the pulp. Ortega-Zaleta and Yahia (2000) observed a slight internal L values change in mango fruits.

Rathore et al. (2007) reported that the loss of green colour in Dosehari mango is due to the physico-chemical changes on degradation of chlorophyll structure and increase in carotenoid pigments during storage. The principal agents responsible for this degradation might be the oxidative system, pH change and enzymes like chlorophyllases (Wills et al., 1982). Our results agree with those of Doreyappa-Gowda and Huddar (2001) who reported that the concentration of carotenoids were increased due to a series of physico-chemical changes in green mature Alphonso and other varieties of mango stored at 18-34 $^{\circ}$C during ripening.

The fruits from water deficit retained a peel red colour at maturity while those from the irrigated trees were green-red. Water deficits in braeburn apples has been found to enhance red colour development at preharvest and increased total soluble solids (TSS) and total titratable acidity (TTA) during post harvest storage (Mills et al., 1996). This improved consumers' acceptance of the fruits. The red colour could be due to high sugar deposition due to high photosynthesis in the fruits from non-irrigated than in the fruits from irrigated trees. The red colour development acts as a protective mechanism that reduces the amount of light absorbed by the fruits.

4.2 .9. Firmness

The firmness of the fruits decreased with increase in storage days (Fig. 23). The fruits from non-irrigated trees were firmer than the fruits from irrigated trees.

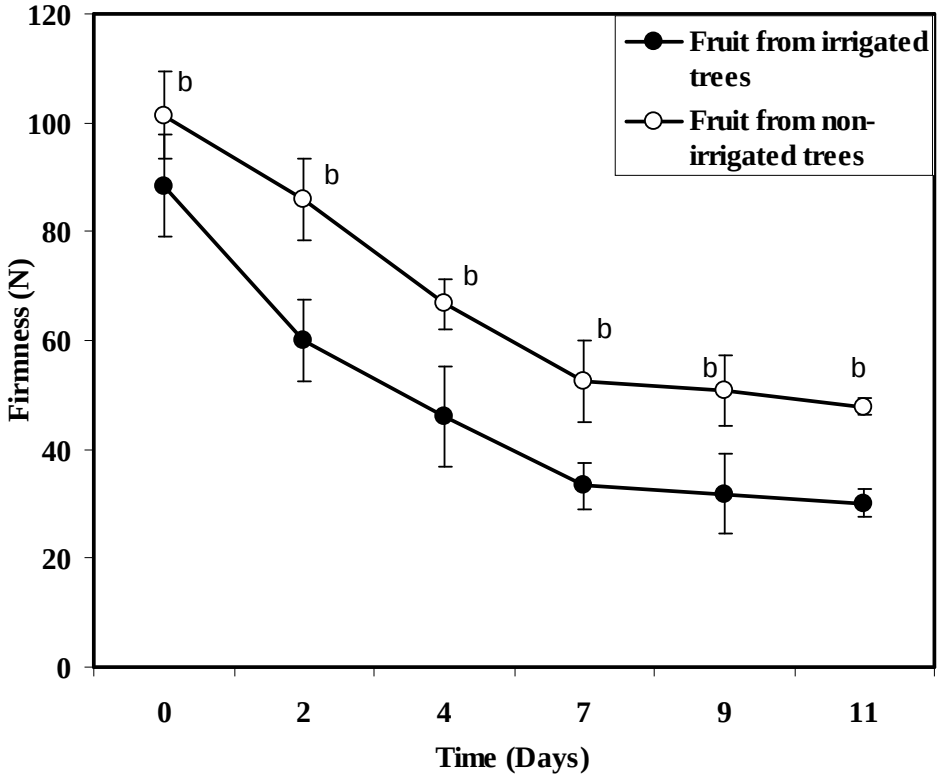

Figure 23. Firmness in fruits from the irrigated and non-irrigated trees during postharvest storage. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

The fruits from irrigated trees might have had a lot of water due to increased degree of hydration in their cell walls resulting in the reduction in firmness. As the fruits ripened, firmness decreased most probably due to some compositional changes that occurred in the cell wall. For example, substantial decrease in cell wall bound glycosyl residues have been reported to occur in pears with 71, 36 and 60% of the cell wall arabinose, galactose and glucose, respectively being released in the period between the pre-climacteric and the post-climacteric stage (Trinchero et al., 2004).

Tateishi et al. (2005) reported that at fruit maturation the extensibility of the cell wall constrains expansion, and cell wall enlargement to occur (Cosgrove, 1997; Rose et al., 2003). The cell wall of expanding tissues posses numerous enzymes, among them β-galactosidase which contribute to modification of its mechanical properties (Brummell and Harpster, 2001). Some of the enzymes involved in cell wall metabolism, such as expansins not only have a role in facilitating the expansion of plant cells but also contribute to cell wall disassembly in non growing ripening tissues (Rose and Bennett, 1999; 2003).

Enzymes of β-galactosidase have been isolated from various fruits, including tomato (*Lycopersion esculentum* Mill.); (Carey et al., 1995), avocado (*Persea Americana* Mill.) (Tateishi et al., 2001), and Japanese pear (Kitagawa et al., 1995), and have been characterized in relation to removal of galactosyl residues during fruit softening. The disassembly of the fruit cell wall is largely responsible for softening and textural changes during ripening, but the precise

roles of particular cell wall alteration and /or of cell wall-modifying enzymes that bring about these changes are not clearly understood (Brummell and Harpster, 2001).

4.2.10. Vitamin C content

Ascorbic acid decreased with increase in storage time reaching a minimum of 1.48 and 1.51 mg/100g from the fruits from irrigated and non-irrigated trees, respectively (Fig. 24). Sablani et al. (2005) also found that ascorbic acid content in tomato decreasing with increasing storage time at both refrigeration and room temperatures with the decline in ascorbic acid at room temperature being higher than at refrigeration temperature.

A decrease in ascorbic acid may be due to the acid being used in respiration or its transformation to other metabolites such as sugars and amino acids. The reduction is also caused by destruction of ascorbic acid when the commodity is subjected to adverse handling and storage conditions (Sablani, et al., 2005). A reduction in ascorbic acid during ripening is due to the susceptibility of ascorbic acid to oxidative destruction particularly at high ambient storage temperatures (Aina, 1990). Ascorbic acid which is sensitive to light and oxygen and may be degraded under normal transport and storage conditions resulting in reduction of the nutritional value of the foodstuffs (Arias et al., 2000). There was no significant difference in ascorbic acid content between the fruit from irrigated and non-irrigated trees. Ascorbic acid content does not seem to be affected by water stress.

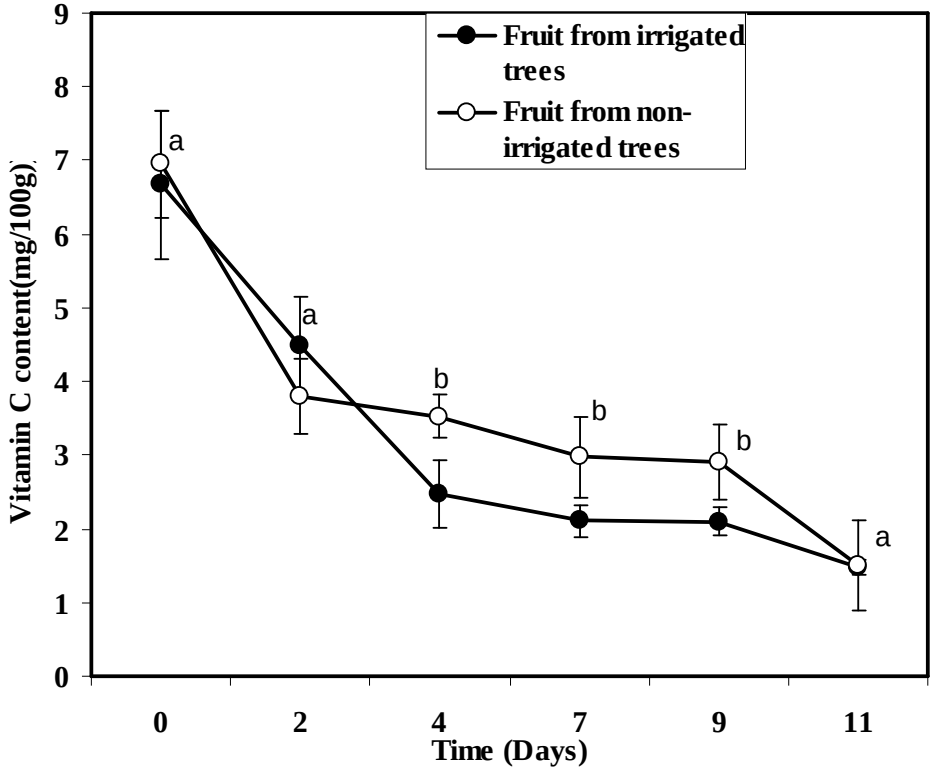

Figure 24. Vitamin C in fruits from the irrigated and non-irrigated trees during postharvest storage. Vertical bars represent SE of the mean of 18 replications. When absent, the SE fall within the dimensions of the symbol. a denotes a period of no significance difference while b denotes a period of difference between the fruits from irrigated and non-irrigated trees ($P<0.05$).

CHAPTER FIVE

CONCLUSION AND RECOMMEDATIONS

A high correlation was observed between the increase in length and diameter r^2= 0.992 and 0.996 in the fruits from irrigated and non-irrigated trees, respectively. The formula of the equation can be calculated and therefore used by farmers. Minimal increase in length and diameter, a sudden increase in glucose and TSS with a decrease in starch content accompanies this. This can also be confirmed by a sudden decrease in anthocyanin content, firmness and very low or no phosphorus content being detected in the fruits. This maturity indices give fruits three weeks at ambient temperature before rotting sets in. Fruits from irrigated trees matured were found to earlier than those from non-irrigated trees.

The mango fruits from non-irrigated trees had a longer shelf life than fruits from irrigated trees most probably due to a late maximum climacteric peak and higher degree of firmness. This characteristic together with reduced weight, in the fruits from non-irrigated fruits is what makes for dessert and export market. The latter also have an attractive red color mostly preferred by consumers. The fruit from irrigated trees were higher in total soluble content and β-carotene but had a short life and reduced firmness that makes them suitable for juice production industry and local market.

More investigation on sensory evaluation of these mangoes at various harvestable maturity is recommended. Research in other methods of extending shelf life of mangoes to reduce post harvest losses for instance the use of 1-MCP are highly proposed. More studies in sugar content at postharvest storage in this region is also recommended.

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