EFFECTS OF AGRO-ECOLOGICAL ZONES ON THE POSTHARVEST SHELF LIFE AND QUALITY OF 'APPLE' MANGO (*Mangifera indica* L.) AND THEIR RESPONSE TO 1-METHYLCYCLOPROPENE (1-MCP)

BY

ONSONGO KEMUNTO NANCY

(A56/64429/2010)

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Horticulture of the University of Nairobi

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

2013

DECLARATION

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

Signature ……. Date ……

Onsongo Kemunto Nancy

SUPERVISORS

Dr. Jane Ambuko

Department of Plant Science and Crop Protection

University of Nairobi

Signature ……. Date ……

Dr. Margaret Hutchinson

Department of Plant Science and Crop Protection

University of Nairobi

Signature ……. Date ……

Dr. Willis O. Owino

Department of Food Science and Technology

Jomo Kenyatta University of Agriculture and Technology

Signature…… Date ……..

DEDICATION

This work is dedicated to the Almighty God for His grace during the study period. I also dedicate this work to my dear husband Mr. Carey Francis for his unconditional support, my son Ian Smart and to the Onsongos' family especially my late mum for trusting in me.

ACKNOWLEDGEMENT

I am grateful to the Almighty God for His faithfulness during the entire research period. My sincere gratitude is dedicated to my supervisors; Dr. Ambuko Jane for mentoring me through acquisition of writing skills and also making me believe that anything is possible before the Almighty God. I am also grateful to my other supervisors; Dr. Hutchinson Margaret and Dr. Owino Willis for their positive critics and guidance during the period of study.

My sincere gratitude to the University of Nairobi through the department of Plant Science and Crop Protection for granting me the scholarship which facilitated my studies. I acknowledge Kenya Agricultural Productivity and Agribusiness Project (KAPAP) for sponsoring my entire research work through a research grant awarded to Dr. Ambuko Jane.

I am grateful to Jomo Kenyatta University of Agriculture and Technology administration for allowing me to conduct my laboratory work and I appreciate the efforts of Mr. P. Karanja and Mr. D. Votha who are the chief technologists at the department of Food Science for their guidance and patience during the research time. I also appreciate the efforts of Mr. Mibei and Mr. N. Wekesa who were my laboratory assistants.

I thank my dear parents Mr. and Mrs. Onsongo for believing in me and for their encouragement and support during my period of study. Special thanks to my husband Mr. Carey Francis for his unending love and support. To my sister Judy, words alone cannot explain how grateful I am to you for being there for me in the course of my study. To all my friends from Jomo Kenyatta University of Agriculture and Technology, thanks for your hospitality and to my precious friends (Ruth, Peninah, Maureen, Susan, Joel and Oliver) from University of Nairobi, I appreciate learning new scientific ideas from you.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF FIGURES

CHAPTER 3

CHAPTER 4

LIST OF ABBREVIATIONS AND ACRONYM

1-MCP	1- Methylcyclopropene
AEZs	Agro-Ecological Zones
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
AVG	Aminoethoxy Vinyl Glycine
Ca	Calcium
DAH	Days after Harvest
DAT	Days after Treatment
FAO	Food Agricultural Organization
GC	Gas Chromatograph
GDP	Gross Domestic Product
HCDA	Horticultural Crops Development Authority
HPLC	High Performance Liquid Chromatograph
K	Potassium
KOH	Potassium Hydroxide
LSD	Least Significance Difference
Mg	Magnesium
MOA	Ministry of Agriculture
NaOH	Sodium Hydroxide
NBD	Norbomadiene
PPM	Parts per million
RH	Relative Humidity
S1	Stage 1
S2	Stage 2
STS	Silver Thiosulphate
TSS	Total soluble solids
TTA	Titratable Acidity

ABSTRACT

Mango (*Mangifera indica* L.) is the third most important fruit produced in Kenya, after avocado and passion fruit. Mango is widely grown in Kenya because of its adaptation to a wide range of agro-ecological zones (AEZs); from sub-humid to semi-arid. The variations in climatic factors affect fruit growth and development and ultimately the fruits' postharvest characteristics. Additionally, preharvest production conditions have an effect on the fruits' physiological status and consequently their response to postharvest treatments. Ethylene inhibitor, 1-Methylcyclopropene (1-MCP) is one of the postharvest treatments applied to climacteric fruits to extend their shelf life and reduce postharvest losses through inhibition of ethylene perception and action. The fruits' response to 1-MCP is reported to be affected by preharvest production conditions and commodity factors such as maturity stage.

The objective of the present study was to determine the effect of different agro-ecological zones on the shelf life and postharvest quality of 'apple' mango harvested at two maturity stages and their response to 1-MCP treatment. The study was conducted over two seasons; season 1 (year 2011) and season 2 (year 2012) on fruits harvested from commercial orchards in Embu (a high potential AEZ) and Makueni (a low potential AEZ).

In the first experiment, the fruits were harvested at two stages of maturity based on flesh color as stage 1 (flesh mostly white, just turning yellow near the seed) and stage 2 (flesh mostly yellow, turning orange at the seed). The fruits (from different AEZs and of different maturities) were selected for uniformity and freedom from blemishes and left to undergo normal ripening in separate batches at ambient room conditions (Temperature; 25 ± 1 ^{o}C and RH 60 ± 5%)until a predetermined end stage. Five fruits were randomly sampled from each batch for daily determination of respiration, ethylene evolution and cumulative weight loss. From the remaining bulk of each batch, five fruits were taken randomly every 3 and 5 days in (season 1 and 2) respectively for destructive sampling to determine changes in physical and chemical parameters. The physical parameters measured included peel/flesh hue angle and firmness while the chemical parameters determined included titratable acidity, total soluble solids, ascorbic acid, beta-carotene, soluble sugars (fructose, glucose and sucrose) and minerals (magnesium, calcium and potassium). A comparative assessment of sensory qualities of tree-ripened fruits from the two zones was done using 40 untrained panelists.

In the second experiment, a homogeneous sample of fruits harvested at stage 1 (S1) and stage 2 (S2) from Makueni and Embu were treated with 1 ppm of 1-MCP for 24 hours and thereafter allowed to undergo ripening at ambient room conditions. Five fruits were randomly sampled for daily determination of respiration rate, ethylene evolution and cumulative weight loss. The other physical and chemical parameters were sampled as described in experiment one. The treated fruits were compared with an untreated batch which served as the control.

The results of the first experiment showed that fruits from Makueni had a longer shelf life (3 days more) compared to Embu fruits. As expected, fruits harvested at S1 had a longer shelf life compared to those harvested at S2. The differences between AEZ and stage of maturity were more evident in season 2. Makueni fruits showed significantly ($p<0.05$) lower respiratory activity compared to fruits from Embu as evidenced by the smaller and delayed climacteric peak. Additionally, Makueni fruits had relatively high initial peel/flesh hue angles and firmness with minimal weight loss at the end of storage. Significantly ($p<0.05$) high total soluble solids (12.6ºBrix), ascorbic acid (57mg/100ml) and sugars (sucrose) 4.9 g/100ml was recorded in Makueni fruits at S1 compared to Embus' 9ºBrix, 50mg/100ml and 2.9 g/100ml respectively. The TTA content of Embu fruits at S1 and S2 at the end of storage was 50% higher compared to that of Makueni fruits. Titratable acidity, ascorbic acid, Mg and Ca were significantly ($p<0.05$) high in S1 fruits while total soluble solids (TSS), beta-carotene, sugars and K were significantly high in fruits at S2. Generally, fruits harvested from Makueni scored higher than Embu fruits for most of the sensory parameters evaluated.

The results of the second experiment showed that 1-MCP treated fruits had a relatively longer shelf life (3 days) compared to untreated controls, irrespective of AEZ or stage of maturity. However, fruits harvested at S1 and fruits from Makueni were more responsive to 1-MCP treatment. For stage 1, 1-MCP treated fruits had a shelf life of 15 and 12 days compared to untreated controls' 12 and 9 days respectively for Makueni and Embu AEZs. A similar trend was observed for stage 2 fruits. The onset of ethylene production and the respiratory climacteric were significantly ($p<0.05$) delayed (by 2 to 3 days) or suppressed in 1-MCP treated fruits irrespective of maturity stage or production location. 1-MCP treatment significantly ($p<0.05$) delayed ripening related changes including decrease in hue angle, firmness, titratable acidity and increase in total soluble solids. Reduction in fruit tissue Ca and Mg was significantly ($p<0.05$) slowed in 1-MCP treated fruits. Overall, 1-MCP treated fruits from both locations retained higher

nutritional quality attributes at the end stage of untreated controls. In conclusion, production conditions in the two AEZs and the stage of maturity significantly affected the fruits' quality at harvest, their shelf life and response to 1-MCP treatment. It is therefore recommended that the source of mango fruits (AEZ) and maturity stage should be considered in postharvest handling of the fruits; including the design of effective postharvest treatment regimes and processing of consistent mango products.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The agricultural sector plays a key role in Kenya's economy since it accounts for 24% of national Gross Domestic Product (GDP). An estimated 75% of the population depends on the agricultural industry directly and 25% indirectly through linkages with agro-based and associated industries. Overall, the agricultural sector employs over 80% of the total labor force, generates 60% of foreign exchange earnings and provides 75% of industrial raw materials (HCDA, 2009). The agricultural sector records an average growth of 15 to 20% per annum (HCDA, 2008). The horticultural sub sector (comprising of vegetable, fruits and flowers) is a major contributor to the increased growth.

The horticultural sub sector is now ranked the second most important foreign exchange earner in Kenya after tourism and tea (HCDA, 2008). Exponential growth in the sub-sector has been observed over the last two decades, attracting many investors both locally and internationally (HCDA, 2010). In 2007, the total horticultural production was valued at Kshs 119.7 billion and in 2008, the horticultural industry generated Kshs 65 billion (HCDA, 2008) from the domestic market and Kshs 73.7 billion in foreign exchange from exports. The total value generated by the horticulture sector to the general economy in the year 2010 was Kshs 114.59 billion, equivalent to an increase of 6.8 per cent. The value of Kenya's horticultural produce was estimated at Kshs 205.1 billion in 2011. The industry earned the country Kshs 91.2 billion from exports which is an increase from the previous years (HCDA, 2010).

The horticultural sub sector is dominated by small-holder farmers who play an important role towards enhancing food security especially in the rural population, creating job opportunities and overall improving their livelihoods. The small scale farmers also account for 75% of the total agricultural production and 70% of marketed agricultural produce (HCDA, 2011).

Fruits account for about 35% of the total horticulture output in Kenya. A wide range of fruits are produced in Kenya including, banana, mango, avocado, pineapple, water melon, oranges among others. The major fruits produced for export market include avocadoes (62%), mangoes (26%), passion fruits (8%) and others (4%) (HCDA, 2011). Mango production and consumption in Kenya has continued to increase significantly over the years. In 2005, Kenya produced about 250,000 metric tons of fresh mangoes. This amount has continued to increase reaching about

475,000 metric tons in 2009. This is attributed to expansion of mango producing areas as well as a slight increase in productivity (HCDA, 2009). There was an increase in acreage of about 15% in 2009 and 3.4% in 2010 (HCDA, 2010). The increase in production is attributed to adoption of better crop husbandry practices and improved marketing strategies by stakeholders (KARI, 2009). Mango is either traded in its fresh form or value added products such as juice and dehydrated products. Over the years, there has been increasing demand for mango and its products in the domestic and international market as a result of increased awareness of health benefits of fruits and vegetables.

Over 90% of the mangoes produced are consumed locally despite the increasing demand in the international market (HCDA, 2009). The importers of Kenyan mangoes are United Arab Emirates (53%), Saudi Arabia (22%), Tanzania (20%), Bahrain (2%) and other countries (3%) (HCDA, 2010). The main export destination has shifted over the years from Europe to Middle East, where countries like Saudi Arabia and the United Arab Emirates purchase about 85% of Kenya's mangos. However, this is still a very small percentage of the amount of mangos produced (HCDA, 2005). One of the main reasons for this change is the high market standards the European Union sets (FAO, 2003). The fruits produced in Kenya have over the years failed to meet high market standards required to access the lucrative traditional markets in Europe. This is a result of a range of preharvest and postharvest factors that greatly impact fruits quality (Nyambo *et al.*, 2006).

Production constraints such as poorly adapted mango varieties which are not suited for some agro-ecological zones, poor soil nutrition, damage caused by insects (mango fruit fly and mango seed weevil) and diseases (anthracnose and powdery mildew); greatly reduce the market value of the fruits especially for the international market (Griesbach, 1997). Additionally, poor orchard management result to poor fruit quality at harvest (HCDA, 2010). Fruits of low quality fail to meet high standards for both export and high end domestic markets thus fetching low prices resulting in low profits for farmers. This situation is further aggravated by poor postharvest handling of the highly perishable mango fruits (Kader, 2008).

Mango is a climacteric fruit that produces high levels of ethylene which triggers ripening leading to senescence. Failure to manage ripening in the supply chain results in high losses especially for fruits destined for markets further from the production areas. It is estimated that 40 –

50% the mango fruits produced are lost along the supply chain due to poor postharvest handling (HCDA, 2006).

Mango fruit is adapted to a wide range of agro-climatic conditions and as a result, it is produced across many tropical regions worldwide. In Kenya, mango is produced in most of the agro-ecological zones (AEZs) ranging from sub-humid to semi-arid (Griesbach, 2003). The fruits are grown in the low potential AEZs (in Eastern and North Eastern regions) with characteristic low rainfall amounts and high temperatures and also in the high potential AEZs (Central and Rift Valley regions) known for high rainfall amounts and relatively low temperatures. These diverse environmental conditions differ in temperature, water availability, light intensity, soil factors and the farmers' agronomic practices in the orchard. All these factors affect fruit growth and development and consequently the yield and quality potential at harvest.

1.2 PROBLEM STATEMENT AND JUSTIFICATION

Mango is a highly perishable climacteric fruit with a very short shelf life (3 to 14 days), depending on the harvest maturity and storage conditions. It is estimated that > 40% of mangos produced in Kenya are wasted along the supply chain due to seasonality and poor postharvest handling practices (Gathambiri *et al*., 2010). Reduction of these losses requires management of the factors that contribute to the losses and application of postharvest techniques and technologies that slow down deteriorative processes.

In Kenya, mango fruit production is suited for the various AEZs, from sub-humid to semi-arid. The different AEZs present a variation in fruit growth environment with respect to temperature, light, water availability, soils, and cultural practices. These conditions have a profound effect on fruit growth and development and hence quality potential at harvest, postharvest characteristics and response to postharvest treatments. There is need to establish how the diverse agro-ecological conditions found in the different AEZs affect mango fruit quality at harvest for the benefit of consumers and processors. For processors of juices and dehydrated products, quality attributes such as total soluble solids, titratable acids affect the finished products. Additionally, knowledge about the quality attributes of fruits from different AEZs is critical for them (processors) to make informed choices to ensure consistency in their products. Growth and development environment of the fruits also affects their physiology and hence response to any

postharvest treatment (Watkins, 2006). This is important for postharvest handling as the actors have to take it in consideration when designing postharvest treatment regimes.

Like other climacteric fruits, mango experiences a surge in ethylene production and respiration rate as it ripens. Ethylene is a naturally occurring plant hormone that affects the growth, development and storage life of many fruits. It plays an important role in the initiation and continuation of ripening in all climacteric fruits (Saltveit, 1999). Management of ethylene production and action in the supply chain of climacteric fruits such as mango is critical in slowing down ripening and related postharvest losses (Hoa *et al.*, 2002). There are several ethylene antagonists such as silver thiosulfate, 2, 5-norbornadiene, diazocyclopentadiene and 1-Methylcyclopropene (1-MCP) that have been used in many commodities (Watkins, 2006). Of these chemicals, 1-MCP has proved to be a better alternative for various reasons. It has a non-toxic and negligible residue and retards the ripening of fresh produce at a very low concentration. The safety, toxicity and environmental profiles of 1-MCP in regard to humans, animals and the environment are extremely favorable (EPA, 2002). 1-MCP has been widely used in United States of America and Europe to extend the shelf life of perishable commodities including fruits, vegetables and flowers (Sozzi and Beaudry, 2007). Previous studies indicate that the efficacy of 1-MCP is affected by various pre-harvest and commodity factors (Watkins, 2008).

In Kenya, the shelf life and marketing period of a wide range of perishable commodities could be extended through application of 1-MCP. However, few studies have been conducted on locally produced candidate commodities to ascertain the efficacy of 1-MCP. There is therefore need for research on locally grown commodities such as mango to precisely determine the optimum conditions for 1-MCP application including concentration, length of exposure and responsive maturity stage. There is also need to establish the effect of 1-MCP treatment on fruit quality attributes.

1.3 OVERALL OBJECTIVE

To establish the effect of different agro-ecological zones on the postharvest shelf life and quality of ‘apple’ mango fruits and their response to 1-Methylcyclopropene (1-MCP).

1.4 SPECIFIC OBJECTIVES

1. To compare the postharvest shelf life and quality attributes of ‘apple’ mango fruits produced from a high potential agro-ecological zone (Embu) and low potential agro-

ecological zone (Makueni).

2. To compare the response of ‘apple’ mango fruits produced under two different agro-ecological zones (low potential and high potential) to 1-Methylcyclopropene (1-MCP) treatment.

1.5 HYPOTHESIS

1. The postharvest shelf life and quality attributes of ‘apple’ mango fruits produced under high potential agro-ecological zone (Embu) and low potential agro-ecological zone (Makueni) will be the same.

2. The response of ‘apple’ mango fruits produced under the two different agro-ecological zones (high potential and low potential) to 1-Methylcyclopropene (1-MCP) will be the same.

CHAPTER 2: REVIEW OF LITERATURE

2.1 MANGO BOTANY

2.1.1. The Mango Tree

Mangos belong to the genus *Mangifera* of the family Anacardiaceae. The genus *Mangifera* includes 25 species (Mabberly, 1997) with edible fruits such as *M. caesia* and *M. foetida* although *M. indica,* the mango, is the only species that is grown commercially on a large scale (Griesbach, 1997). Within *M. indica*, there are two distinct types that can be distinguished on the basis of reproduction and their respective centers of diversity: a subtropical group with monoembryonic seed (Indian type) and a tropical group with poly embryonic seed (South-east Asian). The mango tree is evergreen, erect with a height of 3 m to 5 m with a broad, oval or elongated canopy. The leaves are simple and alternate, with petioles that range in length from 1 to 1.25 cm. Young leaves are copper-colored, changing gradually to light and then dark green with age. The leaves are spirally arranged in whorls and produced in flushes (Griesbach, 2003). The root system consists of a long, vigorous taproot and abundant surface feeder roots. In deep soils the taproot can reach a depth of 2 m.

2.1.2. The Fruit

The mango fruit is a large, fleshy drupe, containing an edible mesocarp of varying thickness. The exocarp is thick and glandular. The endocarp is woody, thick and fibrous; the fibres in the mesocarp arise from the endocarp. The mango fruit is climacteric and increased ethylene production occurs during ripening. Carotenes, chlorophyll and anthocyanins are present in the fruit. Skin color at maturity is genotype dependent and is a mixture of green, yellow and red pigment. During ripening, the chloroplasts in the peel become chromoplast, which contain red and yellow pigments (Mitra and Baldwin, 1997).

2.1.3. Mango Flavor

The flavor of the mango mesocarp is a function of organic acids, carbohydrates, monoterpene hydrocarbons, lactones and fatty acids (Mitra and Baldwin, 1997). The flavor ranges from turpentine to sweet. During fruit maturation, the accumulated starch is hydrolyzed to fructose, sucrose and glucose (Kumar *et al.,* 1994). Organic acid content decreases during ripening. The dominant organic acid is citric acid but malic acid, oxalic and tartaric acid are also

present. The peach-like flavor of mangoes is attributed to the presence of lactones (Watada *et al.*, 1990).

2.1.4. Mango Nutrition and Uses

Mango is one of the most popular tropical fruits in the world. Mango fruits are usually eaten ripe, when they are soft and sweet. However some people prefer them unripe, when they are harder with a more sour taste. The fruit is eaten for its nutritional and medicinal value, and also for its pleasant flavor. Mango is a highly nutritious fruit containing carbohydrates, proteins, fats, minerals, organic acids and vitamins, in particular vitamin A (beta carotene), B1, B2, and vitamin C (ascorbic acid) (Rodriguez-Amaya, 1999). During the ripening process, the fruits are initially acidic, astringent and high in ascorbic acid. Ripe mangoes contain a moderate amount of vitamin C (27.7 mg/100g) but are fairly rich in pro-vitamin A (765 IU) and vitamins B1 and B2 (USDA, 2010). Fruit acidity is majorly due to presence of citric acid and malic acids. The sugars present (sucrose, fructose and glucose) generally increase with fruit ripening (Wilson *et al.*, 1990).

Raw mango fruits are utilized for products like pickles and mango sauce. The fruit is eaten green, processed into juices and jams for long storage. The fruits can also be frozen or dried (HCDA, 2010). Today, mango and its flavor are added to many products such as fruit juices, ice creams, wines, teas, breakfast cereals and biscuits. The fruit is also an important source of sustenance (Litz, 1997) for birds, bats, insects, and mammals. The fruit and its by-products are used for animal fodder and the bark of the tree is an important source of tannins for curing leather.

Table 2.1: Composition of the edible portion of mango fruit

Nutrient	Unit	Value per 100 g edible portion
Water	G	81.71
Sugars(total)	G	14.8
Carbohydrates	G	17.00
Proteins	G	0.51
Vitamin C	Mg	27.7
Vitamin A	IU	765
Thiamine	Mg	0.058
Riboflavin	Mg	0.057
Calcium	Mg	10
Magnesium	Mg	9
Phosphorus	Mg	11

Source: (USDA, 2010)

2.2. MANGO PRODUCTION

The largest numbers of Mangifera species occur in the Malay Peninsula, the Indonesian archipelago, Thailand, Indochina and the Philippines (Mukherjee, 1953). Mango was introduced to East Africa in the 14th century (Salim *et al.*, 2002). Mangoes are found in all tropical regions of the world. Two races of mango exist- the India and the Southeast Asia races (Griesbach, 1997). The Indian race is intolerant to humidity and subject to powdery mildew and anthracnose though it bears mono-embryonic fruit of desirable color and regular shape. On the other hand, the Southeast Asia race is tolerant to excess moisture and resists powdery mildew.

Among the local varieties raised in Kenya for decades include Kittovu, Kimji, Klarabu, Punda and Mayai. In Kenya, the popular varieties for the Middle East markets are the Apple and Ngowe, while European markets prefer Tommy Atkins, Kent, Keitt, Haden and Van Dyke (HCDA, 2010). 'Apple' mango, the variety used in the present study is adapted to coastal and lowland areas and is very susceptible to rust in high altitude areas (Griesbach, 1997). 'Apple' mango fruits are large, round and apple-shaped, and have rich yellow-orange to red color. The fruit is fleshy, juicy, fibreless and with firm texture and matures early in the season between November and January (Litz, 1997).

2.2.1. MANGO PRODUCTION STATISTICS

Mango currently ranks fifth in total production (metric tons) among major fruits in the world after banana, citrus, grapes and apples (FAO, 2006). According to FAO, (2006), world mango production has increased from 16,903,407 in 1990 to 28,221,510 metric tons in 2005. The recent leading producers of mango after India in the world include China (3,450,000 MT), Thailand (1,800,000 MT), Pakistan (1,673,000 MT), Mexico (1,600,000 MT) and Indonesia (1,478,204) among others. The major exporting countries are Mexico (212,505 MT), India (156,222 MT) and Brazil (111,181 MT). The total area under production of mango in the world is 3.69 million hectare (FAO, 2009).

The mango industry in Kenya has expanded considerably over recent years as the area under cultivation has risen from 500 ha in 1970 to over 15,000 ha today (HCDA, 2007). There is traditional mango growing and commercial cultivation with distinct differences between the location of production and the performance of the orchard in terms of the harvest period, the fruit quality and the yield level. The yield varies for the different provinces due to diverse production conditions (Griesbach, 2003). The major producing provinces are Eastern (93,958 metric tons), Nyanza (26,360 metric tons) and Coast (363,783 metric tons). The national average yield is at 15.6 metric tons per hectare. In 2005, Kenya produced about 250,000 metric tons of fresh mangoes (HCDA, 2007). This amount has continued to increase reaching about 475,000 metric tons in 2009. In 2010, Kenya produced more than 550,000 metric tons of mangoes. Approximately 98% of mangoes produced in Kenya go to local consumption or processing, while the remaining 2% go to export markets (HCDA, 2011). Figure 2.1 below shows the changing trend in mango production in Kenya during the last decade (FAOSTAT, 2010).

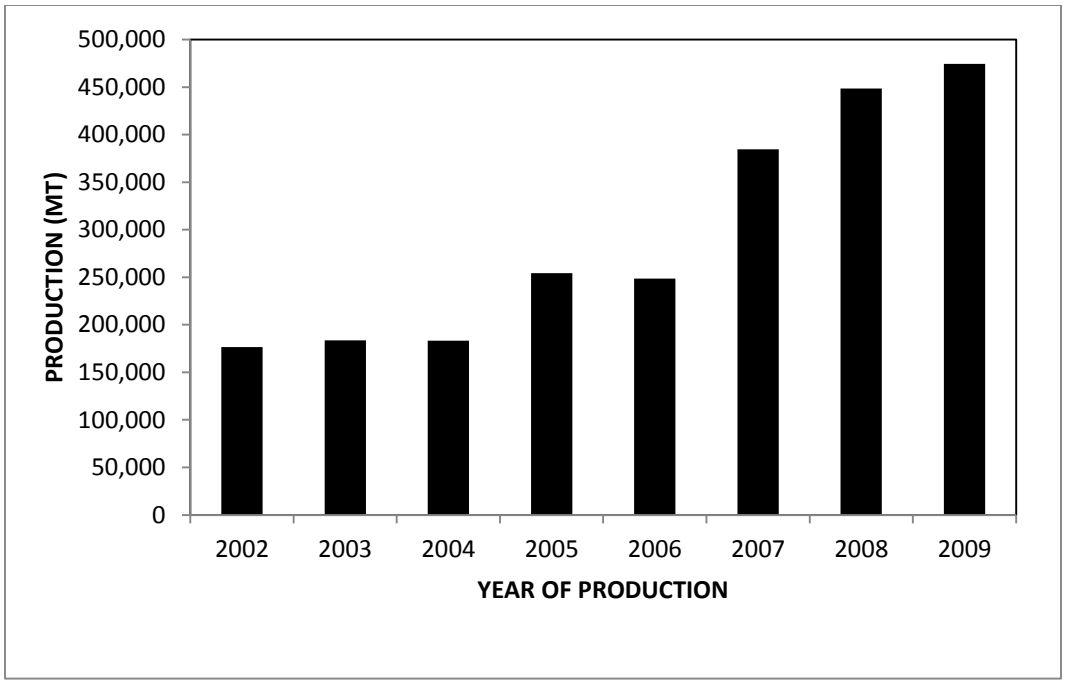

Figure 2.1: Changing trend in mango production in Kenya. Source: (FAOSTAT, 2010)

2.3. ECOLOGICAL REQUIREMENTS FOR MANGO PRODUCTION

2.3.1. Rainfall

Mango grows over wide range of climatic conditions. The trees produce best in climates that have a well-defined, relatively cool dry season with high heat accumulation during the flowering and fruit development period (Whiley, 1994). Mango trees grow over a wide range of rainfall volumes. The trees produce best when the most rain falls during summer months and there is a well-defined dry period. In hot, wet, tropical climates, where soil moisture does not limit growth, the trees remain vegetative with little or no fruit production. Bearing is best when the dry period lasts from 1 to 2 months before flowering to after harvest (Davinport, 1997). Mean annual rainfall preferred is between 400 mm- 3600 mm. High humidity during the flowering and fruiting period, favor the development of fungal diseases that cause flower and fruit drop (Frean, 1991).

2.3.2. Temperature

Mango's optimum growing temperature is 24ºC–27°C. Temperature has a direct effect on tree and fruit growth rates (Griesbach, 1997). A leaf flushing cycle takes approximately 20 weeks when growing under 20°C days and 15°C nights. This is reduced to 6 weeks under 30°C-25°C

temperatures. The time taken for fruit to reach maturity is also influenced by temperature. Under high temperature and low-humidity conditions, mangos' photosynthetic efficiency is reduced and respiration is high, resulting in low carbon accumulation, which lowers the trees' ability to hold heavy crop loads. Wagner *et al.,* (1999) noted that low temperature stress is necessary for floral induction.

2.3.3. Solar radiation

Mango grows best in full sun because its flowers and fruit are produced at the edge of the canopy in full sun. The best fruits are from sun-exposed branches (Lechaudel, 2002).

2.3.4. Soils

Mango tree tolerate a range of soils from alkaline-calcareous soils to heavy clay soils. Mangoes do not require soils with high nutrient content but the soils must be free draining and deep. The optimal pH range is 5.5–7.5, but the tree will grow outside this range, with low pH (acidic) being the most deleterious to growth. Production is best on well drained sandy or gravelly soils that dry out rapidly after the wet season, forcing the trees into a dormant period, essential for heavy flowering (Litz, 1997).

2.3.5. Altitude

Mangos grow well up to 1,500 m above sea level. Most commercial varieties do not produce consistently below 300 m elevation. However some varieties mainly Sabre, Peach, Tommy Atkins, Kent, Van Dyke and Keitt are adapted to altitude of up to 1,500 m above sea level, while Apple and Ngowe grow well in areas below 1000 m above sea level (Griesbach, 1997).

2.4. AGRO-ECOLOGICAL ZONING IN KENYA

Kenya has climatic and ecological extremes with altitude varying from sea level to over 5000 m in the highlands. The mean annual rainfall ranges from less than 250 mm in semi-arid and arid areas to greater than 2000 mm in high potential areas. Soils vary from the coral types on the coast to alluvial, swampy, and black cotton soils along river valleys and plains. The Kenyan highlands have fertile volcanic soils whereas soils in the semi-arid regions are shallow and infertile. The country is divided into 7 agro-climatic zones using a moisture index based on annual rainfall expressed as a percentage of potential evaporation (Sombroek *et al.,* 1982). Areas with an

index greater than 50% have high potential for cropping, and are designated zones I, II, and III. These zones account for 12% of Kenya's land area. The semi-humid to arid regions (zones IV, V, VI, and VII) have indexes of less than 50% and a mean annual rainfall of less than 1100 mm. These zones are generally referred to as the Kenyan rangelands and account for 88% of the land area (Table 3). The seven agro-climatic zones are each sub-divided according to mean annual temperature to identify areas suitable for growing major food and cash crops (Griesbach, 2003). Most of the high potential land areas are located above 1200 m altitude and have mean annual temperatures of below 18° C, while 90% of the semi-arid and arid zones lies below 1260 m and has mean annual temperatures ranging from 22° C to 40° C (Sombroek *et al.*,1987).

Table 2.2: Classification of Agro-Ecological Zones of Kenya based on Moisture Parameters

Agro Climatic Zone	Classification	Moisture Index (%)	Annual Rainfall (mm)	Land Area (%)
I	Humid	>80	1100-2700	10
II	Sub-humid	65 - 80	1000-1600	12
III	Semi-humid	50 - 65	800-1400	15
IV	Semi-humid to semi-arid	40 - 50	600-1100	5
V	Semi-arid	25 - 40	450-900	15
VI	Arid	15 - 25	300-550	22
VII	Very arid	<15	150-350	46

Source: (Sombroek *et al.*, 1987).

2.5. EFFECT OF PREHARVEST PRODUCTION ENVIRONMENT ON FRUIT QUALITY

2.5.1. Temperature

The prevailing weather conditions during growth influence postharvest fruit quality and of particular importance is temperature. The effect of temperature variation has been found to affect the total soluble solids of stone fruits (Vangdal *et al.,* 2005). Temperature affects fruit growth especially the rate of cell division and hence the final fruit size at harvest (Léchaudel *et al.*, 2005a). It has been suggested in Satsuma mandarin (Marsh *et al.,* 1999) and apples (Austin *et al.*, 1999), that temperature may affect the rate of cell division.

2.5.2. Light

Postharvest eating quality of fruits is greatly determined by light intensity and quality during growth and development (Kays, 1999). Light utilization is important in determining the amount of dry matter accumulated by fruits hence the trees' productivity in terms of the fruit and the vegetative growth (Tustin *et al.,* 2001). If the carbon supply decreases, fruit growth in terms of dry mass is reduced as well. Hofman *et al.,* (1995) found that, fruit size and dry matter content decreased in 'Kensington' fruit from upper to lower positions in the canopy. Soluble solids content and total sugars which can be related to dry matter content were found to be lower in mango fruit harvested from the lower portion of the canopy that received less amount of light due to shading effect (Hollinger, 1996). Light exposure affects the production of anthocyanin pigments involved in determining fruit skin color hence the visual attractiveness. Mangoes inside the canopy retain a greener skin color due to the decrease of fruit exposure to sunlight (Simmons *et al.,* 1998a). High light intensity caused low acidity in grapes and affected apple fruit texture, taste and sugar levels.

2.5.3. Water

The effect of water on postharvest fruit quality is mainly due to the quantity and the time which the water stress occurred during growth and development of the plant organ. Water availability alters the final fruit size (Simmons *et al.,* 1995). When water stress occurs during flowering period and the first half of the growing period, mango fruit growth rate and final size is affected (Simmons *et al.,* 1995). Water stress two weeks prior to harvesting had no effect on final fruit size. Early water stress from the end of the first half of the growing fruit period altered final mango fruit size through an effect on the cell number and size. This effect can be explained by the

decrease in carbon assimilation and in water fluxes entering the fruit, because of the lower leaf conductance and leaf water potential, respectively (Schaffer *et al.,* 1994). According to Hartung *et al.,* (2002) abcissic acid is produced during water stress leading to closure of the stomata. Simmons *et al.,* 1998b observed that moderate water stress reduces fruit size and increases contents of soluble solids and ascorbic acid. On the other hand, excessive water supply to the fruit reduced firmness, delayed maturity and reduced soluble solids (Lechaudel, 2005a).

2.5.4. Carbon

Fruit growth is mainly affected by the availability of carbohydrates. Several studies have shown that mango fruit size increased with increasing carbohydrates. Managing cultural practices like pruning which affect crop load enhanced carbohydrates availability to all bearing branches hence improving fruit size at harvest (Spreer *et al.,* 2007). Mango fruit size was smaller in low leaf to fruit trees (Léchaudel *et al.,* 2005a). However, increasing the number of leaves per fruit increased source size and carbon availability leading to fruit with higher sugar contents in the flesh but no significant increase in fruit size (Léchaudel *et al.,* 2005a).

The shortage of carbohydrates supply increases glucose and fructose content per unit of structural dry mass in mango flesh. It has been observed that the breakdown of starch mainly leads to an increase in sucrose content rather than an increase in glucose content (Wang and Stutte, 1992). The rates of sucrose accumulation were higher when assimilate production increased (Hubbard *et al.,* 1990). Fruit flesh from lower leaf to fruit ratios accumulated more citric acid (Léchaudel *et al.,* 2005b). An increase in leaf to fruit ratio had a positive effect on sweetness and a negative one on acidity (Léchaudel and Joas, 2006). Calcium concentration was higher in flesh from low leaf to fruit ratios trees while the opposite was for magnesium and potassium (Simmons *et al.,* 1998a).

2.5.5. Mineral Nutrition and Cultural Practices

Optimum plant performance depends on a balanced and timely availability of mineral nutrients that may be limiting in many soils around the world. Mineral ions are of prime importance in determining the fruit nutritional value (Lechaudel *et al.,* 2005). Potassium (K), calcium (Ca) and magnesium (Mg) are the major mineral nutrients. Inorganic mineral nutrients can influence the quality of horticultural crops in many ways but particularly in physiological fruit

disorders (Ferguson and Boyd, 2002). Some specific postharvest quality disorders of fruits and vegetables result from nutritional imbalances of certain minerals elements (Kays, 1999).

High levels of nitrogen (N) application are linked with increased green coloration on ground color and low levels of total soluble solids (Oosthuyse, 1993). Nguyen *et al.,* (2004) demonstrated that high N applications during fruit growth inhibited the degreening of ripening fruit, causing green skin at ripeness. Excess N may result in reduced firmness and enhanced susceptibility to postharvest decay. High levels of N have a drastic effect on fruit Ca availability due to shoot-fruit competition (Bramlage, 1993). High Ca content in fruits has been related to longer postharvest shelf life due to reduced rates of respiration and ethylene production, delayed ripening, increased firmness and reduced incidence of decay (Ferguson *et al.,* 1999). Potassium is an activator of enzymes involved in photosynthesis, respiration and starch and protein synthesis. Increased K fertilization has been shown to increase fruit weight (5.15%), ascorbic acid (27%) and sensory score for color, flavor and reducing physiological weight loss (Shinde *et al.*, 2006). Mg is involved in green coloration in chlorophyll and carbohydrate metabolism (Stassen *et al.,* 1999). Production environment and cultural practices all affect the nutrients levels and balance in the soil. This in turn affects nutrient supply to the tree and consequently nutritional quality of the harvested fruit (Crisosto *et al.,* 1995).

2.6. MANGO RIPENING AND THE ASSOCIATED PHYSIOLOGICAL AND BIOCHEMICAL CHANGES

Ripening is an irreversible process that leads to changes in chemical constituents, flavor, texture and organelle disruption. Ripening leads to a reduction in postharvest shelf life of mango fruit and is promoted by high temperature, mechanical injury and ethylene. Lowering the storage temperatures, reducing mechanical injuries and reducing ethylene production can delay ripening (Chun, 2010).

2.6.1. Changes in Ethylene Evolution and Respiration

Mangos are climacteric fruits which show an autocatalytic ethylene production after harvesting (Lalel *et al.,* 2003a). The initiation of ethylene production within the fruit triggers changes that occur during ripening. Both climacteric and non-climacteric fruits evolve and synthesize ethylene throughout their growth and development (Carrillo *et al.,* 2007). During the ripening phase of climacteric fruits, ethylene assumes a more dominant regulatory role and

appears to represent a separate system from the normal background levels of ethylene synthesized by the plant (Kader, 2008). Mango fruits become increasingly sensitive to ethylene and respond faster at a lower concentration of ethylene as they approach senescence. According to Thompson, (2003), the increase in ethylene production in climacteric fruits corresponds with a rise in respiration while in non-climacteric fruits each works independently. Ethylene is thought to bind to specific receptors found in the tissues resulting in a signal transduction which then triggers ripening and other responses (Kays, 2003). Therefore ethylene action can be affected by altering the number of receptors or by interfering with binding of ethylene to its receptors (Patterson and Bleecker, 2004). Ripening behavior and respiratory patterns vary among cultivars, growing locations and climatic conditions. Respiration is very high after fruit set and then declines and is maintained at a low rate until fruit ripening begins. After fruit harvesting, there is a gradual increase in respiration rate to a peak level then a gradual decline as the fruit approaches senescence, generally showing a typical climacteric pattern (Lalel *et al.,* 2003a).

2.6.2. Changes in Soluble Sugars

The increase in soluble sugars is a major change during fruit ripening and sweetness is the most important compositional change related to mango flavor. Hydrolysis of mango fruit starch to formation of sugar is associated with the ripening process; with glucose and fructose constituting most of the monosaccharides while sucrose constituting the major disaccharide (Ueda *et al.*, 2000). Conflicting reports on the relative concentrations of the individual sugars in mango during ripening is cultivar dependent and due to different storage and handling conditions (Medlicott and Thompson, 1985). Sucrose content increases during ripening as a result of starch hydrolysis from increased amylase activity. Reducing sugars, mainly fructose, increase slightly during ripening and sucrose synthase activity increases ten times during the phase of rapid sucrose accumulation (Castrillo *et al.,* 1992).

2.6.3. Changes in Organic Acids

Organic acids are important for respiratory activity and as flavor constituents. A substantial loss of organic acid is experienced during ripening. According to Ueda *et al.*, (2000), total titratable acidity decreases with fruit ripening possibly due to organic acids being used as respiratory substrates (Turker, 1993). The predominant acids in mature mango fruit are citric,

succinic, malic and tartaric acids. Citric acid has the highest concentration and tartaric acid the lowest. Citric and succinic acid decrease during ripening while malic acid shows different changes with various cultivars (Lizada, 1993).

2.6.4. Changes in Peel and Flesh Color

Mango skin color is important for determining the appropriate maturity for harvesting (Cocozza *et al.,* 2004) and consumption (Jha *et al.,* 2007). The loss of green color is a sign of fruit ripening in most of the fruit cultivars. The development of the optimum skin color defines mango quality. Some mango cultivars retain the green color in ripe fruit. Skin color can change from dark to olive green; sometimes reddish, orange-yellow hues appear from the base color. Lizada, (1993) found that the loss of green color due to degradation of the chlorophyll structure is the most common visible change in climacteric fruits during ripening. The disappearance of chlorophyll is associated with the synthesis of pigments like carotenoids that are synthesized during the development stages on the fruit but remain masked by the presence of chlorophyll (Lizada, 1993). The chloroplasts in the fruit peel are converted into chromoplasts, which are red or yellow pigments, while others cultivars such as Tommy Atkins may show reddish blush because of anthocyanin. Other mango cultivars may remain green in color. The carotenoid content during ripening varies among the cultivars, geography and climate, different maturity stages and treatments after harvest. Mango fruit pulp contains high concentration of carotenoids (up to 9mg/100g) causing the development of an intense yellow to orange color. The pulp carotenoid level is cultivar dependent. It has been reported that the level of carotenoid increases with a gradual decrease of anthocyanin in mangoes (Mercadante *et al.,* 1998).

2.6.5. Changes in firmness

Fruit softening and cell wall changes are major changes associated with fruit ripening. Fruit texture changes are due to changes in cell walls and pectin substances in the middle lamella, and are cultivar related. Softening of mango fruit is characterized by increased solubility of cell wall pectins (Nasrijal, 1993). Ripening in mangos is characterized by decreased tissue firmness and is initiated in inner mesocarp tissue close to the seed progressing outwards (Lazan *et al.,* 1993).

2.6.6. Water loss

Water loss is one of the main causes of physiological weight loss and deterioration. Water is lost from mango fruit through stomata, lenticels and other openings. According to Amarante and Banks, (2004), the fruit skin composition and structure, relative humidity and surrounding atmosphere temperature and air velocity affect the rate of water loss. Water loss not only leads to loss of saleable weight but also reduces the marketability of fresh fruits due to shriveling (Lizada, 2003).

2.6.7. Overall Fruit Senescence

According to Turker, (1993), the end of fruit ripening is followed by senescence whereby anabolic reactions are suppressed by degradative changes leading to decay of the fruit tissue. Senescence is catalyzed by postharvest disorders caused by pathogenic, physiological or mechanical damage. The shelf life of mango varies among varieties depending on storage conditions. Carrillo *et al.,* (2000) noted that the shelf life of mature fruits ranges from 4 to 8 days at room temperature and 2-3 weeks in cold storage at 13ºC limiting the long distance transportation. Temperature is an important factor that influences the deterioration rate of harvested commodities (Burdon, 1997). During respiration, heat is generated as sugars and organic acids get oxidized. According to Crisosto and Ganer, (2001), the higher the storage temperature, the higher the respiration rate of the fruit. In climacteric fruit, low temperature can be used to achieve a delay in the onset of ripening. Fruit sensitivity to decay, low temperature and general fruit perishability due to the rapid ripening and softening limits the storage, handling and transport potential (Hoa *et al.,* 2002).

2.7. ETHYLENE, THE RIPENING HORMONE

Ethylene (C_2H_4) is a natural plant growth regulator that affects growth and developmental processes including ripening and senescence (Abeles *et al.,* 1992). It is a simple and gaseous hydrocarbon that can diffuse into and out of plant tissues from both non-biological and biological sources thereby affecting postharvest quality of produce Saltveit, (1999). These effects can be beneficial or harmful depending on the produce, its ripening stage and the desired use (Saltveit, 1999). Ethylene is biologically active at very low concentration measured in the parts per million (ppm) and parts per billion (ppb) ranges. Ethylene biosynthesis is a highly regulated process occurring in most plant species. The precursor for ethylene biosynthesis is the amino acid

methionine, which is converted to s-adenosyl methionine (SAM) in the presence of the enzyme SAM synthetase. SAM is then converted to 1-amino-cyclopropane carboxylic acid (ACC) by the enzyme ACC synthase. This conversion is regarded as the rate-limiting step in ethylene biosynthesis and therefore critical in ethylene management strategies. 1-amino-cyclopropane carboxylic acid (ACC) is oxidized by the enzyme ACC oxidase to form ethylene (Lin *et al.,* 2009). The steps of ethylene biosynthesis are summarized below:

Methionine → S-adenosyl methionine (SAM) → 1- aminocyclopropane 1-carboxylic acid (ACC) → ethylene.

2.8. STRATEGIES FOR ETHYLENE AND RIPENING MANAGEMENT IN CLIMACTERIC FRUITS

The strategies employed in ethylene management in harvested produce can be broadly categorized as those aimed at avoiding ethylene, inhibiting ethylene biosynthesis and inhibiting ethylene perception and action (Sisler and Serek, 2003). Some of the strategies employed in ethylene management include controlled/modified atmosphere storage/packaging, calcium chloride treatments, low temperature storage and application of chemicals that target various steps in the ethylene biosynthetic pathway.

2.8.1. Controlled and Modified Atmosphere Storage or Packaging

Ripening and senescence rates in many climacteric fruits like mangoes, can be affected by controlling the availability of O_2 (oxygen) and CO_2 (carbon dioxide) to the fruit environment. This has a significant inhibitory effect on ability of ethylene to initiate ripening (Ben-Yehoshua *et al.,* 2005). Modified and controlled atmosphere packaging involves manipulating composition of gases surrounding fresh produce by respiration and transpiration when such commodities are sealed in plastic film with selective permeability to the gases. It involves increased carbon dioxide concentration, reduction of oxygen concentration and increased humidity levels. Reduced O_2 concentration reduces the metabolic activities hence slowing down the deterioration of the produce (Valero and Serrano, 2010). Low O_2 also inhibits ethylene production by inhibiting the conversion of 1-Aminocyclopropane-1-carboxylic acid **(**ACC) to ethylene since oxygen is critical for the activity of ACC oxidase enzyme. Elevated carbon dioxide levels compete with ethylene for the receptors leading to reduced ethylene effects hence delayed ripening and senescence.

2.8.2. Calcium Chloride Treatments

Pre-harvest and postharvest calcium application has been a common method used to enhance the postharvest shelf life of most climacteric fruits. Calcium as a mineral has been utilized in postharvest systems to strengthen fruit membrane tissues. High calcium content in fruits has been related to longer postharvest shelf life due to reduced rates of respiration and ethylene production, delayed ripening, increased firmness and reduced incidence of decay (Ferguson *et al.*, 1999).A number of studies have been conducted investigating a calcium chloride treatment for extending the storage life of mango. In studies of 'Julie' (Mootoo, 1991) and 'Willard' (Suntharalingam, 1996) mangoes, treatments of 4% to 6% calcium chloride extended the shelf-life of the fruit by 5 to 7 days.

2.8.3. Low Temperature Storage

Low temperature storage reduces the respiration rate and possibly lowers ethylene production due to reduced activities of the ripening related enzymes. However, there is a limit to the low temperature that mangos can tolerate due to their susceptibility to chilling injury, inhibition of ripening and surface blemishes. The lowest safe temperature for long-term exposure (2 weeks or more) of mature, green mangos is 12°C; immature fruit can be injured even at temperatures above 12°C. The storage period for ripe and mature green Tommy Atkins mangoes was found to be 35 days at 10°C. During cold storage at 12°C, ripening was retarded effectively for immature green fruits than mature green in Kent cultivars whereas, sensation mangoes ripened quickly under cold storage. Medlicott, (1990) noted that immature fruits failed to develop full ripeness characteristics compared to half and full mature during ripening at 25°C.

2.8.4. Chemical Options for Ethylene Management

The chemicals in ethylene management usually target various stages of the ethylene biosynthetic pathway ultimately inhibiting ethylene biosynthesis or action. Examples of these chemicals include: Aminooxyacetic acid (AOA) and Aminoethoxyvinylglycine (AVG) which act by binding to 1-aminocyclopropane-1-carboxylic acid (ACC) synthase (Serek, 1993). Inhibition of ethylene action is achieved by use of several chemical compounds such as silver ions (Ag^{+}) applied as silver thiosulphate, 2, 5-norbornadiene (NBD) and 1-Methylcyclopropene (1-MCP). Silver is a heavy metal which limits its use in food products and is also environment unfriendly

and hence restricted in most countries. 2, 5-norbornadiene (NBD) has been successfully used in slowing down ripening in apples (Sisler and Serek, 2003) although it is not commonly used in postharvest system because higher concentrations are required to achieve ethylene inhibition. In the last decade, 1-Methycyclopropene (1-MCP) has gained prominence as the better alternative to previously used chemicals named above.

2.8.5.1-Methylcyclopropene (1-MCP)

At standard temperature and pressure, 1-MCP is a gas with a molecular weight of 54 and a formula of C_4H_6 which is structurally similar to ethylene C_2H_4 making it an effective competitor. The safety, toxicity and environmental profiles of 1-MCP in regard to humans, animals and the environment are extremely favourable (Environmental Protection Agency, 2002). The compound odourless, effective at very low concentrations and has a non-toxic mode of action. In tests for acute toxicity, no death or clinical signs of systemic toxicity were seen (Environmental Protection Agency, 2002). The trade name SmartFresh™ is used for the commercial formulation of 1-MCP, and the product is registered for use up to 1 ppm on mangoes in the USA and a number of other countries (Sozzi and Beaudry, 2007). 1-MCP has been used effectively to slow down senescence and ripening in many horticultural crops including fruits, vegetables and flowers (Watkins, 2006). The application of 1-MCP is best suited for a crop like apples, where the goal is to maintain the crunchy texture from harvest through to consumption. In fruits like mangoes, where the goal is to have a change in texture between harvest and consumption, the use of 1-MCP is more challenging because the requirement is to delay, not inhibit, ripening. In these types of crops careful control of 1-MCP concentration and exposure time must be conducted, which can be challenging in commercial settings (Watkins, 2008).

The majority of 1-MCP research has been conducted on apples. In apples, many factors including cultivar, maturity, storage type, storage temperature, time between harvest and 1-MCP application, packaging or bin materials, and pre-harvest cultural practices have been shown to affect the performance of 1-MCP (Sozzi and Beaudry, 2007; and Watkins, 2008).

2.8.6. Factors Affecting the Efficacy of 1-MCP

2.8.6.1. Treatment concentrations

1-MCP treatment concentration depends on time, method of application, commodity and temperature. A minimum concentration of 0.1 ppm was required in apples to block ethylene action

(Jiang and Joyce, 2002; Sisler *et al.,* 1996a; Fan *et al.*, 1999a). In 'Tommy atkins' mango variety, 1 ppm was reported to effectively inhibit ethylene perception in fruits harvested at the mature green stage (Githiga, 2012). Jiang and Joyce (2002) found that while 1 ppm was sufficient to produce a decrease in ethylene, 10 ppm further reduced ethylene production in intact and cut apples. While 0.05 ppm and 0.5 ppm had no effect on unripe bananas, 5ppm delayed ripening (Harris *et al.*, 2000). A concentration of 0.09 ppm for 24 hours was not enough to produce a response in avocado softening while 0.45 ppm for 24 hours affected softening and associated enzyme activity (Jeong *et al.,* 2002). Feng *et al.,* (2000) found that 0.03ppm or higher were sufficient to delay ripening in avocado.

2.8.6.2. Treatment duration

Different fruits and vegetables respond differently to the treatment duration hence the effectiveness of 1-MCP also treatment duration. In most studies, treatment duration ranged from 12 to 24 hours, which was sufficient to achieve a full response. In avocado, an exposure of 6 hours was not sufficient to induce respiratory or ethylene production changes (Jeong *et al.,* 2002). An interaction between time and temperature was noted in banana fruit (Jiang *et al.,* 1999b) such that higher concentrations of 1-MCP were required for shorter treatment duration. In passion fruits, Yumbya, (2012) reported that different time (12 hours and 24 hours) versus concentration (4 ppm and 2 ppm) combinations respectively, achieved the same effect in inhibiting ethylene action.

2.8.6.3. Temperature

1-MCP has been applied at temperatures ranging from 20-25 ^{0}C. Lower temperatures have been used but a relationship exists between concentration, time and temperature. However, applications at low temperatures are not effective. Studies done on apples showed that lower temperatures might lower the affinity of the binding site for 1-MCP (Mir *et al.*, 2001). A relationship between treatment time and temperature was noted; apples at 3^{0}C required 9 hour treatment, whereas only 6 hour was needed at higher temperatures to delay ripening (DeEll *et al.*, 2002).

2.8.6.4. Developmental Stage and Plant Maturity

Plant developmental stage must be considered when applying 1-MCP as effects vary with

plant maturity. Previous reports in mango showed that 1-MCP was more effective when applied to fruits at early maturity compared to those at advanced maturity (Ricardo *et al.,* 2004; Githiga, 2012). In banana, Harris *et al.,* (2000), showed that maturity was a major factor in the response of the fruit to 1-MCP. Stage of ripeness in pears was found to be significant in 1-MCP treatment effects when testing pears for tissue mechanical properties (Baritelle *et al.,* 2001). According to Fan *et al.,* (2000a), 1-MCP effects in apricots decreased with advanced fruit development.

2.8.6.5. Time from Harvest to Treatment Application

The efficacy of 1-MCP application also depends on time from harvest to treatment. Perishable produce need to be treated immediately after harvest compared to the non-perishable ones. Ethylene production, softening, and internal browning in ripening apricots and plums was inhibited when fruit were treated with 1-MCP after storage, but not before storage (Dong *et al.,* 2002). In bananas treated with ethylene, the fruit had to be treated with 1-MCP within 24 hours to delay ripening (Jiang *et al.,* 1999b).

CHAPTER 3: EFFECT OF AGRO-ECOLOGICAL ZONES ON THE POSTHARVEST SHELF LIFE AND QUALITY ATTRIBUTES OF 'APPLE' MANGO FRUITS

3.1 ABSTRACT

Fruit quality at harvest is greatly influenced by preharvest production factors including climatic factors and farmers' cultural practices. The diverse production conditions affect fruit growth and development and the subsequent postharvest quality. Commodity factors including fruit cultivar and stage of maturity at harvest also dictate postharvest shelf life and fruit eating quality. In the present study, the effect of agro-ecological zones on postharvest shelf life and quality of 'apple' mango fruits harvested from Embu (a high potential AEZ) and Makueni (a low potential AEZ) was evaluated.

The fruits were harvested at two stages of maturity based on flesh color as stage 1 (flesh mostly white, just turning yellow near the seed) and stage 2 (flesh mostly yellow, turning orange at the seed). The fruits were selected for uniformity and freedom from blemishes and left to undergo normal ripening in their different batches at ambient room conditions (Temperature; 25 ± 1 ^{o}C and RH 60 ± 5%). Five fruits were randomly selected from each batch and used in daily determination of respiration, ethylene evolution and cumulative weight loss until the end of storage period. From the remaining bulk of each batch, five fruits were taken randomly every 3 and 5 days in (season 1 and 2) respectively for destructive sampling to determine changes in physical and biochemical parameters associated with mango ripening. The physical parameters measured included peel/flesh hue angle and firmness while the biochemical parameters determined included titratable acidity, total soluble solids, ascorbic acid, beta-carotene, soluble sugars (fructose, glucose and sucrose) and minerals (magnesium, calcium and potassium). A comparative assessment of sensory qualities of tree-ripened fruits from the two zones was done using 20 untrained panelists.

The results showed that fruits from Makueni had a longer shelf life (3 days more) compared to Embu fruits. As expected, fruits harvested at S1 had a longer shelf life compared to those harvested at S2. The differences between AEZ and stage of maturity were more evident in season 2. Makueni fruits showed significantly ($p<0.05$) lower respiratory activity compared to fruits from Embu as evidenced by the smaller and delayed climacteric peak. Additionally, Makueni fruits had relatively high initial peel/flesh hue angles and firmness with minimal weight loss at the end of storage. Significantly ($p<0.05$) high total soluble solids (12.6^{o}Brix), ascorbic acid (57mg/100ml)

and sugars (sucrose) 4.9 g/100ml was recorded in Makueni fruits at S1 compared to Embus' 9ºBrix, 50mg/100ml and 2.9 g/100ml respectively. The TTA content of Embu fruits at S1 and S2 at the end of storage was 50% higher compared to that of Makueni fruits. Titratable acidity, ascorbic acid, Mg and Ca were significantly ($p<0.05$) high in S1 fruits while TSS, beta-carotene, sugars and K were significantly ($p<0.05$) high in fruits at S2. Generally, fruits harvested from Makueni scored higher than Embu fruits for most of the sensory parameters evaluated including sweetness and general acceptability. In conclusion, it is evident that variations in mango production location affect fruit shelf life and their postharvest quality.

3.2 INTRODUCTION

Mango (*Mangifera indica* L.) is one of the high potential fruits in Kenya, suitable for different agro-ecological zones (AEZs) ranging from sub-humid to semi-arid. Due to its adaptation to a wide range of AEZs, mango production occurs in most of the seven AEZs in Kenya. Variation in production conditions in these AEZs variably affect fruit growth and development and subsequently on their postharvest quality.

Climatic factors and cultural practices influence post-harvest performance of mango fruit (Hofman and Smith, 1994).The location of production and the season in which the fruits are grown can determine their nutritional composition including the carotene, ascorbic acid, thiamine and flavonoid contents (Silva *et al.*, 2008). Temperature variations during production influence the uptake of mineral nutrients since transpiration rates increase with increasing temperature (Mattheis and Fellman, 1999). Temperature affects the rate of fruit growth and development hence implication on the final fruit size (Léchaudel *et al.*, 2005a).

Light exposure to the fruit influences its attractiveness especially on the red pigmentation of skin through the influence of light on anthocyanin production (Hollinger, 1996). Light also affects the ascorbic acid content of the fruit. The lower the light intensity the lower the ascorbic acid content of the fruit (Hollinger, 1996). Rainfall affects water supply to the fruit influencing its composition and susceptibility to mechanical damage and decay during postharvest operations (Behboudian and Mills, 1997). Excess water supply to plants results to excessive turgidity leading to increased susceptibility to physical damage, reduced firmness, delayed maturity and reduced soluble solids content (Simmons *et al.*, 1995).

The soil type, the rootstock used for fruit tree cultivation, mulching, irrigation and fertilization influence the water and nutrient supply to the plant, which in turn affect the nutritional

quality of the harvested fruit (Kays, 1999). High calcium uptake in fruits has been shown to reduce respiration rate and ethylene production, to delay ripening, increase firmness, and reduce the incidence of physiological disorders and decay, all of which result in increased post-harvest shelf-life (Ferguson and Boyd, 2002). High nitrogen content on the other hand, is often associated with reduced postharvest-life due to increased susceptibility to mechanical damage, physiological disorders, and decay (Hewett, 1997). Previous studies indicate that increasing the nitrogen and phosphorus supply to citrus trees results in reduced acidity and ascorbic acid content in citrus fruits, while increased potassium fertilization results in increased acidity and ascorbic acid content (Ferguson *et al.*, 1999).Cultural practices such as pruning and thinning determine the crop load and fruit size, which can in turn influence the nutritional composition of fruit (Hewett, 2006). Effective pre-harvest disease control greatly influences disease incidence and severity during post-harvest handling of mango fruits.

Maturity at harvest is the most important determinant of storage-life and final fruit quality (Crisosto *et al.,* 1995). The quality and the postharvest life of mango fruit depend on the maturity stage at harvest. Therefore, the fruit has to be harvested at the suitable stage of maturity in order to develop the optimum sensory quality attributes and extended postharvest life (Yahia, 1998a). Immature fruit have inferior quality and may fail to ripen adequately. Fruit harvested at over mature stage is highly susceptible to mechanical damage such as bruising, decay and water loss, resulting in quality deterioration. Therefore, appropriate harvest maturity for the target market is important to minimize the quantitative and qualitative losses.

The objective of this study was to establish the effect of agro-ecological zones (AEZ) and harvest maturity on the post-harvest shelf life and other quality parameters of 'apple' mango fruits. The fruits were produced from two different AEZs; a high potential AEZ (Embu) and a low potential AEZ (Makueni).

3.3 MATERIALS AND METHODS

3.3.0 EXPERIMENTAL SET UP

The experiment was conducted during the month of January to March of the year 2011 and 2013 at Jomo Kenyatta University of Agriculture and Technology in the Postharvest Laboratory. The 'apple' mango fruits were harvested from twelve trees of approximately the same age (6-7 years) in three commercial farms in Embu and Makueni. Embu County is semi-humid and lies in AEZ III. Embu is a high potential area lying 1200 m above sea level with mean annual

temperature of 19ºC and annual rainfall between 950 mm to 1350 mm. Embu orchard soils have good drainage and water holding capacity. The soils are fertile and rich in organic content. The soils are high in potassium (1.48ppm) and nitrogen (0.12%) nutrients. Makueni County is semi-arid and lies in AEZ V of Kenya. It is a low potential zone lying at 450 m above sea level and receiving an annual average rainfall of 550 mm or less. The mean annual temperature varies between 26ºC to 35ºC. Soils in Makueni are a combination of sandy-loam with relatively lower nutrient content. Soil tests indicated lower N content (0.07%), organic carbon (0.52%) and potassium nutrient (1.40 ppm).

Using fruit peel/pulp color and 'shoulder' orientation as maturity indices, the fruits were harvested at stage 1 (flesh mostly white, just turning yellow near the seed) (Figure 1.2) and stage 2 (flesh mostly yellow, turning orange at the seed) (Figure 1.3). Fruits used for sensory analysis were harvested at stage 3 (tree ripe stage). The harvested fruits were packed in crates lined with wetted cushioning materials to reduce mechanical damage during transportation. The fruits were then transported to the Postharvest laboratory at Jomo Kenyatta University of Agriculture and Technology. Only the firm and well developed fruits of uniform size and free from pest and disease, injuries, bruises and blemishes were selected for the experiment. The selected fruits at stage 1 and 2 were then washed in water containing 1% acetic acid to disinfect and then left to dry in open air. The fruits from each stage harvested from the different location were then batched and arranged in single layers on plastic trays which were then separately stored for evaluation of their shelf life under ambient room conditions (Temperature; 25 ± 1 ºC and RH 60 ± 5%). From each batch, five fruits were randomly selected for analysis of changes in physical and biochemical parameters associated with mango ripening. This was done after every three or five days in (season 1 and 2) respectively. In both seasons, five fruits from each batch were selected at the beginning, weighed and labeled (1-5) for daily evaluation of respiration rate, ethylene evolution and fruit weight measurement.

The experimental design used was Completely Randomized Design (CRD) with a factorial layout with three replications. The factors were two stages of maturity (S1 and S2) and two production locations (Embu and Makueni).

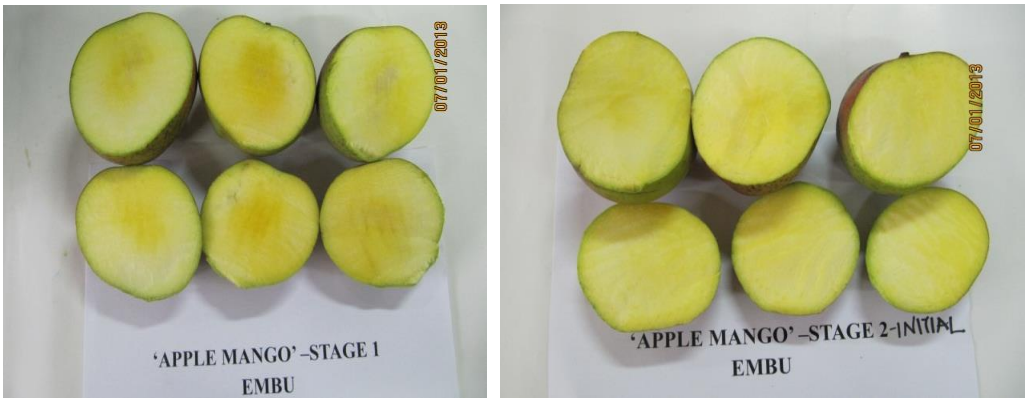

Figure 2.2: Flesh color of 'apple' mango harvested from Embu at stage 1 and stage 2 respectively

Figure 2.3: Flesh color of 'apple' mango harvested from Makueni at stage 1 and stage 2 respectively

3.3.1 ANALYSES OF FRUIT PHYSIOLOGICAL PARAMETERS

Five fruits from each treatment were randomly selected and numbered (1-5) for the determination of rate of respiration, ethylene production and cumulative weight loss daily. The end stage for all the parameters for evaluation was pre-determined at a peel firmness of between 3 to 4 Newton after which the fruits were discarded.

3.3.1.1 RESPIRATION RATES AND ETHYLENE PRODUCTION

Depending on the fruit size, five fruits were placed in plastic jars of 5775 ml whose covers were fitted with a self-sealing rubber septum for gas sampling. The fruits were then incubated for two hours at room temperature 25^0C. Gas samples from the headspace gas were taken using an airtight 1ml hypodermic syringe and injected into gas chromatographs (Models GC-8A and GC-

9A, Shimadzu Corp., Kyoto, Japan for respiration and ethylene production rates, respectively). The gas chromatograph for carbon dioxide determination was fitted with a thermal conductivity detector (TCD) and a Poropak N column and that for ethylene determination was fitted with an activated alumina column and a flame ionization detector (FID). Rate of carbon dioxide production was expressed as ml per Kg per Hour at standard atmospheric pressure while ethylene production was expressed as µl per Kg per Hour.

3.3.1.2 CUMULATIVE WEIGHT LOSS

Weights of five fruits from each treatment were taken on each sampling day using a scientific balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). The fruits were clearly numbered one to five and used for each sampling day until end stage. The initial weight (W_1) of each fruit at day 0 and the new weight of the same fruit (W_2) on each sampling day were noted. The below formula was used to calculate the cumulative weight loss (%):

Cumulative weight loss (%) = $(W_1 - W_2)/W_1 X100$

3.3.2 FRUIT PHYSICAL PARAMETERS MEASUREMENTS

3.3.2.1 COLOR

The peel and pulp color was measured at three different points on each of the three fruits using a NF-333-color spectrophotometer (Nippon Denshoku industries, Japan) that was calibrated with a white and black standard tile. The L*, a* and b* coordinates were recorded and, a* and b* values were converted to hue angle (H°) as follows;

Hue angle (H°) = arc tan (b/a) (for +a and +b values)

= arc tan (b/a) + 180 (for -a and +b values)

= arc tan (b/a) + 180 (for -a and –b values)

3.3.2.2 FRUIT FIRMNESS

Peel firmness of three whole fruits from each location was measured at three different spots of the fruits while flesh firmness was determined by slicing the upper portion of the fruit then measuring three different spots using a penetrometer (Model CR-100D, Sun Scientific Co. Ltd, Japan) fitted with a 5 mm probe. The probe was allowed to penetrate the peel and flesh to a depth of 1cm and the corresponding force required to penetrate this depth was determined. Firmness was then expressed as Newton (N) (Jiang *et al.*, 1999).

3.3.3 ANALYSES OF FRUIT BIOCHEMICAL PARAMETERS

After the measurement of the physiological and physical parameters above, five fruits from each batch were diced, packed in zip-lock bags and frozen at -20^{0}C for two weeks awaiting the evaluation of biochemical parameters.

3.3.3.1 TOTAL SOLUBLE SOLIDS

Total soluble solids (TSS) content was determined using an Atago hand refractometer (Model 500, Atago, and Tokyo, Japan). On each destructive sampling day, 3 ml of the fruit juice was extracted from three different fruits and placed on the hand refractometer to obtain the brix level. The total soluble solid was then expressed as ^{o}Brix.

3.3.3.2 TOTAL TITRATABLE ACIDITY

Total titratable acidity (TTA) was determined by titration. Five milliliters of the juice extracted was diluted with 25ml of distilled water. Only 10ml of the diluted juice was used for titration with 0.1N Sodium Hydroxide using phenolphthalein as an indicator. The TTA content was calculated as follows:

% citric acid equivalent = sample reading (ml)*Dilution factor/sample weight (ml)*Citric acid factor (0.0064)*100

3.3.3.3 ASCORBIC ACID DETERMINATION

The ascorbic acid was determined according to AOAC (1996) method number 1 of dye titration. Five milliliters of the juice was topped up with 10% trichloroacetic acid (TCA) in 100ml volumetric flask. The indicator used (2, 6-dichlophenolindophenol) was titrated into 10ml of the fruit juice extracted. Ascorbic acid content was calculated as follows:

Ascorbic acid (mg/100ml) = (A-B) X C X 100/S X (50/5)

Where A = volume in ml of indophenol solution used in the sample.

B = Volume (in ml) of indophenol solution used for the blank.

C = Mass (in mg) of ascorbic acid equivalent to 1 ml of standard indophenol solution.

S = Weight of the sample taken (in ml)

50/5 = total extraction volume/volume of titrated sample

3.3.3.4 DETERMINATION OF BETA-CAROTENE CONTENT

The beta-carotene content was determined by a modified chromatographic procedure (Heionen, 1990). Five millilitres of juice extract was mixed with 50 ml of cold acetone and filtered using glass funnel. Partitioning was done using 25ml petroleum ether in a separating funnel to obtain the beta carotenerich upper layer. Distilled water was added along the walls of the funnel. The two phases were separated as the lower aqueous phase discarded. Acetone residues were removed by washing 3 times with distilled water without discarding the upper phase. The upper phase was collected using anhydrous sodium sulphate to drain water and then stored in sample bottles in a dark cabinet. β-carotene content was determined using UV-Vis spectrophotometer (Model UV mini 1240, Kyoto Shimadzu) and absorbance read at 450nm. The β−carotene content was calculated as follows:

$$\beta\text{−carotene (mg/100ml)} = \frac{A * \text{Volume (ml)} * 10^4}{A^{1\%}_{1cm} * \text{sample weight (ml)}}$$

Where A= absorbance; volume = total volume of extract (25 ml); $A^{1\%}_{1cm}$ = absorption coefficient of β−carotene in PE (2592).

3.3.3.5 DETERMINATION OF FRUCTOSE, GLUCOSE AND SUCROSE CONTENT

Sugars were analyzed using AOAC method (1996). Five ml of the extracted juice was mixed with 50ml distilled water. Two ml of lead acetate was added and then mixed thoroughly. The solution was filtered in 5% anhydrous oxalate and finally micro-filtered. The individual sugars were analyzed using a high performance liquid chromatography (HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with a refractive index (RI) detector and running under the following conditions: Oven temperature: 30^{o}C, Flow rate: 0.5-1.0 ml/min. Injection volume: 20 uL and mobile phase: Acetonitrile: water (75:25). The sugars present were identified and their individual concentration calculated using the standards.

3.3.3.6 MINERALS DETERMINATION

Minerals were analyzed using the AOAC (1996) method. Five grams of the pulp was charred in the oven for 30 minutes then put in a muffle furnace at 550^{0}C for eight hours to ash. The ash was allowed to cool and diluted with 10ml of 1N hydrochloric acid. The mixture was filtered and diluted with 100ml of distilled water. Calcium and magnesium were analyzed using an

atomic absorption spectrophotometer (Model AA-6200, Shimadzu Corp., Kyoto, Japan) while potassium was analyzed using flame emission photometer (Model FA- 410, Shimadzu Corp., Kyoto, Japan).

3.4 FRUIT SENSORYANALYSIS

The sensory attributes of fresh fruits was done on tree ripe fruits (stage 3). The fruits were diced into approximately equal-sized slices and then 3 slices placed on white plate which were anonymously coded based on location (Makueni or Embu) to ensure objectivity. A panel of 20 untrained judges was guided on the scoring procedure for various sensory attributes including fruit color, aroma, texture, taste/flavor, mouth feel and the general acceptability. The panelists scored for these attributes on a five point hedonic scale where 1 = dislike extremely (worst), 2 = (dislike moderately), 3 = (neither like nor dislike), 4 = (like moderately) and 5 = (like extremely) (best).

3.5 STATISTICAL ANALYSIS

Data was analyzed using Genstat statistical package 14th edition. Comparison of means was done by Analysis of Variance (ANOVA) and Least Significance Difference (LSD) at $P \leq 0.05$. The sensory evaluation data was analyzed using SPSS. The data is presented as graphs and tables showing the changing trends for various parameters based on the main treatment effects. The ANOVA tables showing the levels of significance and interactions between the factors are presented in the appendices to the main text.

3.6 RESULTS

3.6.1 CHANGES IN PHYSIOLOGICAL PARAMETERS

3.6.1.1 RATE OF RESPIRATION AND SHELF LIFE

Respiration rate followed a typical climacteric pattern with a gradual rise to peak levels followed by a decrease until the end of storage (Figure 3.1 (A and B). Higher respiration rates were observed in stage 2 (S2) fruits compared to those harvested at stage 1 (S1) irrespective of the production location and season. In season 1, fruits from Makueni had generally lower respiration rates and ultimately smaller respiration peaks 53.5 and 56.1 ml/ Kg/Hour (S1 and S2 respectively) compared to 57.6 and 59.8 ml/ Kg/Hour for fruits from Embu. Significantly higher respiration rates were reported in season 2 compared to season 1. However, just as observed in season 1, fruits from Makueni had significantly ($p<0.05$) lower respiration rate and lower peak levels, 54.0 and 55.3 ml/Kg/Hour compared to 75.4 and 78.2 ml/Kg/Hour (S1 and S2 respectively) for fruits from Embu. In season 2, respiration rate was significantly ($p<0.001$) affected by the interaction between location and stage of maturity.

Overall based on respiratory activity, fruits harvested at early maturity (S1) had a relatively longer shelf life of 10 and 13 days (Embu and Makueni respectively) compared to 8 and 9 days those harvested at advanced maturity (S2) (Figure 3.1 (A). Additionally from the foregoing, fruits from Makueni (both stages) had a relatively longer shelf life compared to those from Embu.

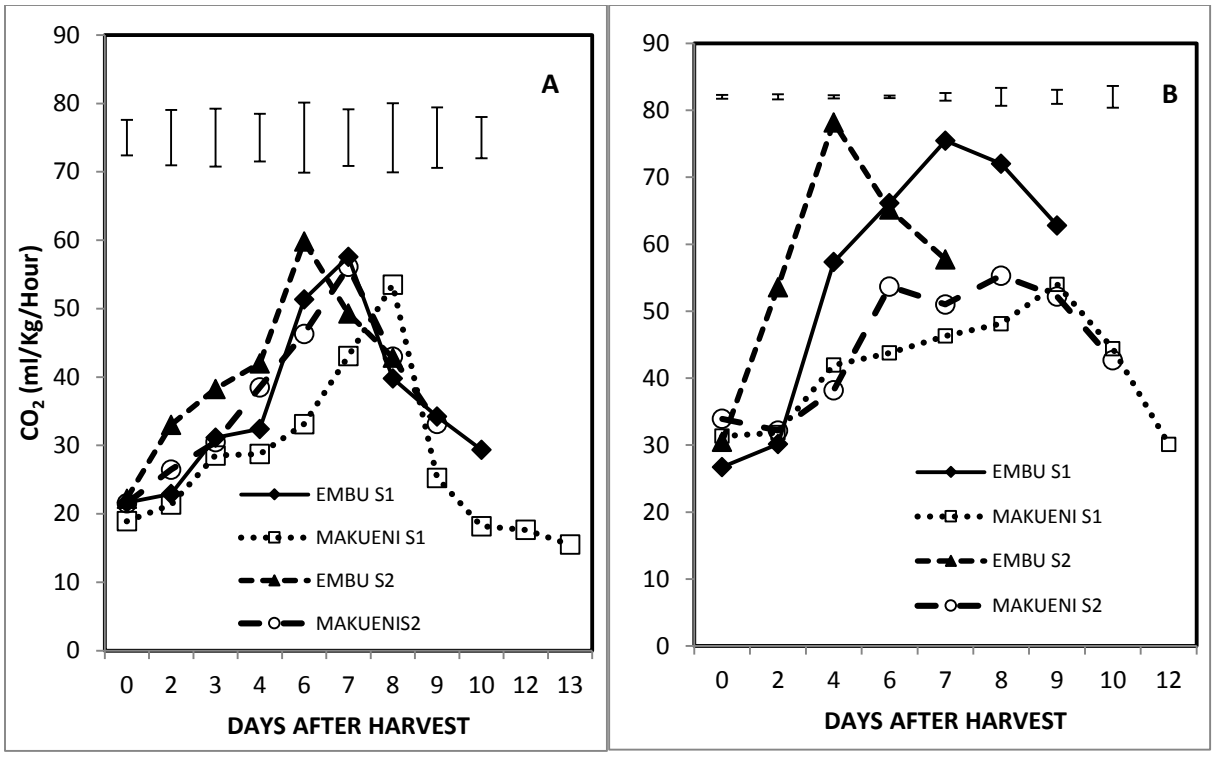

Figure 3.1: Changes in CO_2 production of 'apple' mango harvested from Embu and Makueni at two stages of maturity; mature green (S1) and advanced in maturity (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$ for the four treatment means on each sampling day.

3.6.1.2 RATE OF ETHYLENE PRODUCTION

The rate of ethylene production was detected in fruits harvested from Makueni and Embu at S1 and S2 in season 1. The results show no clear pattern of ethylene evolution. Ethylene was first detected four days after harvest in fruits harvested at S2 from both locations (Figure 3.2). Fruits harvested at S1 from Makueni had significantly ($p<0.05$) lower ethylene levels compared to those from Embu at S1 on day 4 (0.12 µl/Kg/Hour and 0.28 µl/Kg/Hour) respectively. The highest ethylene amount was detected in fruits harvested at S1 from Embu (0.28 µl/ kg/hour) on day 6 then followed by (0.25 µl/Kg/Hour on day 9) from Makueni S2 fruits. Ethylene levels of 0.15 µl/Kg/Hour was detected on the final day of storage for fruits harvested at S1 from Makueni.

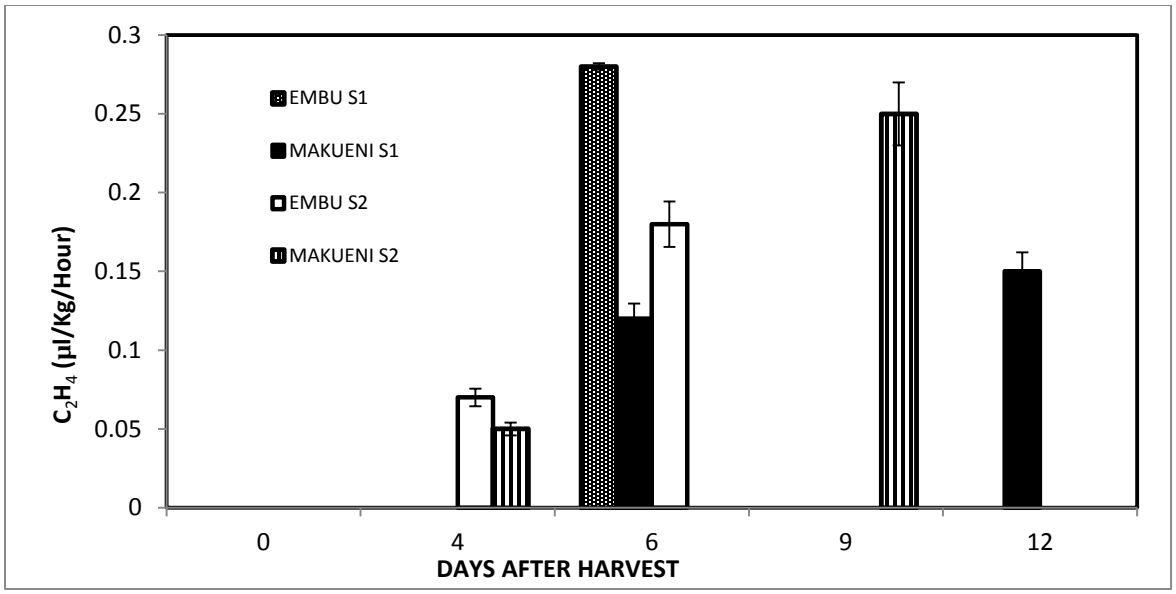

Figure 3.2: Ethylene evolution of 'apple' mango harvested from Embu and Makueni at two stages of maturity; mature green (S1) and advanced in maturity (S2) in season 1. Vertical bars represent means ± standard errors at $p<0.05$.

3.6.2 CHANGES IN PHYSICAL PARAMETERS

3.6.2.1 CHANGES IN PEEL HUE ANGLE

A general reduction in peel hue angle was observed as ripening progressed (Figure 3.3 (A and B). In season 1, the hue angles gradually reduced from the initial values of 102.07^0 and 101.8^0 to 65^0 and 70.3^0 for S1 fruits and from the initial 100^0 to 67.8^0 and 74.8^0 for S2 fruits from Makueni and Embu respectively, at the end of storage. No significant ($p<0.05$) difference in hue angles was observed in fruits from Makueni (both stages) and S1 fruits from Embu. However, S2 fruits from Embu had significantly ($p<0.05$) lower hue angle values throughout the storage period. In season 2, the fruits had relatively higher initial hue angle values compared to season 1 fruits. Just like in season 1, the hue angles reduced gradually from initial values of 106.3^0 and 108.6^0 to 63.7^0 and 75.5^0 for S1 fruits and from 103.8^0 and 104^0 to 66.3^0 and 71.5^0 for S2 fruits from Makueni and Embu respectively. Fruits from Makueni (both stages) retained significantly ($p<0.05$) higher hue angles throughout the storage period compared to fruits from Embu. Fruits harvested at S1 from Makueni had the least peel hue angle at the end of storage in both seasons.

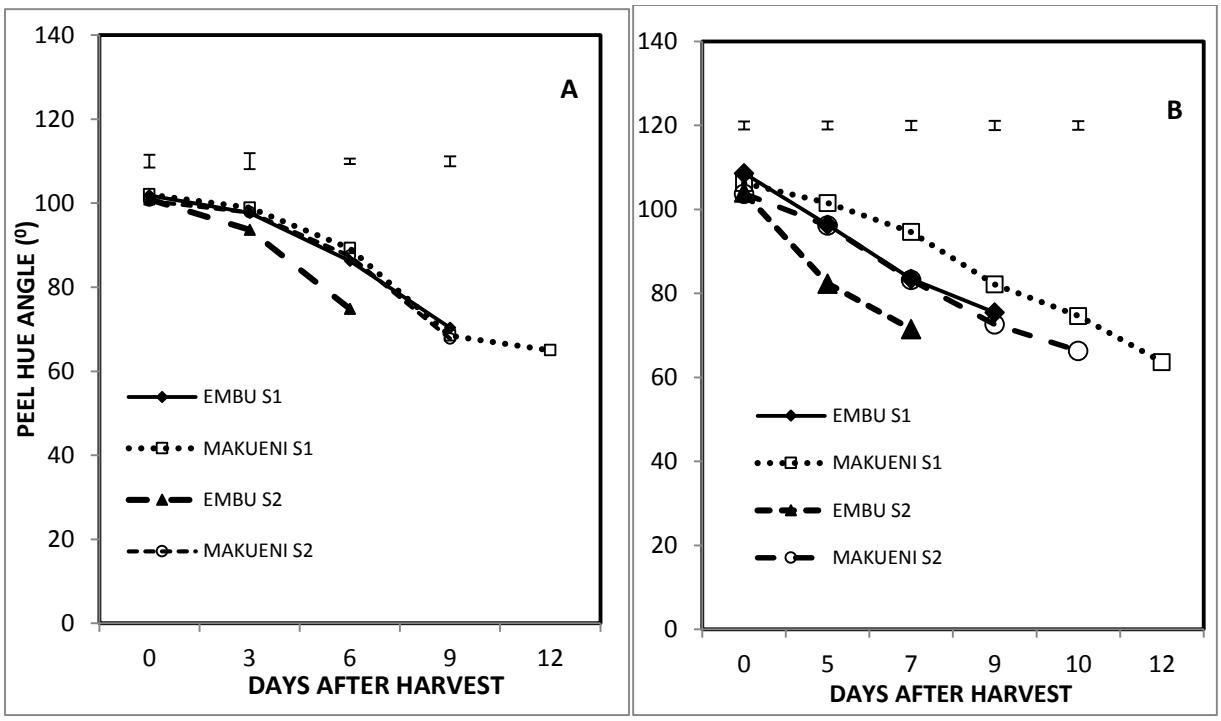

Figure 3.3: Changes in peel color expressed as hue angle of 'apple' mango harvested from Embu and Makueni at two stages of maturity; mature green (S1) and advanced in maturity (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$ for the four treatment means on each sampling day.

3.6.2.2 CHANGES IN FLESH HUE ANGLE

Flesh hue angle decreased gradually with increase in fruit storage time in both seasons (Figure 3.4 (A and B). Relatively higher flesh hue angle was recorded in fruits harvested at S1 compared to those harvested at S2 for both locations. In season 1, the hue angles gradually reduced from the initial values of 99º and 99.9º to 65.6º and 74º for S1 fruits and 97.7º and 97º to 74.7 º and 71.9 º for S2 fruits from Makueni and Embu respectively, at the end of storage. Fruits from Makueni retained relatively higher hue angles compared to Embu fruits. In season 2, the hue angle slowly reduced from the initial values of 101.6 º and 98 º to 58.3 º and 63.4 º for S1 fruits and 99.7 º and 96.4 º to 62 º and 65.4 º for S2 fruits from Makueni and Embu respectively by the end of storage period. As observed in season 1, fruits from Makueni (both stages) retained significantly ($p<0.05$) higher hue angles throughout the storage period. No significant ($p<0.05$) interaction between location and stage on flesh hue angle was noted in both seasons.

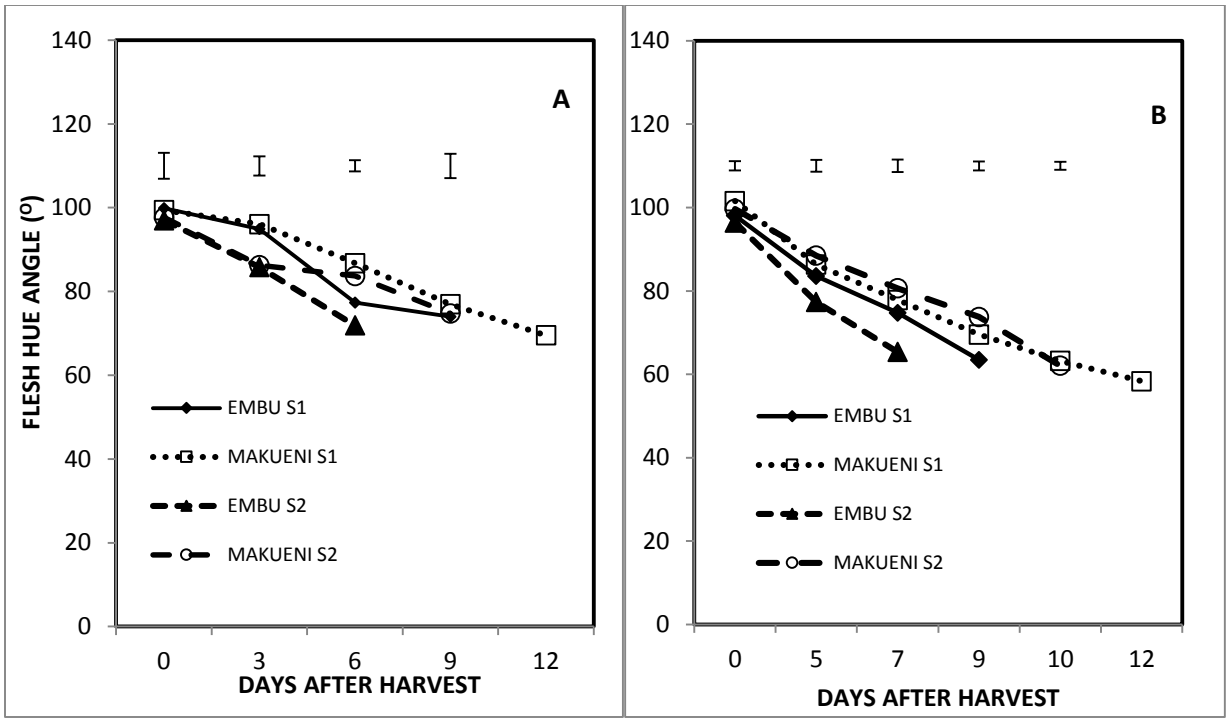

Figure 3.4: Changes in flesh color expressed as hue angle of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$ for the four treatment means on each sampling day.

3.6.2.3 CHANGES IN PEEL FIRMNESS

A gradual reduction in peel firmness was observed in all the fruits as ripening progressed (Figure 3.5 (A and B). Significantly ($p<0.05$) higher peel firmness was recorded in fruits harvested at S1 compared to S2 fruits, regardless of season of production or location. In season 1, at the end of storage, fruits harvested at S1 had lost 85.4% and 76% of their initial firmness (24.7 and 22.8 N), while S2 fruits had lost 83.3% and 72.03% of their initial firmness (22.4 and 19.5N) for Makueni and Embu respectively. Significant location differences were observed in season 2 with Makueni fruits having significantly ($p<0.05$) higher initial firmness of 20.4 and 18.8 N compared to Embu's 17.4 and 16.6 N respectively for S1 and S2 fruits. At the end of storage, S1 fruits had lost73% and 65.5% of their initial firmness at day 12 and 9 from Makueni and Embu respectively. Similarly, fruits at S2 lost 70.7% and 75.6% of their initial firmness at day 10 and 7 from Makueni and Embu respectively. Peel firmness was not significantly ($p<0.05$) affected by the interaction between location and stage of maturity in both seasons.

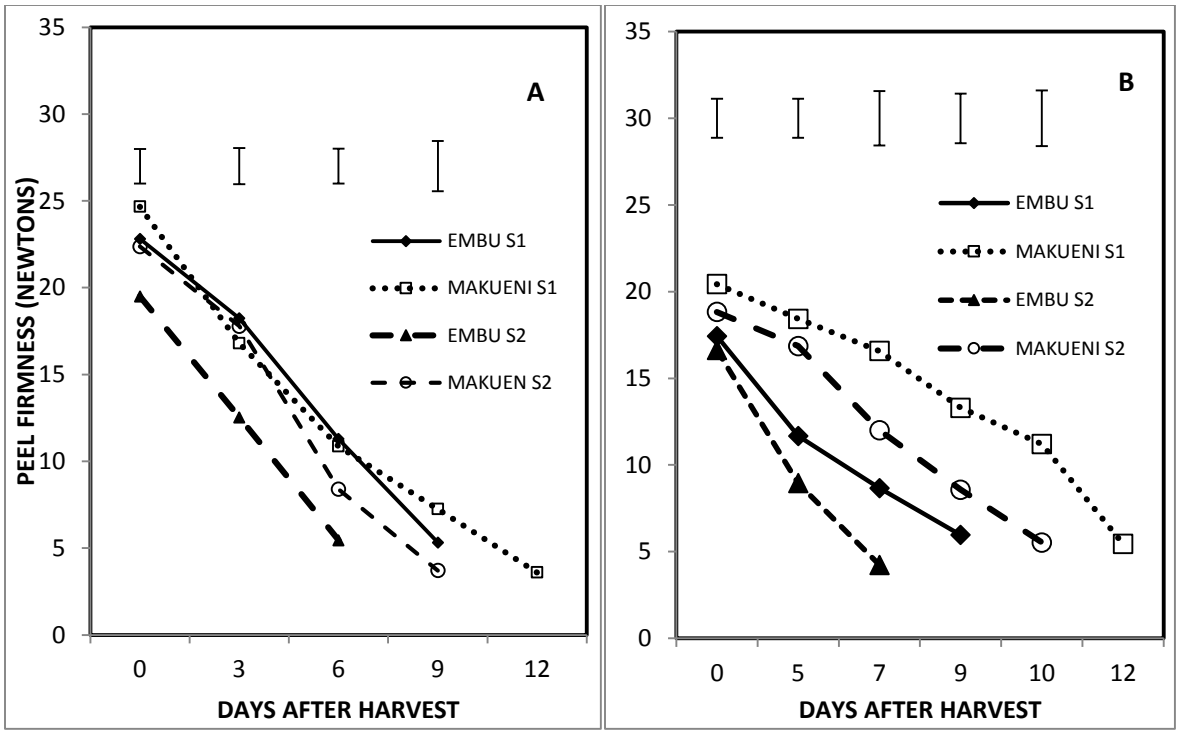

Figure 3.5: Changes in peel firmness of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$ for the four treatment means on each sampling day.

3.6.2.4 CHANGES IN FLESH FIRMNESS

There was a general reduction in flesh firmness as ripening progressed (Figure 3.6 (A and B). Fruits harvested at S1 were significantly ($p<0.05$) firmer than those at S2 irrespective of season of production or location. In season 1, fruits harvested at S1 had lost 82.4% and 83% of their initial firmness (14.9 and 14.5 N) (at day 12 and 9) while fruits harvested at S2 had lost 70% and 68% of their initial firmness (12.6 and 12.0 N) (at day 9 and 6) of their initial firmness (Makueni and Embu respectively). Makueni fruits (both stages) retained relatively higher flesh firmness compared to Embu fruits throughout the storage period. In season 2, significantly lower flesh firmness was observed compared to season 1. At the end of storage, S1 fruits had lost 75.2% and 58.9% of their initial firmness (11.7 and 9.5 N) (day 12 and 9) while fruits at S2 fruits had lost 64.9% and 56.7% of their initial firmness (9.7 and 9.0 N) (at day 9 and 6 respectively) for Makueni and Embu respectively. Fruits from Makueni retained significantly ($p<0.05$) higher flesh firmness compared to fruits from Embu throughout the storage period. Flesh firmness was significantly ($p<0.001$) affected by the interaction between location and stage of maturity in season 2.

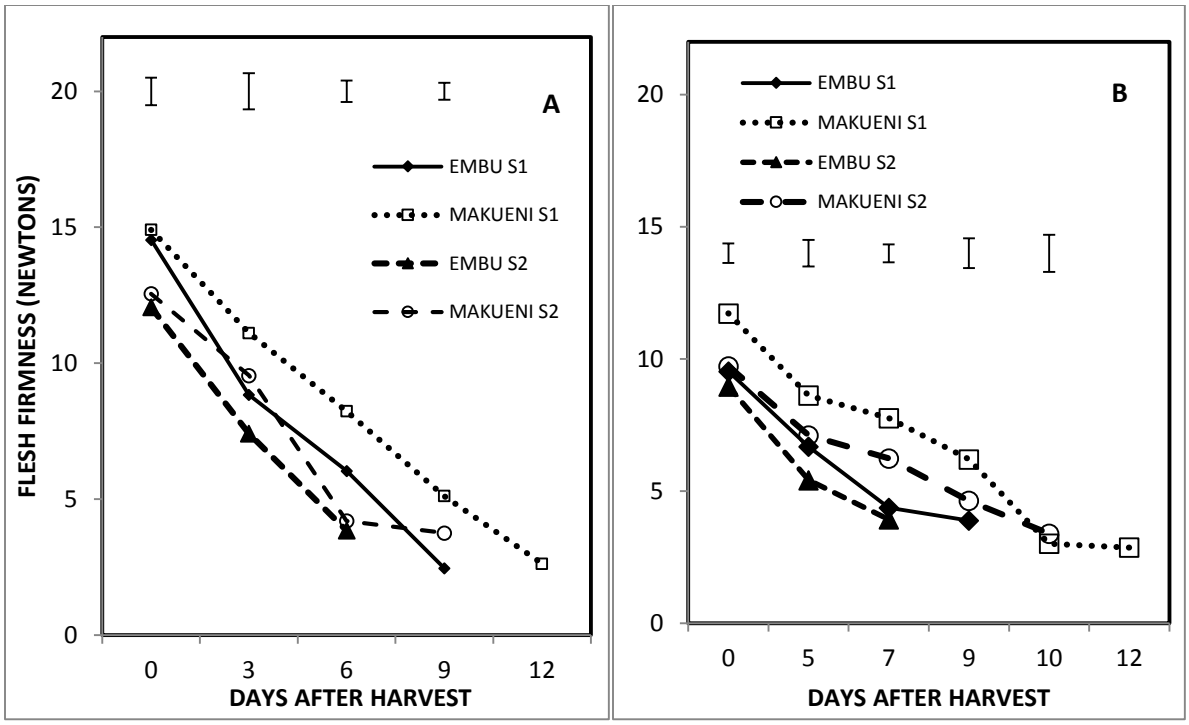

Figure 3.6: Changes in flesh firmness of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$ for the four treatment means on each sampling day.

3.6.2.5 PERCENT CUMULATIVE WEIGHT LOSS

The percent cumulative weight loss increased with fruit ripening in both season 1 and 2 (Figure 3.7 (A and B). Fruits harvested at S1 retained significantly ($p<0.05$) higher percentage of their initial weight than at fruits S2. Similarly, Makueni fruits retained significantly ($p<0.05$) higher percentage of their initial weight compared to fruits from Embu. In season 1, fruits harvested at S1 from Embu lost 11.5% of their initial weight at day 10 compared to 10% at day 12 for fruits from Makueni. Fruits harvested at S2 from Embu lost 10.5% at day 8 compared to 10.3% a day later for fruits from Makueni. In season 2, fruits at S1 lost 10% at day 9 and 11.6% three days later while at S2 fruits lost 8.9% at day 7 and 8.4% of their initial weight at day 12, respectively for Embu and Makueni.

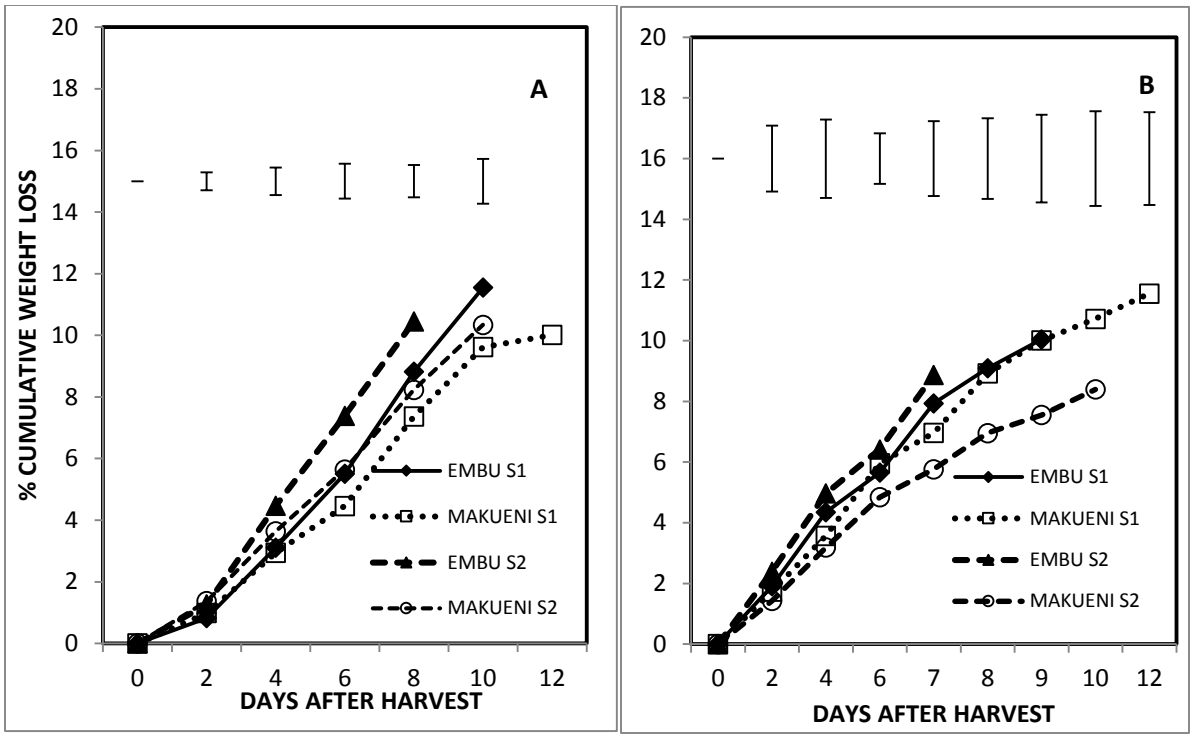

Figure 3.7: Changes in cumulative weight loss of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

3.6.3 CHANGES IN FRUIT CHEMICAL PARAMETERS

3.6.3.1 TOTAL SOLUBLE SOLIDS (TSS)

Observations on fruit TSS showed an increase with progress in ripening (Figure 3.8 (A and B). In season 1, the TSS levels gradually increased from the initial values of 4.3 and 3.4 ºbrix for S1 fruits and 5.3 and 5.4 ºbrix for S2 fruits from Makueni and Embu respectively at the end of storage period. S1 fruits harvested from Embu had the lowest TSS levels throughout the storage period. In season 2, relatively higher TSS levels were observed than in season 1. Similar to season 1, the TSS levels gradually increased from the initial values of 5.4 and 4.7 ºbrix to 12.6 and 9 ºbrix for S1 fruits and from initial values of 6.2 and 4.9 to 10.8 and 13.8 ºbrix for S2 fruits from Makueni and Embu respectively. Fruits harvested from Makueni at S2 maintained significantly ($p<0.05$) higher TSS levels compared to those from Makueni at S1 during their storage period. At the end of storage, fruits harvested at S2 had the highest TSS levels in both seasons. In both seasons, TSS content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity.

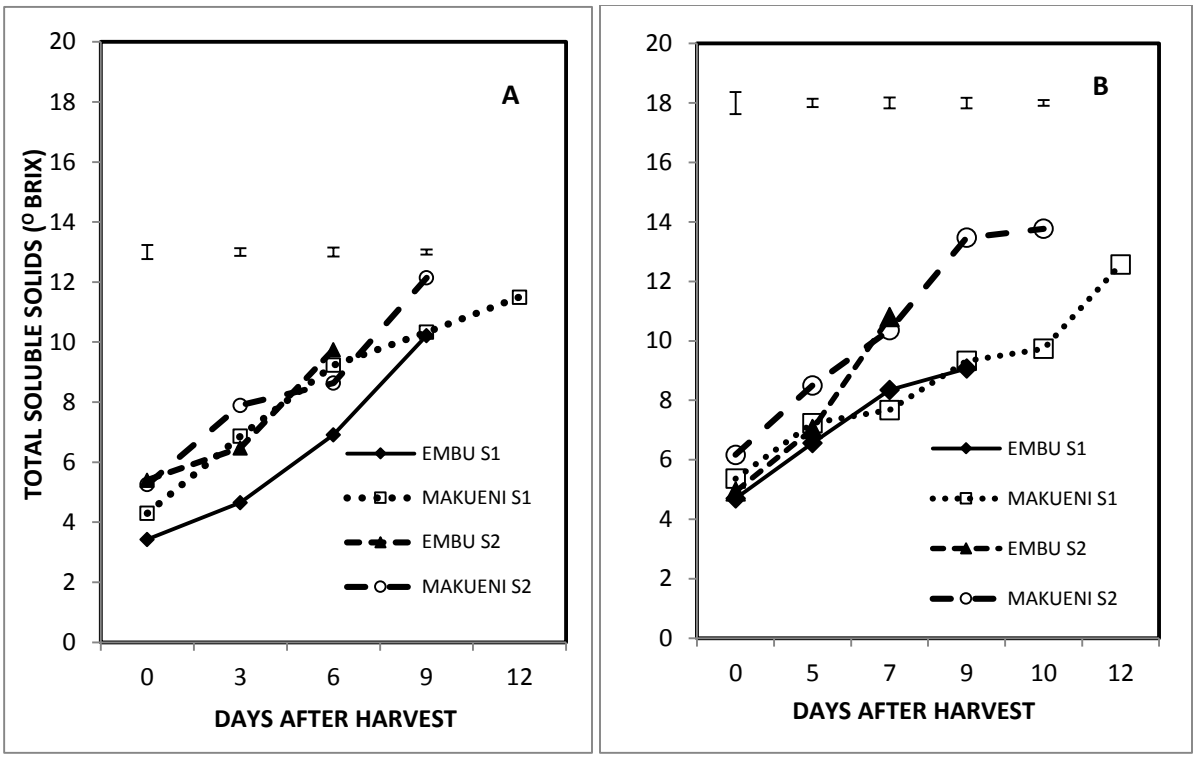

Figure 3.8: Changes in total soluble solids of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at p≤0.05for the four treatment means on each sampling day.

3.6.3.2 TOTAL TITRATABLE ACIDITY (TTA)

TTA levels reduced gradually in all the fruits as they ripened (Figure 3.9 (A and B). Fruits harvested at S1 had significantly ($p<0.05$) higher TTA content than those at S2 regardless of production location and season. In season 1, the TTA levels gradually reduced from the initial values of 0.56 and 0.65% to 0.03 and 0.1% for S1 fruits and from the initial 0.34 and 0.4% to 0.03 and 0.18% citric acid equivalent for S2 fruits from Makueni and Embu respectively, at the end of storage. Fruits harvested from Makueni at S1 retained significantly lower TTA levels during their entire storage than fruits from Embu at S1. In season 2, the TTA levels of fruits at S1 gradually reduced from the initial values of 0.6 and 0.7% to 0.07 and 0.14% and from the initial 0.55% and 0.62% to 0.11% and 0.21% citric acid equivalent for S2 fruits from Makueni and Embu respectively at the end of storage period. TTA content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity in season 1 only.

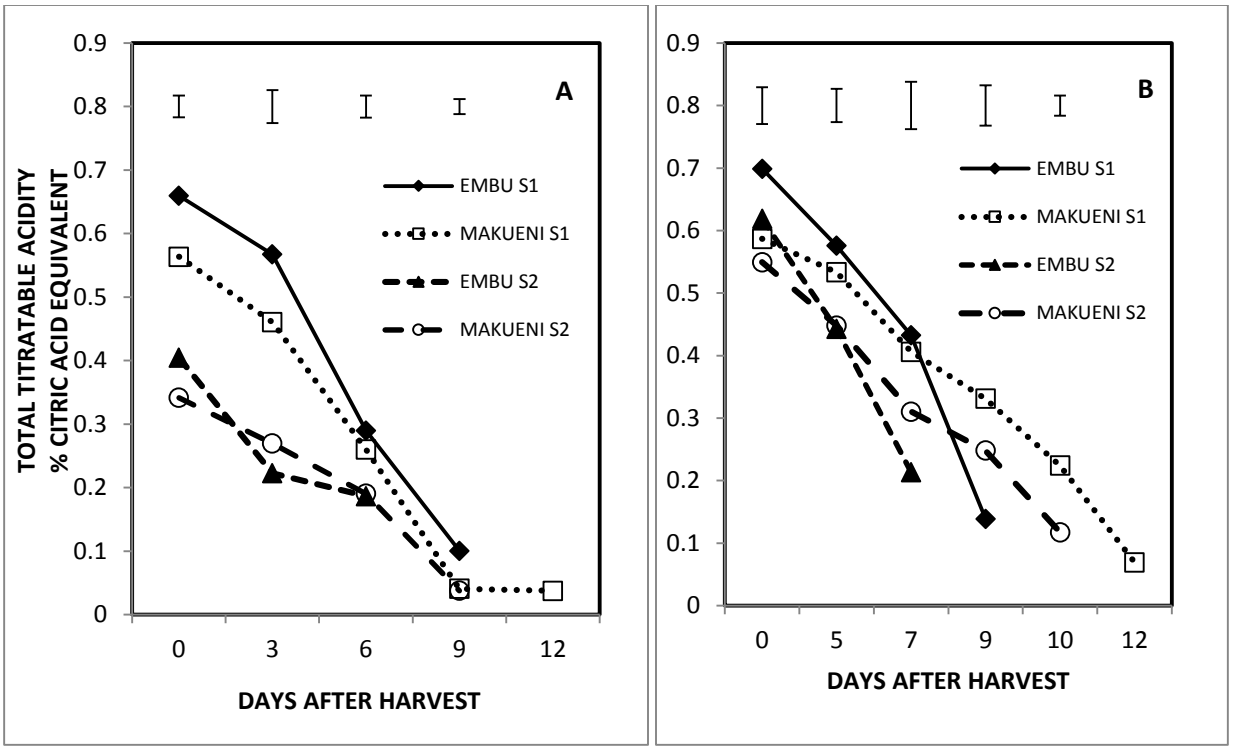

Figure 3.9: Changes in total titratable acidity of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at p≤0.05for the four treatment means on each sampling day.

3.6.3.3 ASCORBIC ACID

As ripening progressed, the levels of ascorbic acid reduced in all the fruits (Figure 3.10 (A and B). Fruits harvested at S1 had significantly ($p<0.05$) higher ascorbic acid levels compared to S2 fruits irrespective of the production location and season. Fruits from Makueni (both stages) had higher initial ascorbic acid levels in both seasons. In season 1, the initial ascorbic acid content in S1 fruits was 98.85 and 85.64 mg/100ml while S2 fruits had 82.78 and 77.44 mg/100ml respectively for Makueni and Embu. Fruit ascorbic acid content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity in season 1. Significantly ($p<0.05$) higher initial levels of ascorbic acid were observed in season 2. In season 2, the initial ascorbic acid content in S1 fruits was 110.5 and 104.5 mg/100ml while S2 fruits had 106.3 and 96.3 mg/100ml respectively for Makueni and Embu. Fruits harvested from Makueni at both stages of maturity retained significantly ($p<0.05$) high ascorbic content during their storage period compared to fruits from Embu.

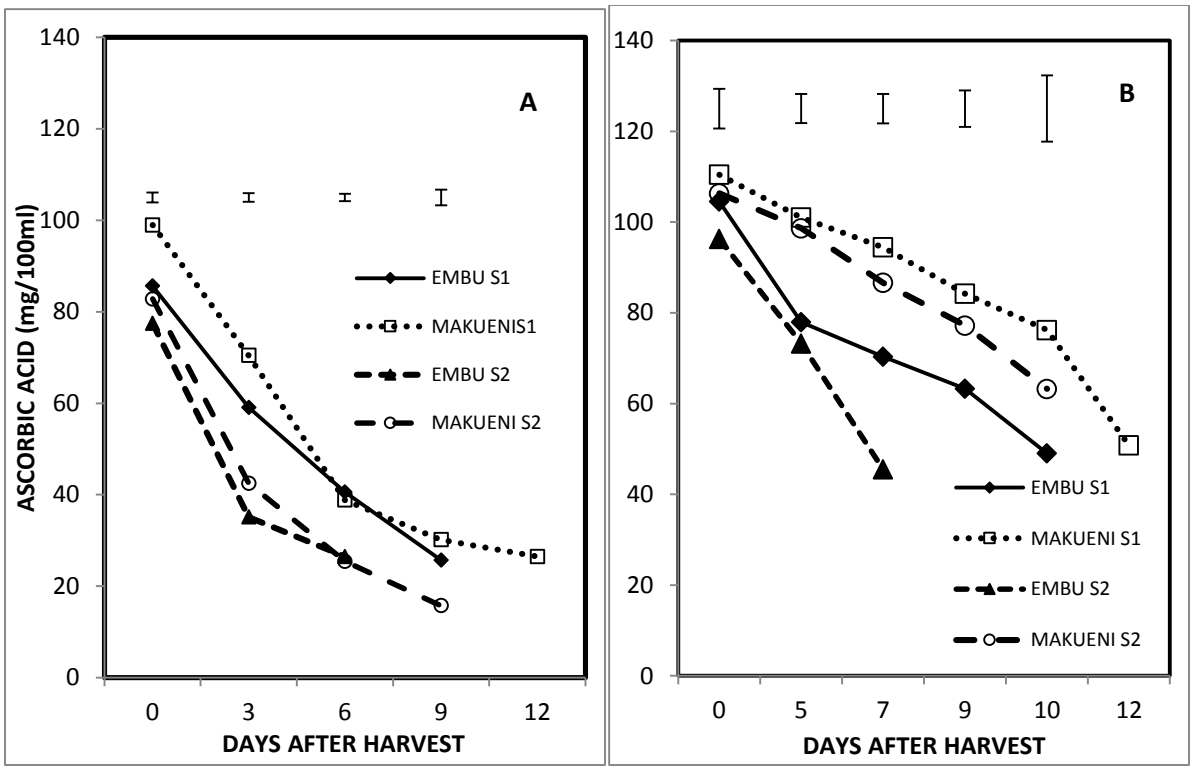

Figure 3.10: Changes in ascorbic acid content of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

3.6.3.4 BETA-CAROTENE

A general increase in beta-carotene content was observed as fruit ripening progressed (Figure 3.11 (A and B). Fruits harvested at S2 had significantly ($p<0.05$) higher initial beta-carotene content compared to S1 fruits regardless of production location and season. In season 1, the levels of beta-carotene increased gradually from the initial values of 0.4 and 0.15 mg/100ml to 7.4 and 4.8 mg/100ml for S1 fruits and from the initial 0.9 and 0.8 to 10.13 and 4.8 mg/100ml for S2 fruits from Makueni and Embu respectively, at the end of the storage period. Fruits from Makueni retained significantly ($p<0.05$) higher beta-carotene levels compared to those from Embu. In season 2, a gradual increase in beta-carotene levels from the initial values of 0.6 and 0.7 mg/100ml to 6.6 and 6.5 mg/100ml for S1 fruits and from 1.33 and 0.9 mg/100ml to 7.9 and 5.5 mg/100ml for S2 from Makueni and Embu respectively, was observed at the end of storage period. Fruits harvested from Makueni at S1 retained significantly lower beta-carotene levels from day 7 up to day 9 compared to those from Embu at S1. At the end of storage period, fruits at S2 from Makueni attained the highest beta-carotene levels in both seasons.In both seasons, fruit beta-

carotene content was significantly ($p<0.05$) affected by the interaction between location and stage of maturity.

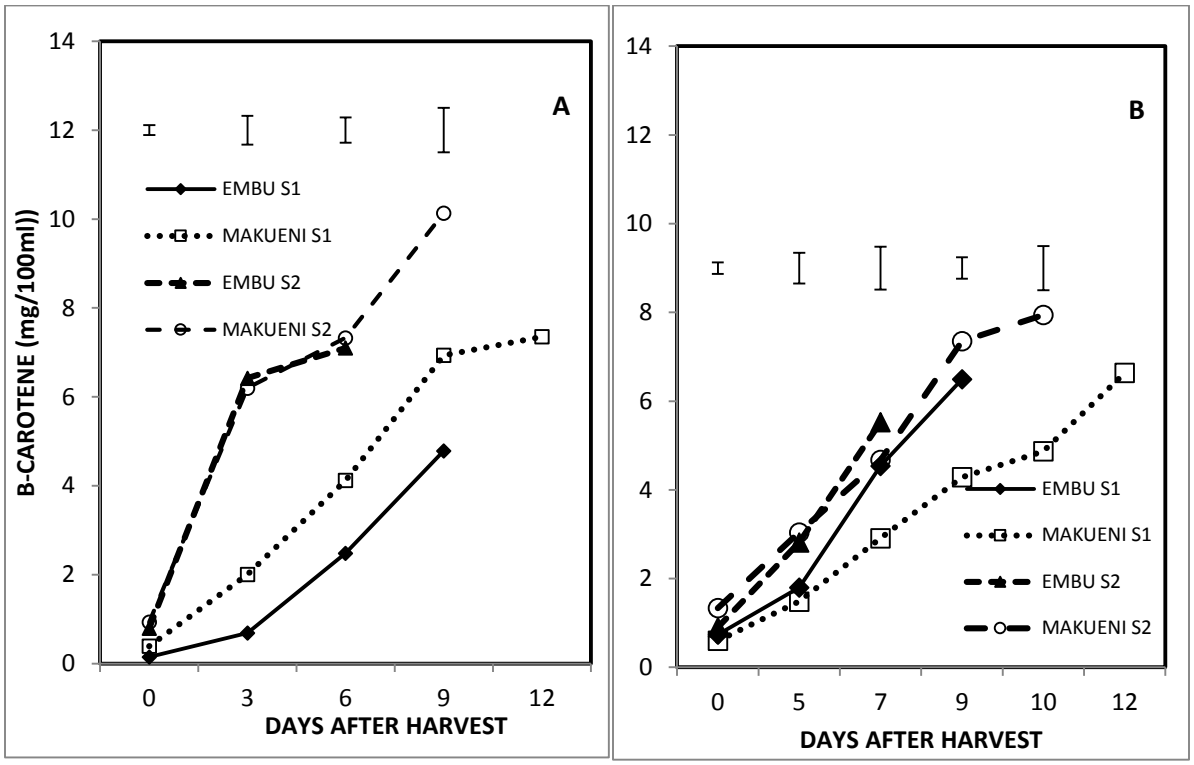

Figure 3.11: Changes in beta-carotene content of 'apple' mango harvested from Embu and Makueni at two stages of maturity; (S1) and (S2) in season 1 (A) and season 2 (B). Bars above the graph represent LSD at $p\leq0.05$for the four treatment means on each sampling day.

3.6.3.5 CHANGES IN MAJOR SUGARS

3.6.3.5.1 FRUCTOSE

The fructose content increased with advancement in fruit ripening (Table 3.1 and 3.2). Significantly ($p<0.05$) high fructose content was observed in fruits harvested at S2 than at S1 irrespective of the production location and season. In both seasons, fruits from Makueni at S1 and S2 had significantly ($p<0.05$) higher fructose content than from Embu at S1 and S2. In season 1, a gradual increase in fructose content was observed from the initial values of 1.6 and 1.1 g/100ml to 6 and 4.8 g/100ml for S1 fruits and from initial 2.3 and 1.8 g/100ml to 7.5 and 5.7 g/100ml for S2 fruits from Makueni and Embu respectively, at the end of storage. In season 2, the levels of fructose increased gradually from initial values of 1.9 and 1.3 g/100ml to 7.7 and 5.1 g/100ml for S1 fruits and from initial values of 2.6 and 2.1 for S2 fruits to 11.7 and 7.3 g/100ml from Makueni

and Embu in that order, at the end of storage. In both seasons, fructose content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity.

Table 3.1: Changes in fructose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 1.

	DAYS AFTER HARVEST				
LOCATION * STAGE	0	3	6	10	12
EMBU S1	1.1c	3.1a	3.8b	4.8c	
EMBU S2	1.8b	2.2b	5.7a		
MAKUENI S1	1.6b	2.1b	3.2c	5.5b	6.0
MAKUENI S2	2.3a	3.3a	5.5a	7.5a	
LSD	**0.34**	**0.52**	**0.51**	**0.53**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

Table 3.2: Changes in fructose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	1.3c	3.3c	3.5c	5.1c		
EMBU S2	2.1b	6.3a	7.3a			
MAKUENI S1	1.9b	2.4d	4.7b	8.2b	8.1b	7.7
MAKUENI S2	2.6a	5.3b	8.1a	11.9a	11.7a	
LSD	**0.26**	**0.7**	**0.97**	**0.49**	**1**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.3.5.2 GLUCOSE

A gradual increase in glucose content was observed as fruit ripening progressed (Table 3.3 and 3.4). Fruits harvested at S2 had significantly ($p<0.05$) high glucose content than fruits at S1 irrespective of production location and season. In season 1, the levels of glucose increased gradually from initial values of 1.2 and 0.9 g/100ml to 3.6 and 1.8 g/100ml for S1 fruits and from 1.2 and 1.6 g/100ml to 4.4 and 4.0 g/100ml for S2 from Makueni and Embu respectively, at the end of storage. Fruits harvested from Embu at S1 retained significantly ($p<0.05$) lower glucose

levels compared to fruits from Makueni at S1 during their storage period. Glucose content was significantly ($p<0.05$) affected by the interaction between location and stage of maturity in season 1. Similar to season 1, a gradual increase in glucose levels was observed in season 2 from the initial values of 1.2 and 0.90 g/100ml to 4.8 and 2.1 g/100ml for S1 fruits and from initial values of 1.3 and 1.9 g/100ml to 5.7 and 3.4 g/100ml for S2 fruits from Makueni and Embu, at the end of storage period. However, fruits from Makueni maintained relatively higher glucose levels than fruits from Embu.

Table 3.3: Changes in glucose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 1.

	DAYS AFTER HARVEST				
LOCATION * STAGE	0	3	6	10	12
EMBU S1	0.9c	1.6c	1.3d	1.8c	
EMBU S2	1.6a	3.6a	4.0a		
MAKUENI S1	1.2b	1.4c	1.9c	3.1b	3.6
MAKUENI S2	1.2b	2.3b	3.6b	4.4a	
LSD	**0.27**	**0.46**	**0.32**	**0.34**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

Table 3.4: Changes in glucose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	0.9b	1.6c	1.1d	2.1c		
EMBU S2	1.9a	3.7a	3.4b			
MAKUENI S1	1.2b	0.9d	2.3c	4.0b	4.1b	4.8
MAKUENI S2	1.3b	2.3b	5.1a	5.5a	5.7a	
LSD	**0.45**	**0.39**	**0.35**	**0.26**	**0.51**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.3.5.3 SUCROSE

As fruit ripening progressed, the sucrose levels increased gradually with storage time (Table 3.5 and 3.6). Irrespective of production location and season, fruits harvested at S2 had relatively higher sucrose content than fruits at S1. In season 1 and 2, fruits at S2 from Makueni had significantly ($p<0.05$) higher sucrose content than fruits at S2 from Embu. In season 1, sucrose levels increased gradually from the initial values of 1.1 and 1.2 g/100ml to 4.6 and 2.6 g/100ml for S1 fruits and from initial 1.3 and 1.5 g/100ml to 6.0 and 4.5 g/100ml for S2 fruits from Makueni and Embu in that order, at the end of storage period. In season 2, sucrose levels increased from initial values of 1.3 and 1.2 g/100ml for S1 fruits to 5.5 and 2.9 g/100ml and from initial 1.4 and 1.3 g/100ml for S2 fruits to 9.2 and 6 g/100ml from Makueni and Embu respectively, at the end of storage. Fruits harvested from Makueni at S1 and S2 retained significantly ($p<0.05$) higher sucrose levels compared to fruits from Embu at S1 and S2 during their storage period. Fruit sucrose content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity in season 2.

Table 3.5: Changes in sucrose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 1.

	DAYS AFTER HARVEST				
LOCATION * STAGE	0	3	6	10	12
EMBU S1	1.1a	1.4c	1.6d	2.6c	
EMBU S2	1.3a	2.4b	4.5b		
MAKUENI S1	1.2a	2.3b	3.5c	4.0b	4.6
MAKUENI S2	1.5a	2.9a	4.9a	6a	
LSD	**0.28**	**0.37**	**0.39**	**0.26**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

Table 3.6: Changes in sucrose content (g/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	1.2a	1.4c	1.8d	2.9c		
EMBU S2	1.3a	3.7b	6.0b			
MAKUENI S1	1.3a	3.6b	4.5c	4.9b	4.7b	5.5
MAKUENI S2	1.4a	4.7a	7.1a	9.5a	9.2a	
LSD	**0.25**	**0.4**	**0.65**	**0.34**	**0.69**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.3.6 CHANGES IN SELECTED MINERAL NUTRIENTS IN FRUIT TISSUE

3.6.3.6.1 MAGNESIUM (Mg)

A decline in Mg content was noted in all fruits as they ripened (Table 3.7). Fruits harvested at S1 had significantly ($p<0.05$) higher Mg content than at S2 irrespective of location of production. Fruits from Makueni had higher initial Mg levels compared to fruits from Embu. The levels of Mg reduced gradually from initial values of 20.5 and 14 mg/100ml to 8.9 and 5.70 mg/100ml for S1 fruits and from 17.9 and 13.2 mg/100ml to 2.2 and 4.1mg/100ml for S2 fruits from Makueni and Embu in that order, at the end of storage. Fruits from Makueni retained significantly ($p<0.05$) higher Mg levels during their entire storage compared to fruits from Embu. The levels of Mg reduced gradually from initial values of 20.5 and 14 mg/100ml to 8.9 and 5.70 mg/100ml for S1 fruits and from 17.9 and 13.2 mg/100ml to 2.2 and 4.1mg/100ml for S2 fruits from Makueni and Embu in that order, at the end of storage. However, fruits from Makueni at S2 retained significantly ($p<0.05$) higher Mg levels during their entire storage than fruits from Embu at S2. Magnesium content was not significantly affected by the interaction between location and stage of maturity.

Table 3.7: Changes in magnesium content (mg/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	14.0c	7.3c	9.5a	5.7b		
EMBU S2	13.2d	6.2d	4.1b			
MAKUENI S1	20.5a	15.7b	10.6a	5.3c	14.1a	8.9
MAKUENI S2	17.9b	16.7a	10.5a	12.5a	2.2b	
LSD	**1.07**	**0.76**	**1.24**	**1.46**	**2.78**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.3.6.2 CALCIUM (Ca)

The calcium content of fruits harvested from Makueni and Embu at two maturity stages reduced with increase in storage period (Table 3.8). Calcium content was significantly ($p<0.05$) high in fruits harvested at S1 than those at S2. The Ca levels of fruits harvested at S1 and S2 from Makueni increased from the initial 4.1 and 3.5 mg/100ml to peak levels at day 5 (6.20 and 5.9 mg/100ml) then reduced gradually to (1.3 and 2.9 mg/100ml) at day 12 and 10 respectively. Fruits from Embu had significantly ($p<0.05$) higher initial Ca levels compared to those from Makueni at both maturity stages. Although the levels of Ca in S1 fruits from Embu reduced significantly ($p<0.05$) from the initial 7.1 mg/100ml at the end of storage, S2 fruits retained significantly ($p<0.05$) higher Ca levels throughout and at the end of the storage period. Fruit Ca content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity.

Table 3.8: Changes in calcium content (mg/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	7.1a	4.6c	2.3c	1.9b		
EMBU S2	5.4b	5.2b	5.3a			
MAKUENI S1	4.1c	6.2a	4.6a	4.3a	2.3b	1.3
MAKUENI S2	3.5d	5.9a	3.3b	2.5b	2.9a	
LSD	**1.08**	**0.51**	**0.84**	**0.96**	**0.55**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.3.6.3 POTASSIUM (K)

The potassium content of fruits decreased non-linearly with progress in ripening (Table 3.9). Significantly ($p<0.05$) high K content was observed in fruits harvested at S1 than at S2 irrespective of the production location. Fruits from Embu had significantly ($p<0.05$) high K content than fruits from Makueni. The K levels reduced from initial values of 95.1 and 281.4 mg/100ml to 15.0 and 53.8 mg/100ml for S1 fruits and from initial 80.1 and 195.1 mg/100ml to 72.7 and 88.8 mg/100ml for S2 fruits from Makueni and Embu respectively, at the end of storage. Potassium content was significantly ($p<0.001$) affected by the interaction between location and stage of maturity.

Table 3.9: Changes in potassium content (mg/100ml) of 'apple' mango harvested at stage 1 and stage 2 in season 2.

	DAYS AFTER HARVEST					
LOCATION * STAGE	0	5	7	9	10	12
EMBU S1	281.4a	68.8b	86.8a	53.8b		
EMBU S2	195.1b	118.8a	88.8a			
MAKUENI S1	95.1c	76.3b	73.4a	84.2a	93.8a	15.0
MAKUENI S2	80.1d	66.3b	86.3a	74.3a	72.7a	
LSD	**14.85**	**18.8**	**13.39**	**19.75**	**34.02**	

Means within column followed by a different letter differ significantly at ($p<0.05$).

3.6.4 SENSORY QUALITY

3.6.4.1 'Apple' mango sensory quality

The sensory scores of fresh 'apple' mango harvested from Makueni and Embu at tree ripe stage in season 1 and 2 are presented in Figures 3.12 and 3.13, respectively. The sensory parameters evaluated included; color, texture, aroma, taste/flavor, mouthfeel and general acceptability. In season 1, fruits from Makueni scored relatively higher than those from Embu in all of the parameters evaluated. Similarly, in season 2, Makueni fruits scored higher in all parameters except color and aroma. Fruits from Makueni were generally accepted compared to fruits grown from Embu.

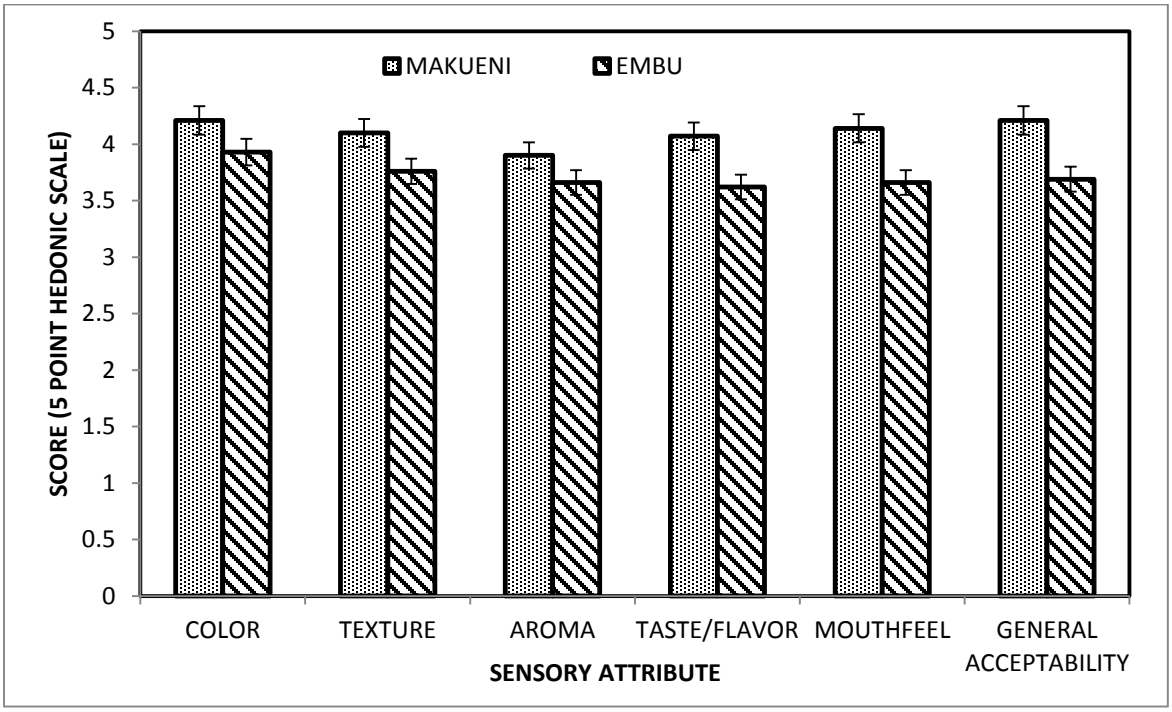

Figure 3.12: Sensory quality scores of 'apple' mango harvested from Embu and Makueni at stage 3 (tree ripe) in season 1. Rating was done on a 5 point hedonic scale (1= dislike extremely and 5= like extremely). The vertical bars represent means ± SE.

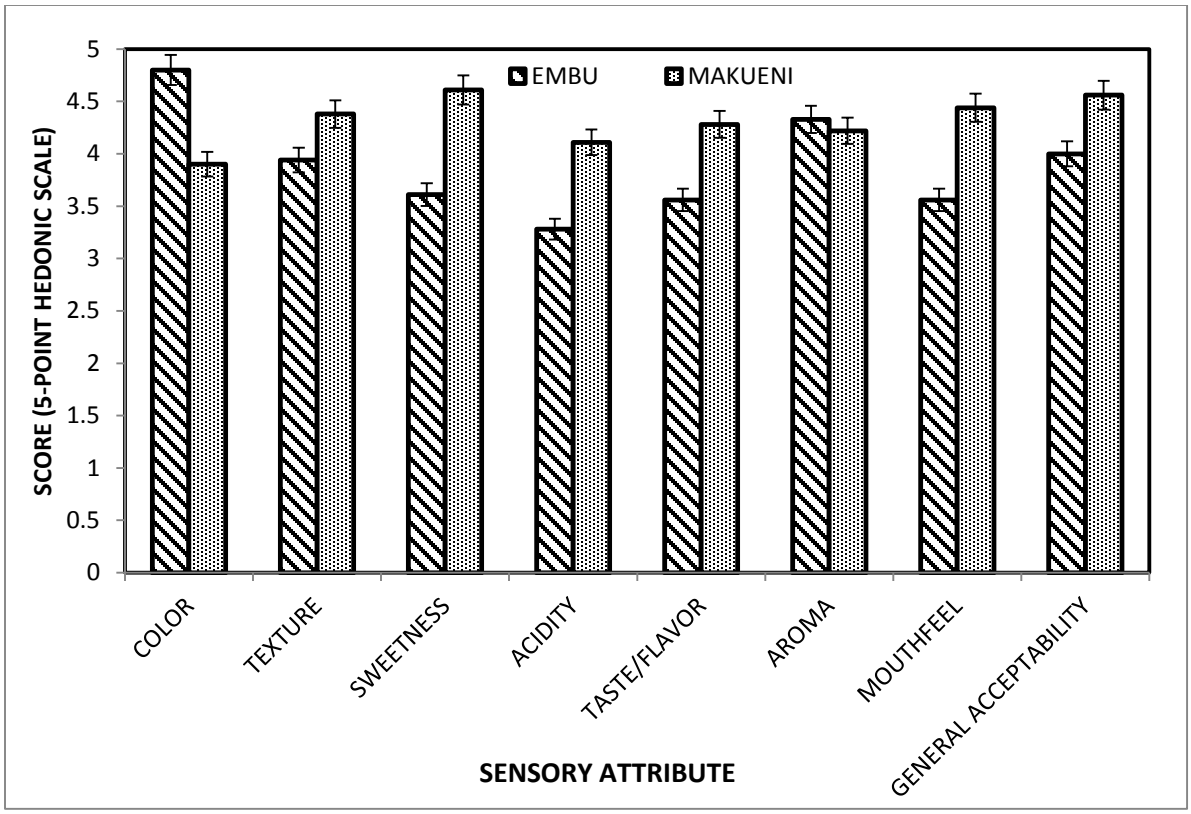

Figure 3.13: Sensory quality scores of 'apple' mango harvested from Embu and Makueni at stage 3 (tree ripe) in season 2. Rating was done on a 5 point hedonic scale (1= dislike extremely and 5= like extremely). The vertical bars represent means ± SE.

3.7 DISCUSSION

Mango is one of the major fruits produced in Kenya under diverse environmental conditions, which affect growth and development and ultimately the fruits' characteristics after harvest. In the present study, a comparative evaluation was done on the quality attributes of mango fruits, variety 'apple' produced under two different agro-ecological conditions, Embu (high potential AEZ) and Makueni (low potential AEZ zone). The fruits were harvested at two stages of maturity; early maturity (S1) and advanced maturity (S2). Physiological and physicochemical changes occurring in the fruits after harvest were evaluated to determine their shelf life and quality attributes. Additionally untrained panelists were used to compare the sensory attributes of the fruits produced under the different agro-ecological conditions.

The results show that fruit quality and postharvest shelf life were significantly affected by the agro-ecological zone and the maturity stage at harvest. These differences were evidenced from the instrumental analyses of physiological, physicochemical and biochemical parameters including respiration rate, changes in peel and flesh firmness, color, total soluble solids, titratable acidity, ascorbic acid and beta-carotenes. Instrumental analysis of quality attributes was further validated through a sensory panel which scored the tree ripe harvested fruits for sensory attributes such as color, sweetness, acidity, aroma and general acceptance. Overall, fruits harvested from Makueni had relatively lower respiration rate which translated to a longer shelf life compared to fruits from Embu. Fruits harvested at stage 1 had a relatively longer shelf life (2 - 3 days) compared to fruits harvested at stage 2. Fruits from Makueni scored highly for most of the sensory parameters evaluated compared to fruits from Embu.

Respiration is one of the major metabolic processes in harvested commodities. It is the central metabolic process in harvested produce and therefore, respiration rate sets the pace of other changes that occur after harvest (Kays and Paull, 2004). According to Day (1993), respiration rate is inversely proportional to shelf-life of the produce; the lower the respiration rates the longer the shelf-life. In the present study, ripening changes followed a similar trend to that of the fruits' respiratory activity. Maturity stage and production location all affected the respiratory activity of the fruits. Fruits produced from Makueni had relatively lower respiration rates which translated to prolonged shelf life compared to fruits from Embu that recorded significantly high respiration rate leading to a reduced postharvest shelf life. Similarly the relatively lower respiration rates in S1 fruits translated into a longer shelf life compared to S2 fruits. Similar observations were made in

guava (Bashir and Abu-Goukh, 2003), avocado (Cutting *et al.*, 1992) and passion fruits (Baraza *et al.*, 2012). The effect of production location on respiratory activity and ultimately on the shelf life is attributed to the effect on fruit growth and developmental processes and hence their physiological condition at harvest. Lower respiration rates were observed in fruits from Makueni (low potential AEZ). Previous studies have shown that production conditions or seasons with low rainfall amounts variably affect fruits postharvest behavior. In banana, fruits produced under dry conditions had relatively longer shelf life compared to those produced under relatively wet conditions (Ambuko *et al.,* 2006, 2013). In avocado, Woolf *et al.,* (2000) showed that fruits that ripened under sunny conditions had a 2–5 days delay in ethylene peak and reduced respiration rate compared to those that ripened under less sunny conditions.

Besides respiratory activity, other ripening related changes evaluated to establish shelf life include fruit color, firmness, cumulative weight loss, total soluble solids and titratable acidity.
Fruit color is a major determinant of consumer appeal (Saks *et al.,* 1999). During mango ripening, changes in the color of the peel result from both chlorophyll degradation and carotenoid synthesis (Ninio *et al.,* 2003). Peel and flesh color expressed as hue angle changed regardless of stage and production location. Hue angle decreased as the fruits ripened, indicating a change in the color of the fruits from greenish yellow to orange-yellow due to degradation of the chlorophyll structure by chlorophyllases enzymes (Medlicott *et al.,* 1986). Jacobi *et al.,* (1995) reported that the rate of skin color development differed according to stage and variety. The decrease in peel and flesh hue angle mirrored the increase in beta-carotene levels. Fruits at S1 had relatively lower beta-carotene levels while fruits at S2 had slightly higher beta-carotene levels. The development of carotenoids increased gradually with fruit maturity explaining the gradual reduction in hue angle with fruit ripening. The present findings concur with those of Doreyappa-Gowda and Huddar, (2001) who reported increased levels of carotenoids as mango fruits ripened. In the present study fruit color and levels of beta-carotene were affected by differences in agro-ecological conditions. Fruits harvested from warmer region (Makueni) had significantly higher hue angle than fruits from Embu which is a cooler region. This could be explained by the fact that light exposure determines fruit color development in fruits. Fruits that have good exposure to the sun develop color better than those that develop under less light or shaded conditions. Increased light exposure during fruit growth and development enhances formation of color pigments including anthocyanins and carotenoids (Mercadante *et al.,* 1998). Studies by Genard and Bruchou, (1992) on peaches showed

that increased light exposure improved color formation. It could be speculated that fruits from Makueni had relatively higher hue angles because of the growing conditions. Makueni is generally hot and sunny, conditions that may have enhanced better color formation compared to fruits from Embu.

Fruit firmness is an important attribute that defines eating quality and determines the shelf life of mango fruit (Valero *et al.,* 2006). In the present study, fruit firmness reduced with increase in fruit ripening indicating chemical and physical changes in cell wall leading to fruit softening. The loss of firmness was affected by stage and production location. Fruits harvested at stage 2 softened faster compared to stage 1 fruit. On the other hand, fruits harvested from Makueni were significantly firmer and softened less faster compared to fruits from Embu. The progressive loss of firmness with ripening is the result of gradual solubilization of protopectin in the cell wall to form soluble pectins by pectinesterase and cellulase enzymes (Martin-Rodriguez, 2002 and White, 2002). The activity of these enzymes is reported to increase as the fruit ripens hence faster softening of S2 fruits compared to S1 fruits (Tridjaja and Mahendra, 2000). A similar trend in firmness reduction during ripening has been reported in mango (Abu– Sarra and Abu-Goukh, 1992; Mahayothee *et al.,* (2002) and Githiga, 2012) and guava (Abu-Goukh and Bashir, 2003). The difference in firmness between mango fruits from Makueni and Embu could be attributed to differences is rainfall, sunlight exposure all of which have been reported to affect fruit firmness. In banana, high peel and flesh firmness were reported in fruits produced during the dry and sunny season compared to those produced during a wet season (Ambuko *et al.,* 2006). Similarly avocado fruits which were exposed to the sun were generally firmer than fruits that were not exposed to enough sun (Woof *et al.,* 2000). Additionally, fruit firmness is positively correlated to cell wall Ca levels (Fegurson *et al.,* 1994). In the present study, fruits from Embu had relatively lower Ca levels compared to fruits from Makueni, which possibly explains the faster softening observed in Embu fruits. According to Krall and McFeeters (1998), relatively high Ca levels inhibit softening of fruits due to an increase in cohesion of pectin network.

Significant weight loss was observed in all the fruits as they ripened. The weight loss during fruit ripening is attributed to water loss due to transpiration and respiration. Previous studies reported similar findings in mango (Githiga, 2012), passion fruits (Baraza *et al.,* 2012) and banana (Ambuko *et al.,* 2008). The increase in weight loss was slightly lower in fruits harvested at S1 than fruits at S2. This can be explained by higher respiration rates recorded in fruits at S2

compared to relatively lower respiration rates in fruits at S1. The loss of weight from fruits from the two locations was almost comparable although fruits harvested from Makueni lost slightly lower percent of weight compared to fruits from Embu.

Total soluble solids (TSS) content is considered as a measure of quality for most of the fruits. Generally taste and especially sweetness of the fruits depend on the percentage of TSS content. It is generally recognized that quality fruits benefit from a higher sugar: acid ratio whereas fruits of lower quality have a lower sugar: acid ratio (Ninio *et al.,* 2003). The results of the present study show an increase in the TSS levels as ripening progressed. The observed increase in TSS during ripening is associated with hydrolysis of complex carbohydrates including starch into simple soluble sugars required for cellular respiratory activity (Zhong *et al.,* 2006). Fruits harvested at advanced maturity (S2) had relatively higher TSS. Fruits harvested from Makueni had significantly high TSS levels than fruits from Embu. The high TSS levels in fruits from Makueni may be due to the longer period of sunlight exposure during the production period leading to increased accumulation of dry matter content. Fruits trees with high dry matter content tend to accumulate more soluble solids (Hollinger, 1996).A positive relationship between light exposure period and TSS levels was previously reported in kiwi fruits (Tombesi *et al.,*1993) and banana (Ambuko *et al.,* 2006).

In fruits, the balance between TSS and titratable acidity (TTA) determines the taste and flavor and hence consumer preference. In the present study, TTA levels expressed as citric acid reduced as the fruits ripened irrespective of maturity stage and production location. The reduction in acidity may be due to the degradation of citric acid which could be attributed to its conversion to respiratory substrates required by the cells (Abbasi *et al.,* 2009). Fruits harvested at S1 had significantly higher TTA levels compared to those at S2 which mirrored the differences in their respiratory activity. These results correspond with previous findings in mango (Srinivasa *et al.,* 2002 and Githiga, 2012) where titratable acidity levels reduced with ripening.

Just like TTA, levels of ascorbic acid reduced gradually with fruit ripening in both maturity stages and production location. Previous studies in mango (Githiga, 2012); passion fruit (Yumbya, 2012) and pepper (Howard *et al.,* 1994) have also reported a decrease in ascorbic acid as fruits ripened. The decrease in the vitamin levels during ripening is attributed to degradation of ascorbic acid through oxidation (Appiah *et al.,* 2011). Contrary to the present findings ascorbic acid levels increased with ripening in apricots, papaya and peaches (Wenkam, 1979). In the

present study, Makueni fruits had significantly high ascorbic acid content than Embu fruits. This is probably due to variation in production factors between the two regions. Fruits exposed to full sun accumulate high ascorbic acid due to lower respiratory activities during maturation (Weston and Barth, 1997).

The levels of fructose, glucose and sucrose increased gradually with advancement in fruit ripening regardless of the maturity stage and location. Fructose and glucose are the main reducing sugars and in this study, fructose was found to be predominant. Selvaraj *et al.,* (1989) reported fructose as the predominant sugar in mango fruit. Fruits harvested at S1 had relatively lower levels of the sugars than fruits harvested at S2, reflecting their different respiratory activities. The gradual increase in the levels of these sugars could be attributed to hydrolysis of starch from increased activity of amylase during fruit ripening (Saranwong *et al.,* 2001). Longer periods of full sunlight and high temperatures characteristic of semi-arid regions such as Makueni, tend to favor photosynthetic activity and carbon accumulation (Lechaudel *et al.,* 2005). Previous studies in apples and avocado showed that fruits harvested from regions receiving full sunlight and high temperatures had higher sugar levels than those from regions receiving less sunlight (Ferguson *et al.,* 1990). Similar observations were also reported in banana (Ambuko *et al.,* 2006) and passion fruits (Baraza *et al.,* 2012).

The mineral composition in fruits can be used to predict fruit quality and postharvest shelf. However, the relation between the mineral composition of fruits and their quality and behavior during ripening is not always predictable (Thompson, 2003). In the present study, slightly higher levels of the mineral elements were observed in fruits harvested at S1 than at S2 and the levels were affected by production location. The levels of Mg, and K reduced non-linearly with advancement in fruit ripening. However, the reduction in Ca levels was linear as ripening progressed. The results of the current study concur with those of Hofman *et al.* (1994) and Yumbya (2012), who reported a reduction in Ca levels in avocado and passion fruits respectively, as they ripened. Calcium is an essential component of the cell walls and membranes and therefore important for integrity to the cells. According to Engelkes *et al.,* (1990), fruit Ca levels are affected by the environment and farmers agronomic practices. From the current study, significantly high initial Ca levels were found in Embu fruits from than in fruits from Makueni. However, Makueni fruits retained relatively higher Ca levels during and at the end of storage. Studies have shown that fruits with high Ca levels tend to have longer postharvest shelf life than

those with lower levels (Ferguson, 1994). Potassium (K) is important in metabolite transport and also plays a major role in stomata aperture size regulation hence controlling tree water loss. In the current study, K was the predominant element observed in the mango fruits. The significantly high K levels detected in fruits from Embu unlike fruits from Makueni could be due to increased use of K fertilizer in Embu orchard than in Makueni orchard since soil analysis results indicated high K content in Embu orchard soil.

Apart from instrumental evaluation of fruit quality attributes, consumer perception of the fruit is critical to preferences and acceptance. Some of the sensory attributes perceived by the consumer and which contribute to the overall acceptability of fresh fruits and juice include color, sweetness, acidity, taste, aroma, mouth feel and general acceptability of the fruit (Mamiro *et al.*, 2007). The sensory profiles of fruit color, taste and flavor impacts greatly its competitiveness in different markets. In the current study, sensory quality evaluation was conducted on fresh tree-ripened fruits harvested from Makueni and Embu, two different AEZs. The results indicated a variation in scores due to production location with fruits from Makueni scoring higher than Embu fruits for most of the sensory attributes. Sometimes the untrained panelists fail to bring out the correlation between the instrumental measurement and human perception. However, in the present study, most of the sensory attributes scored by the panelists including color, flavor and sweetness was reflected in the instrumental measurements. The panelists scored the fruits from Makueni higher for most attributes compared to fruits from Embu. These scores corroborated instrumental analyses that showed higher TSS, soluble sugars, hue angles and lower TTA, which are attributes associated with high quality of fruits.

3.8 CONCLUSION

The results of the present study evidently showed variation in shelf-life and fruit quality due to differences in agro-ecological zones and maturity stage at harvest. Production factors especially light, temperature, water availability and the farmers' agronomic practices greatly influence fruit physiology and postharvest fruit quality. Fruits from Makueni at both maturity stages had significantly lower respiration and ethylene evolution rates resulting in longer shelf life compared to Embu fruits. The sensory evaluation done on tree-ripe fruits rated Makueni fruits higher for most of the parameters evaluated and thus positively correlating with the instrumental evaluation of quality attributes.

CHAPTER 4: RESPONSE OF 'APPLE' MANGO FRUITS HARVESTED FROM DIFFERENT AGRO-ECOLOGICAL ZONES TO 1-METHYLCYCLOPROPENE (1-MCP)

4.1 ABSTRACT

Mango (*Mangifera indica* L.) production in Kenya occurs under different agro-ecological conditions which have a great impact on growth and development of the fruits and further on post-harvest quality and response to postharvest treatments. Mango is a climacteric fruit characterized by a surge in ethylene production at the onset of ripening. One strategy used to slow down ripening and extend shelf life of climacteric fruits is to inhibit ethylene action. Application of 1-MCP is known to inhibit ethylene perception and action in many climacteric fruits. However, its action is affected by several preharvest and postharvest factors.

This study was conducted to investigate the effect of preharvest factors namely agro-ecological zones (AEZ) and harvest maturity, on the efficacy of 1-MCP in 'apple' mango fruits. The response to 1-MCP was compared among fruits produced in a high potential AEZ, (Embu) versus those produced in a low potential AEZ, Makueni. The fruits were harvested at 2 stages of maturity (stage 1 and 2), defined by the flesh color and respiratory activity. A homogeneous sample for each treatment batch was treated with 1 ppm of 1-MCP for 24 hours and thereafter allowed to undergo ripening at ambient room conditions (Temperature; 25 ± 1 ^{o}C and RH 60 ± 5%). The treated fruits were compared with an untreated batch used as a control. Five fruits were randomly selected from each batch and used in daily determination of respiration, ethylene evolution and cumulative weight loss until the end of storage period. From the remaining bulk of each batch, five fruits were taken randomly every 3 and 5 days in (season 1 and 2) respectively for destructive sampling to determine changes in physical and biochemical parameters. The physical parameters measured included peel/flesh hue angle and peel/flesh firmness while the biochemical parameters determined included total soluble solids, titratable acidity, ascorbic acid, beta-carotene, soluble sugars (fructose, glucose and sucrose) and minerals (magnesium, calcium and potassium).

The results showed that 1-MCP treated fruits had a relatively longer shelf life (3 days) compared to untreated controls, irrespective of AEZ or stage of maturity. However, fruits harvested at S1 and fruits from Makueni were more responsive to 1-MCP treatment. For stage 1, 1-MCP treated fruits had a shelf life of 15 and 12 days for compared to untreated controls' 12 and 9 days respectively for Makueni and Embu AEZs. A similar trend was observed for stage 2 fruits. The onset of ethylene production and the respiratory climacteric were significantly ($p<0.05$)

delayed (by 2 to 3 days) or suppressed in 1-MCP treated fruits irrespective of maturity stage or production location. 1-MCP treatment significantly ($p<0.05$) delayed ripening related changes including decrease in hue angle, firmness, titratable acidity and increase in total soluble solids. Reduction in fruit tissue Ca and Mg was significantly ($p<0.05$) slowed in 1-MCP treated fruits. Additionally, 1-MCP treated fruits from both locations retained higher nutritional quality attributes at the end stage of untreated controls. Commercial application of 1-MCP can therefore be recommended in postharvest storage systems for 'apple' mango fruits to extend the fruits' shelf life and marketing period while maintaining desirable quality attributes.

4.2 INTRODUCTION

Mango production occurs under a wide range of agro-ecological conditions. In Kenya, mango fruit is adapted and produced in most of the seven AEZs (Griesbach, 2003). The variations in climatic factors in these AEZs greatly impact on the fruit growth and development thereby influencing postharvest quality and fruits' response to postharvest treatments (Kays, 1999). As a climacteric fruit, mango is highly perishable and prone to postharvest losses especially during peak seasons (Gathambiri *et al.,* 2010). As ripening progresses, there is an increase in ethylene production and respiration rates which enhance faster deterioration in fruit quality and reduced shelf life (Charles, 2009). The control of ethylene production and action is therefore an important component in postharvest handling systems. Ethylene management strategies are based on complete avoidance and removal or inhibition of its biosynthesis and action (Sisler and Serek, 1997). Some of the strategies used to target ethylene action in mangos include; low temperature storage, use of modified/controlled packaging and use of chemicals (Tharanathan *et al*., 2006).

Application of ethylene action inhibitor 1-Methycyclopropene (1-MCP,) is one of the chemical measures used to arrest the effects of ethylene in horticultural commodities (Blankenship and Dole, 2003). 1-MCP was patented in 1996 and is commercially available in powder form which is released as a gas when the powder comes in contact with water. 1-MCP acts by inhibiting the binding of ethylene its receptors thereby blocking or delaying the metabolic processes normally induced by ethylene (Serek *et al.,* 1994). The affinity of 1-MCP for ethylene receptors is approximately ten times greater than that of ethylene, making it an effective competitor. 1- MCP is odorless, colorless, non-toxic and is applied at very low dosage, with proven minimal measurable residues in commodities (Sisler and Serek, 1997). 1-MCP was approved by the United States Environmental Protection Agency in 2002 and currently marketed under the trade name

SmartFresh™. By 2007, registration for 1-MCP use in horticultural produce had been obtained in countries like France, Israel, Canada, Turkey, Brazil, and South Africa. Registration for its commercial application in Kenya is still ongoing.

1-MCP treatment has been reported to delay or slow down ethylene evolution, respiratory activity, color changes, softening, loss of acidity and other changes associated with ripening and senescence (Blankenship and Dole, 2003). In most commodities, 1-MCP treatment has been reported to slow down or delay ethylene evolution (Dong *et al.,* 2002, Girardi *et al.,* 2005), respiratory activity (Jeong *et al*., 2003, Baraza *et al.,* 2012, Valero, 2004), color changes (Colelli *et al.,* 2003), softening (Balogh *et al.,* 2005, Feng *et al.,* 2000), loss of ascorbic acid (Githiga, 2012, Yumbya, 2012) and other changes associated with ripening (Blankenship and Dole, 2003). 1-MCP delayed ripening of harvested mango (Hofman *et al*., 2001 and Githiga, 2012).

The desirable effect of 1-MCP treatment depend on preharvest production factors, stage of maturity, storage temperature and treatment duration (Blankenship and Dole, 2003; Watkins, 2006). The efficacy of 1-MCP treatment decreased with advanced fruit development in apricots (Fan *et al.,* 2000), banana (Harris *et al*., 2000), pears (Mir *et al.,* 2001) and mango (Harris *et al*., 2000).Guillen *et al*., (2007) reported that tomato harvested at later maturity responded better to 1-MCP treatment than early harvested fruits. An exposure of 6 hours at 0.45ppm was not enough to induce respiratory or ethylene production changes in avocado (Jeong *et al.,* 2002) while an exposure for 24 hours was sufficient for 'tommy atkins' mango (Githiga, 2012) . Baraza *et al.,* (2012) found that passion fruits harvested from two different agro-ecological conditions responded differently to 1-MCP treatment.

The above studies reveal that the commodities' response to 1-MCP is affected by various factors including preharvest production conditions, commodity factors and treatment conditions. Therefore, the objective of this study was to establish the response to 1-MCP by 'apple' mango fruits harvested at two maturity stages from two different AEZs in Kenya; a low potential AEZ (Makueni) and a high potential AEZ (Embu).

4.3 MATERIALS AND METHOD

4.3.1 EXPERIMENTAL SET UP

The experimental set up used is similar to that outlined in section 3.3.0.

4.3.2 1-MCP TREATMENT AND SAMPLING

Fruits of uniform size and those of uniform maturity stage (1 and 2) harvested from Embu and Makueni farms were divided into two batches of 60 fruits after being washed in clean water with 1% acetic acid. One batch was treated with 1-MCP while the other batch was left untreated and used as control. Thirty fruits from each maturity stage were sparsely arranged in separate 80 litres airtight containers fitted with self-sealing rubber septum. A preliminary study was carried out to evaluate the response of 'apple' mango fruits to different concentrations of 1-MCP; 0.5 ppm, 1 ppm and 2 ppm. Of the 3 concentrations tested, 0.5 ppm was ineffective, while 1 ppm and 2 ppm effectively slowed down ripening, relative to untreated controls. There was no significant difference in response between 1 ppm and 2 ppm treatments and therefore 1 ppm was selected for further evaluation in the present study.

1-MCP gas was generated from Smartfresh^{TM} powder (Rohm and Haas Co., Japan) according to manufacturer's instructions. A pack of calcium hydroxide powder was inserted into each of the containers to absorb any respiratory carbon dioxide produced by the fruits. The containers were then tightly sealed. A 50ml hypodermic airtight syringe was then used to inject 1 ppm of 1-MCP gas through the rubber septum into the containers with the fruits. After 24 hours, the fruits were removed from the containers and analyzed for changes in physical and biochemical parameters after every three and five days for season 1 and season 2 respectively, during storage at ambient room conditions (Temperature; 25 ± 1 ^{o}C and RH 60 ± 5%). The experimental design used was Completely Randomized Design with a factorial arrangement of three replications. The factors were two stages of maturity (S1 and S2), two production locations (Embu and Makueni) and 1-MCP concentration (1ppm and 0 ppm)

4.3.1 ANALYSES OF CHANGES IN PHYSIOLOGICAL PARAMETERS

Analysis of the changes in fruit physiological parameters is as outlined in section 3.3.1

4.3.1.1 RESPIRATION AND ETHYLENE RATES OF PRODUCTION

Five fruits were randomly sampled from each treatment, numbered and initial weight taken. The fruits were incubated for two hours in air tight containers fitted with self-sealing rubber septa for gas sampling. Gas samples were taken from the head space for measurements of respiration and ethylene production rates as shown in section 3.3.1.1.

4.3.1.2 CUMULATIVE WEIGHT LOSS

Weights of five fruits from each treatment were taken on each sampling day using a scientific balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan) as shown in section 3.3.1.2

4.3.2 ANALYSES OF FRUIT PHYSICAL PARAMETERS

4.3.2.1 FRUIT COLOR

Color of the pulp and peel was measured as shown in section 3.3.2.1

4.3.2.2 FRUIT FIRMNESS

Fruit firmness was measured as described in section 3.3.2.2

4.3.3 ANALYSES OF FRUIT BIOCHEMICAL PARAMETERS

4.3.3.1 TOTAL SOLUBLE SOLIDS CONTENT

Total soluble solids (TSS) content was determined using an Atago hand refractometer (Model 500, Atago, Tokyo, Japan) and expressed as ^{o}Brix.

4.3.3.2 TOTAL TITRATABLE ACIDITY

Total titratable acidity (TTA) was determined by titration with 0.1N NaOH using phenolphthalein as an indicator as shown in section 3.3.3.2

4.3.3.3 ASCORBIC ACID CONTENT

The ascorbic acid was determined using the AOAC (1996) method as shown in section 3.3.3.3

4.3.3.4 BETA-CAROTENE CONTENT

Beta carotene content was determined using the procedure outlined in section 3.3.3.4

4.3.3.5 FRUCTOSE, GLUCOSE AND SUCROSE CONTENTS

The content of soluble sugars (fructose, glucose and sucrose) was determined as indicated in section 3.3.3.5

4.3.3.6 MINERALS DETERMINATION

Minerals were analyzed using the AOAC (1996) method as shown in section 3.3.3.6

4.4 STATISTICAL ANALYSIS

Data was analyzed using Genstat statistical package 14th edition. Comparison of means was done by Analysis of Variance (ANOVA) and Least Significance Difference (LSD) at $P \leq 0.05$. The data is presented below as graphs and tables showing the changing trends for various parameters based on the main treatment effects. The ANOVA tables showing the levels of significance and interactions between the factors are presented in the appendices to the main text.

4.5 RESULTS

In both season 1 and 2, similar trends in 1-MCP treatment effects were observed for physiological, physicochemical and biochemical changes associated with ripening in 'apple' mango fruits harvested from Makueni and Embu at two maturity stages; stage 1 and stage 2. However, these trends were clearer in season 2 whose results are presented below.

4.5.1 CHANGES IN PHYSIOLOGICAL PARAMETERS

4.5.1.1 RATE OF RESPIRATION AND SHELF LIFE

Fruits harvested from Makueni had significantly ($p<0.05$) lower respiration rate compared to fruits from Embu regardless of stage of maturity. The respiration rates of 1-MCP treated fruits at S1 was significantly ($p<0.05$) lower compared to that of treated fruits at S2. 1-MCP treated fruits from Makueni had significantly lower respiration rates compared to treated fruits from Embu. At both maturity stages, 1-MCP treated fruits had significantly ($p<0.05$) lower rate of respiration during the entire storage period compared to untreated fruits. At S1, 1-MCP treated fruits from both locations had relatively lower respiration rates compared to the untreated control. For the fruits from Embu, the significantly ($p<0.05$) smaller respiratory peak (66.9 ml/Kg/Hour) was delayed by 2 days in 1-MCP treated fruits relative to the untreated control's 75.4 ml/Kg/Hour peak which appeared on the 7^{th} day of storage. Similarly for Makueni fruits, 1-MCP treatment resulted in lower respiration rates throughout the storage period, with no clear peaks observed in the treated fruits. In S2 fruits, relatively higher initial respiration rates were observed compared to that at S1 from both locations. 1-MCP treatment effect was more evident in Embu fruits compared to fruits from Makueni. In Embu fruits, a significantly ($p<0.05$) higher respiration rate was observed in untreated fruits, where the early respiration peak (day 4) was significantly bigger (78.2 ml/Kg/Hour) compared to the smaller peak (68.5 ml/Kg/Hour) in 1-MCP treated fruits, which appeared on day 8. Fruits' respiration rate was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment.

Overall, 1-MCP treated fruits had a relatively longer shelf life (3 days more) compared to untreated controls, regardless of production location or stage of maturity. Treated fruits from Makueni at S1 had a long shelf life of 15 days when compared to all the treatments.

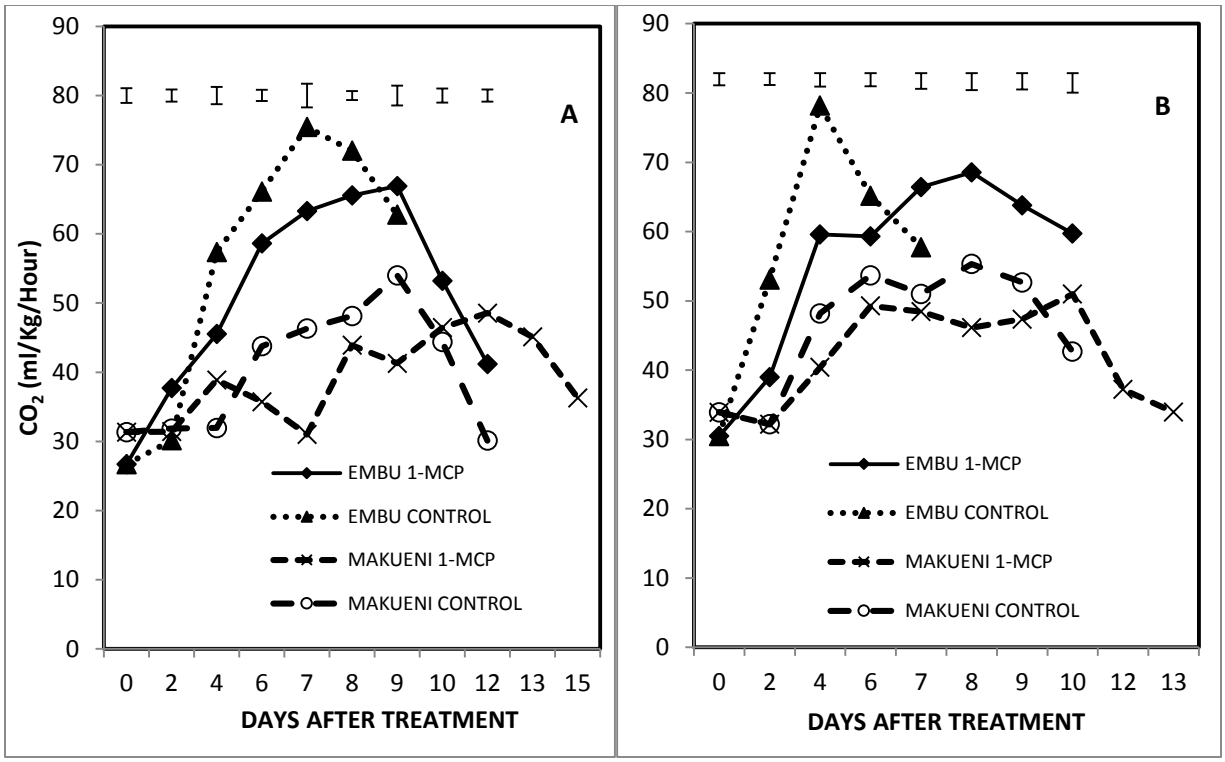

Figure 4.1: Respiration pattern of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

4.5.1.2 RATE OF ETHYLENE PRODUCTION

The rate of ethylene evolution was determined in fruits harvested from Makueni and Embu at two maturity stages in season 1 (Figure 4. 2 A and B). There was an erratic pattern of ethylene evolution in all the fruits hence no clear trends observed. Fruits harvested from Makueni had significantly ($p<0.05$) lower ethylene levels compared to fruits from Embu at both maturity stages. In S1 fruits, ethylene evolution was first detected 6 days after treatment. Treated fruits from Makueni had relatively lower ethylene levels than treated fruits from Embu. In Embu fruits, untreated fruits produced the highest ethylene amount (0.18µl/Kg/Hour) on day 6 while in Makueni fruits, 1-MCP treated fruits had the highest (0.11 µl/Kg/Hour) ethylene amount on day 10. In S2 fruits, ethylene evolution was first detected 4 days after treatment in untreated fruits from Makueni and Embu. Treated fruits from Makueni had relatively lower ethylene levels compared to treated fruits from Embu. The highest ethylene amount (0.23µl/Kg/Hour) for Embu fruits was recorded in untreated fruits on day 4 while the highest (0.14µl/Kg/Hour) for Makueni fruits was recorded on day 8 in untreated fruits.

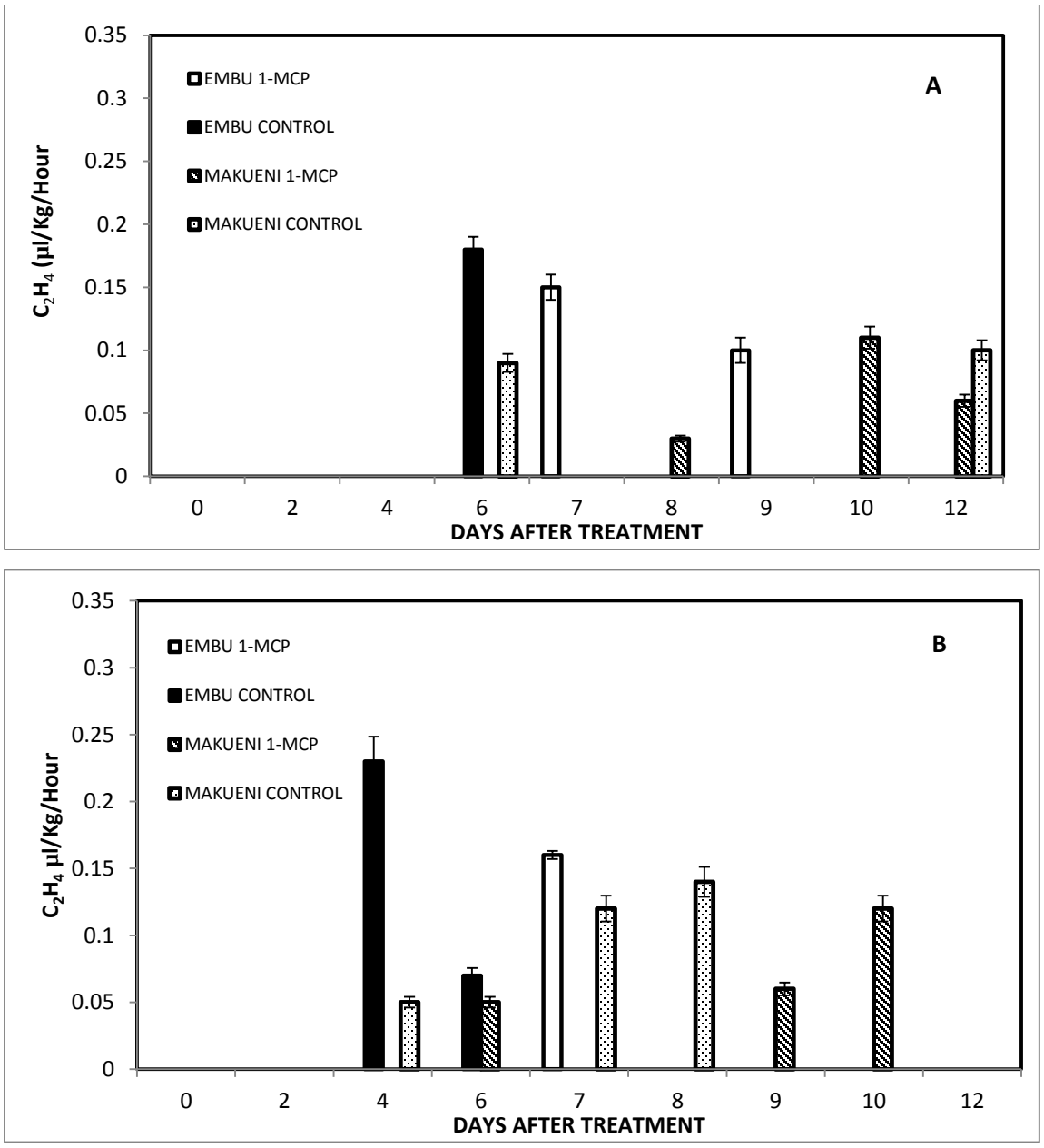

Figure 4.2: Ethylene production of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1ppm) for 24 hours or left untreated (0 ppm) in season 1. Vertical bars represent mean ± standard error value at $p<0.05$.

4.5.2 CHANGES IN PHYSICAL PARAMETERS

4.5.2.1 PEEL COLOR

The peel color (hue angle) reduced gradually in all the fruits as they ripened (Figure 4.3 (A

and B). Fruits harvested at S1 had relatively higher initial hue angle compared to fruits at S2 from both locations. 1-MCP treated fruits at both stages from both locations retained significantly ($p<0.05$) higher peel hue angle compared to the untreated fruits. Peel color was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. At S1 in Makueni fruits, peel hue angle reduced from initial value of 106.2 º to 77.8 º and 63.7 º for 1-MCP treated and untreated fruits respectively on day 12 (the end stage of untreated fruits). The treated fruits lasted up to day 15 attaining a hue angle of 62.1º. In Embu fruits, treated fruits' hue angle was 84.9 º at the end stage (day 9). This was 23% higher compared to untreated fruits' 65.5 º on the same day. At S2, the peel hue angle of Makueni fruits reduced from the initial value of 101.8 º to 74.4 º and 66.3 º for treated and untreated fruits respectively at day 10 (the end stage of untreated fruits). At the end stage of treated fruits (day 13) which was 3 days later, the treated fruits hue angle was 57.6º. In Embu fruits, treated fruits' hue angle was 82.7º, 30.4 % higher relative to untreated fruits' 61.5 º at the end stage (day 7).

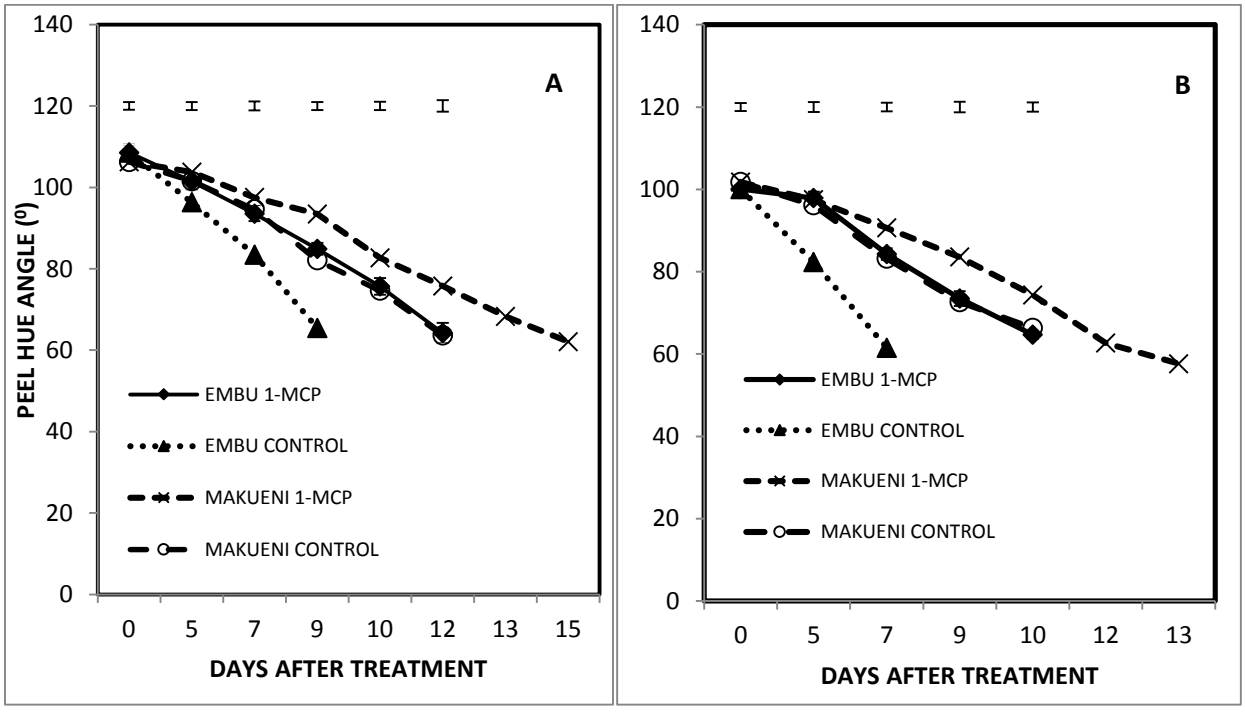

Figure 4.3: Changes in peel hue angle of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p\leq0.05$ for the four treatment means on each sampling day.

4.5.2.2 FLESH COLOR

As ripening progressed, the flesh color (hue angle) of fruits reduced gradually (Figure 4.4 (A - B). 1-MCP treated fruits from both locations retained significantly ($p<0.05$) higher hue angle than untreated fruits irrespective of stage. The interaction between stage of maturity, location and treatment significantly ($p<0.001$) affected fruits' flesh color. In fruits harvested at S1, 1-MCP treatment effect was evident in fruits from Makueni where treated fruits retained a higher hue angle during the entire storage period. In treated fruits from Makueni at day 12 (end stage for untreated fruits), the hue angle was 68.3 º compared to untreated controls' 58.3º. The treated fruits retained a relatively higher hue angle (57.3 º) even after the end stage of untreated controls. In Embu fruits, the hue angle of 1-MCP treated fruits was 75.6º, 16.1% higher relative to untreated controls' 63.4º at the end stage at day 9. At S2, the reduction in hue angle was significantly ($p<0.05$) slower in Embu treated fruits compared to Makueni treated fruits. In treated fruits from Makueni, the hue angle reduced from initial value of 96.7 º to 64.9 º at day 10 (the end stage of untreated controls). The hue angle of untreated fruits on the same day was 62.1 º. However, the treated fruits lasted up to day 13 where the hue angle was 57.3 º. At the end stage (day 7) of Embu fruits, the hue angle of treated fruits was 76.6º, 25.2% higher compared to untreated controls' 59.4 º on the same day.

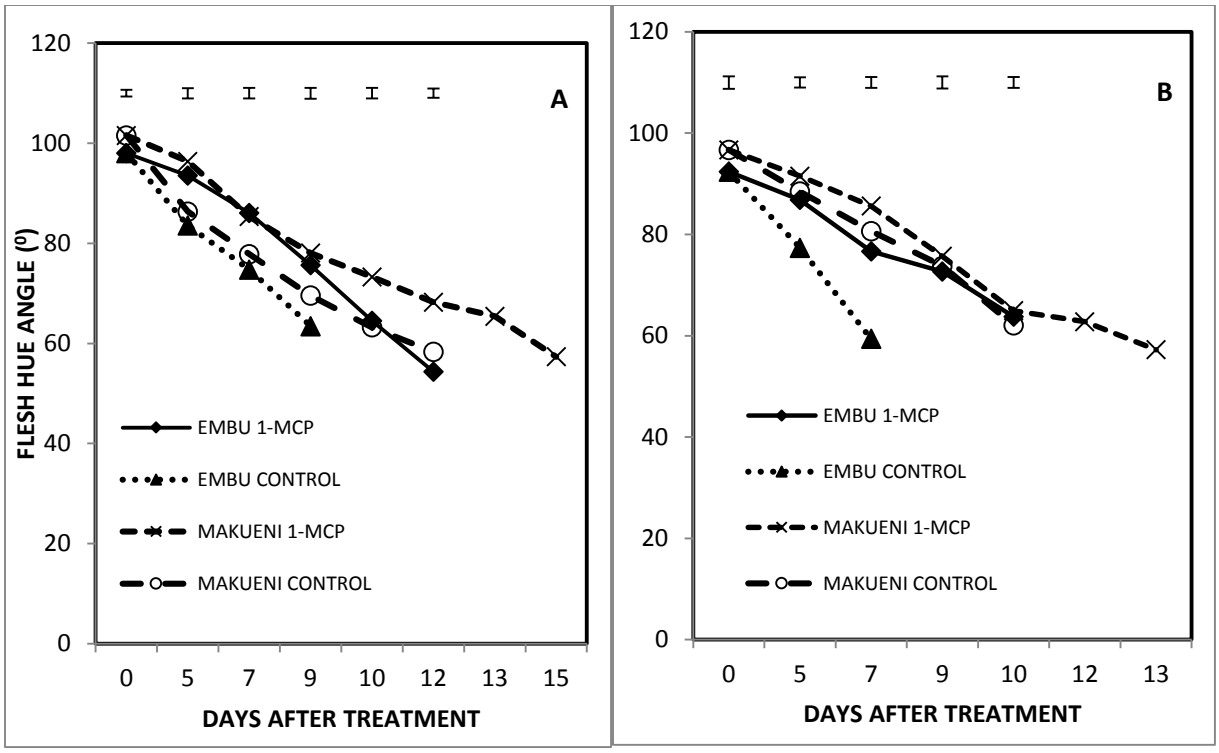

Figure 4.4: Changes in flesh hue angle of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2 (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

4.5.2.3 PEEL FIRMNESS

Peel firmness decreased in all the fruits with progress in ripening (Figure 4.5 (A-B). 1-MCP treated fruits at S1 and S2 from Embu and Makueni retained relatively higher peel firmness compared to untreated control fruits. The interaction between stage of maturity, location and treatment did not significantly affect fruit peel firmness. At S1 in Makueni fruits, peel firmness reduced from initial values of 20.4N to 8.4N and 5.5N in 1-MCP treated and untreated fruits respectively on day 12 which was the end stage of untreated controls. The treated fruits lasted an extra 3 days thereafter with an end stage firmness of 4.7N. In Embu fruits, untreated controls' firmness was 6N at the end stage (day 9). This was 44% lower than the firmness of 1-MCP treated fruits (10.7 N) on the same day. In S2 fruits from Makueni, peel firmness reduced from the initial 18.8 N to 8.2 N and 5.5 N for 1-MCP treated and untreated fruits respectively at the end stage of the untreated controls (day 10). The treated fruits lasted until day 13 where the firmness was 4.6 N. In Embu fruits, 1-MCP treated fruits' firmness was 10.5N, 60% higher relative to untreated controls' 4.2 N at the end stage of the latter (day 7).

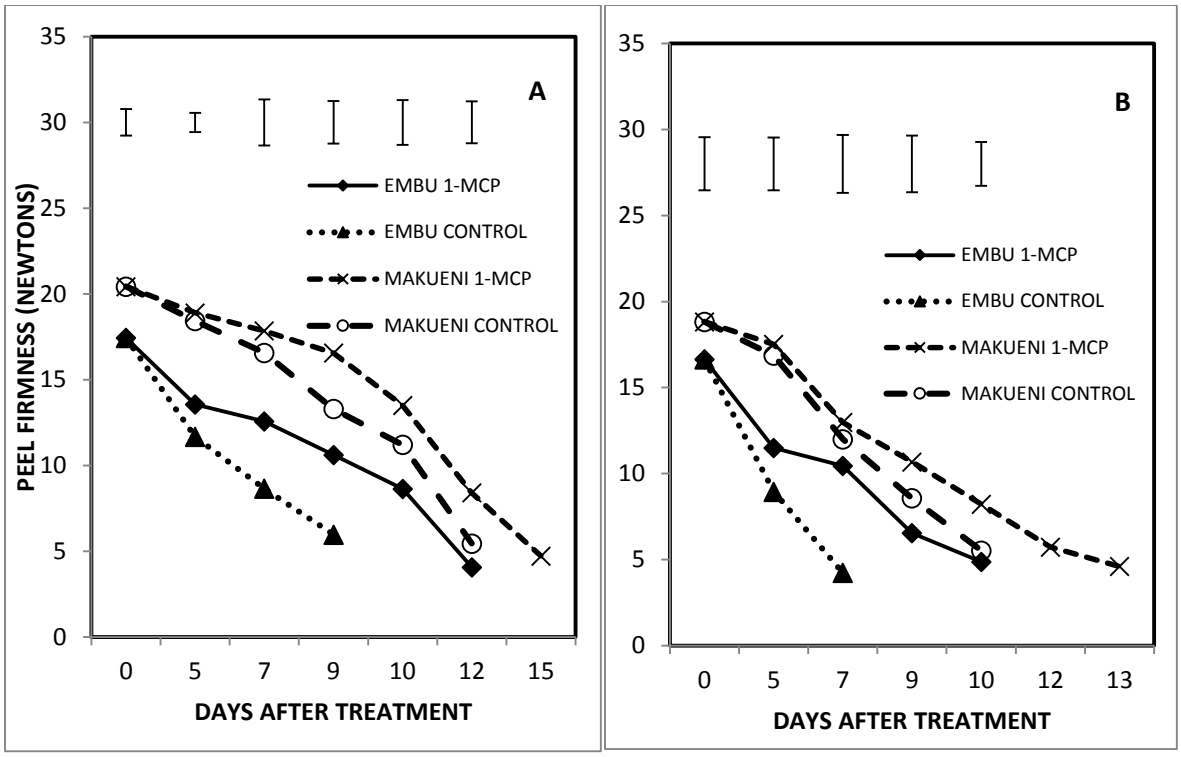

Figure 4.5: Changes in peel firmness of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2 - advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

4.5.2.4 FLESH FIRMNESS

A reduction in flesh firmness was observed in all the fruits as ripening progressed regardless of the production location and stage of maturity (Figure 4.6 (A-B). 1-MCP treated fruits at both maturity stages retained relatively higher flesh firmness compared to untreated controls from both locations. Flesh firmness was significantly ($p<0.05$) affected by the interaction between stage of maturity, location and treatment. At S1 in Makueni fruits, flesh firmness reduced from initial value of 10.1N to 5.2N and 3.3N for treated and untreated fruits respectively on day 12 which was the end stage of control fruits. Treated fruits attained a firmness of 3.6N at end stage which occurred 3 days later. In Embu fruits, untreated controls' firmness was 3.9N at the end stage (day 9). This was 31% lower relative to treated fruits firmness (5.1N) on the same day, but the treated fruits lasted an extra 3 days thereafter. In S2 fruits from Makueni, flesh firmness reduced gradually from initial value of 9.7N to 6N and 3.4N for 1-MCP treated and untreated fruits respectively at day 10 (the end stage of untreated control fruits). Treated fruits thereafter attained a firmness of 3N at the end

stage which was 3 days later. In Embu fruits, 1-MCP treated fruits firmness was 4.8N, 18.9% higher compared to untreated controls' 3.9N at end stage of the latter (day 7).

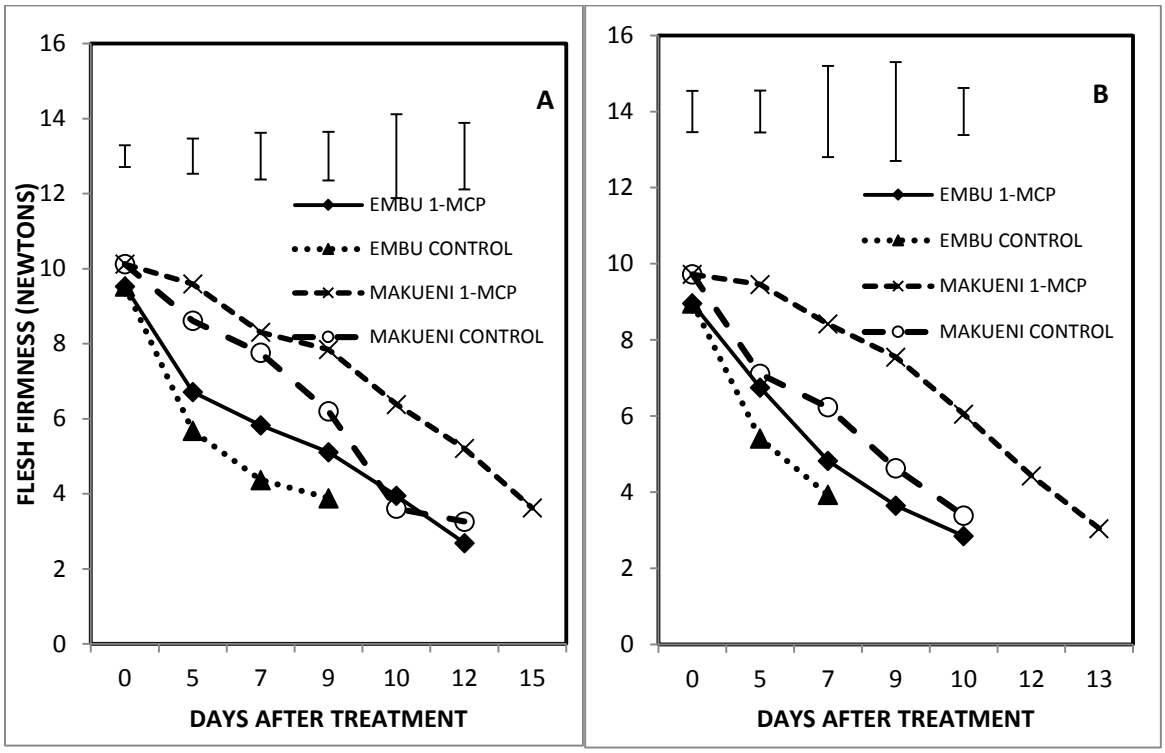

Figure 4.6: Changes in flesh firmness of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2 - advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

4.5.2.5 PERCENT (%) CUMULATIVE WEIGHT LOSS

In all the fruits, there was a gradual increase in percent cumulative weight loss with advancement in fruit ripening (Figure 4.7 (A-B). Treated fruits harvested from Makueni retained significantly ($p<0.05$) higher percentage of their initial weight compared to treated fruits from Embu. Irrespective of maturity stage, the increase in cumulative weight loss was relatively slower in 1-MCP treated fruits harvested from Embu and Makueni compared to untreated fruits from same locations. The effect of the interaction between stage of maturity, location and treatment on fruit weight loss was not significant. In S1 fruits, 1-MCP treatment effect was more evident in Makueni fruits compared to fruits from Embu (Figure 4.7A). At S1, untreated control fruits from Makueni had lost 11.6% of their initial weight on day 12 (end stage) compared to 8.4% loss 1-MCP treated fruits which lasted another 3 days thereafter. In Embu fruits, 1-MCP treated fruits

lost 8.8% of their initial weight compared to untreated fruits' 10.0% at the end stage of the latter (day 9). At S2, 1-MCP treated fruits from Makueni retained significantly ($p<0.05$) higher percentage of their initial weight compared to treated fruits from Embu. 1-MCP treated fruits from Makueni lost 7.3% of their initial weight compared to untreated fruits' 8.4% at the end stage of the latter (day 10). However, Makueni fruits lasted an extra 3 days to day 13; at this point they had lost 9.5% of the initial weight. Similarly, in Embu fruits (S2), untreated controls had lost 8.9% of the initial weight at the end stage (day 7) compared to 1-MCP treated fruits' 8.1% on the same day.

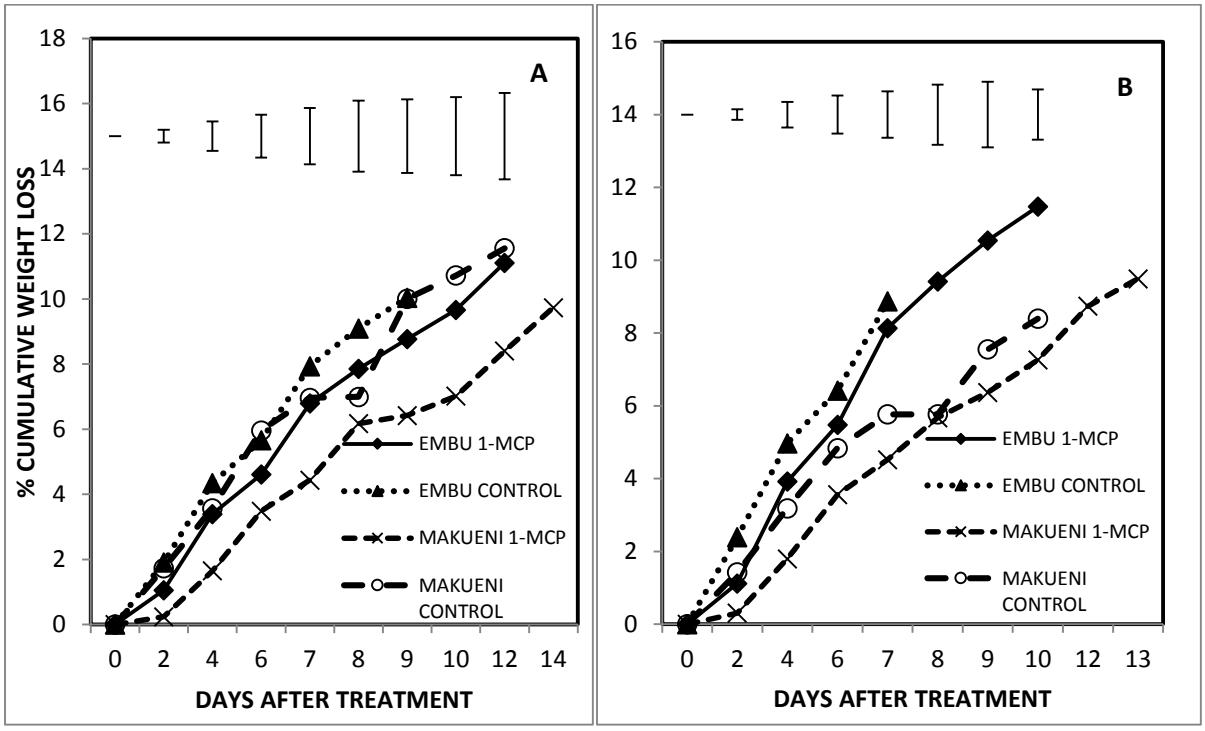

Figure 4.7: Changes in percent cumulative weight loss of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p\leq0.05$for the four treatment means on each sampling day.

4.5.3 CHANGES IN CHEMICAL PARAMETERS

4.5.3.1 TOTAL SOLUBLE SOLIDS (TSS)

A gradual increase in fruits' TSS content was observed as ripening progressed (Figure 4.8 (A-B). The change in TSS content was slower in treated fruits harvested from both locations

compared to untreated fruits. Fruit TSS content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. At S1, treated fruits from Embu retained significantly ($p<0.05$) lower TSS content compared to treated fruits from Makueni. In Makueni fruits, the TSS content of fruits harvested at S1 increased from initial value of 5.4 ºbrix to 13.3 and 12.6 ºbrix for 1-MCP treated and untreated fruits respectively on day 12 (the end stage of untreated controls). In Embu fruits, the TSS content of 1-MCP treated fruits was 8.1 ºbrix at the end stage (day 9). This was 10% lower relative to untreated fruits' 9.0 ºbrix at the same day. At S2, the increase in TSS level in Makueni fruits was from initial 6.2 ºbrix to 10.1 and 13.7 ºbrix for 1-MCP treated and untreated fruits respectively at day 10 (the end stage of untreated fruits). At the end stage of treated fruits which occurred 3 days later, the fruits attained a TSS content of 13.9 ºbrix (Figure 4.8B). In Embu fruits, the TSS content increased from initial 4.9 ºbrix to 8.2 and 10.8 ºbrix for treated and untreated fruits respectively at the end stage of the latter (day 7). At the end stage of treated fruits (day 10), the fruits had a TSS content of 10.7 ºbrix.

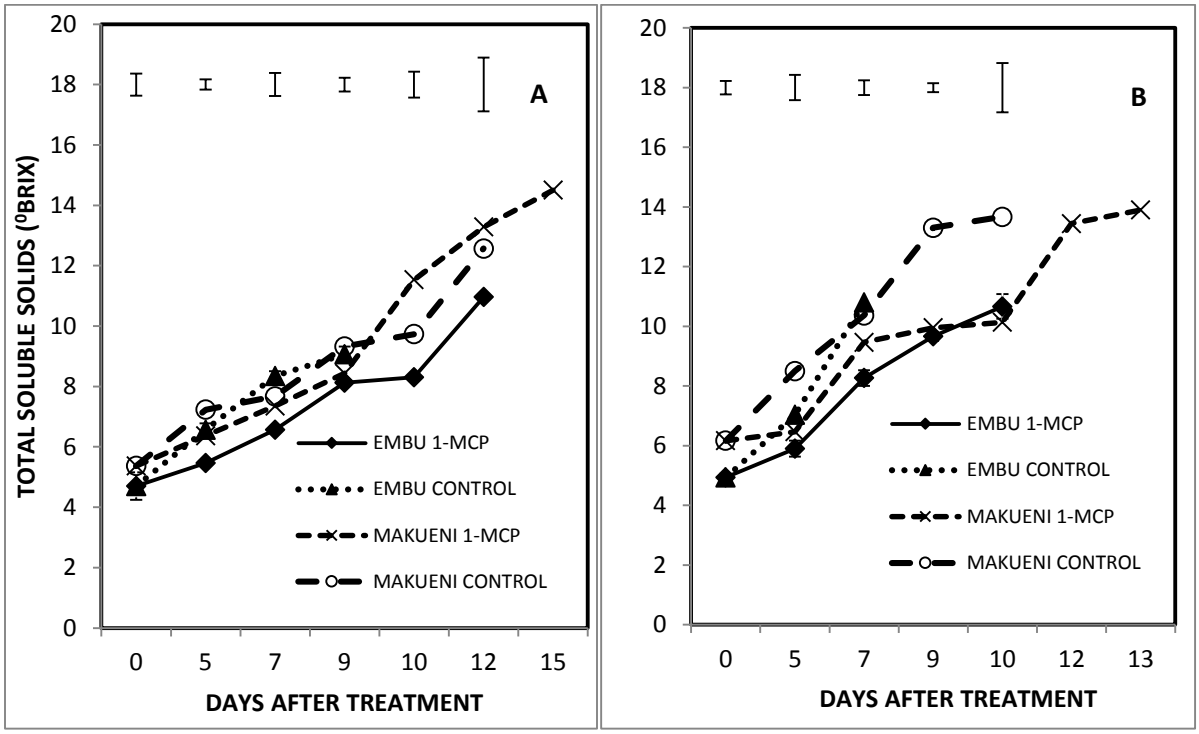

Figure 4.8: Changes in total soluble solids of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2 - advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p\leq0.05$for the four treatment means on each sampling day.

4.5.3.2 TOTAL TITRATABLE ACIDITY (TTA)

A reduction in TTA content was observed in all the fruits as ripening progressed (Figure 4.9 (A-B). 1-MCP treated fruits harvested at S1 retained significantly ($p<0.05$) higher TTA content compared to treated fruits at S2. The decrease in TTA content was significantly ($p<0.05$) slowed down in 1-MCP treated fruits. Fruit TTA content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. In S1 fruits from Makueni, the TTA amount reduced from initial value of 0.6 % to 0.2 and 0.1 % citric acid equivalent for 1-MCP treated and untreated fruits respectively at the end stage on day 12 (the end stage of control fruits). In fruits harvested from Embu, treated fruits had a TTA content of 0.5 % citric acid equivalent at the end stage on day 9. This was 80% higher relative to untreated controls' 0.1% citric acid equivalent on the same day. At S2 in fruits from Makueni, the TTA levels dropped from initial 0.5% to 0.3 and 0.1 % citric acid equivalent for treated and untreated fruits respectively on day 10 (the end stage of untreated fruits). At the end stage (day 13) of treated fruits, the TTA content was 0.05% citric acid equivalent. In Embu fruits, at the end stage (day 7), the untreated fruits attained a TTA content of 0.2% citric acid equivalent. This was 50% lower relative to 1-MCP treated fruits' 0.3% citric acid equivalent on the same day.

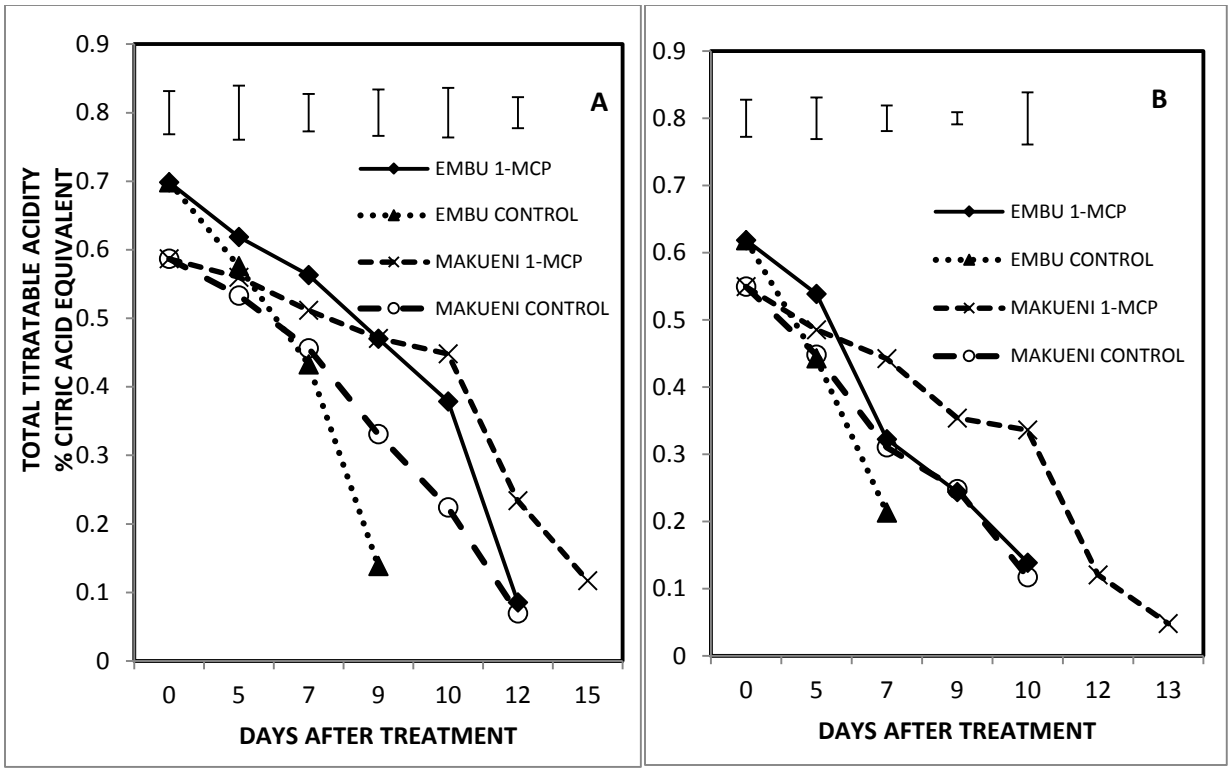

Figure 4.9: Changes in total titratable acidity of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p \leq 0.05$for the four treatment means on each sampling day.

4.5.3.3 ASCORBIC ACID

As ripening advanced, the ascorbic acid (Vitamin C) content decreased gradually in all the fruits (Figure 4.10 (A-B). Irrespective of the stage of maturity and production location, the reduction in ascorbic acid was relatively slower in 1-MCP treated fruits compared to the untreated controls. Ascorbic acid content was significantly ($p<0.05$) affected by the interaction between stage of maturity, location and treatment. In S1 fruits, the effectiveness of 1-MCP treatment in slowing down the reduction in ascorbic acid was more evident in Embu fruits (Figure 10A). In Makueni fruits, the ascorbic acid reduced gradually from initial value of 110.5 mg/100ml to 61.5 and 50.8 mg/100ml for 1-MCP treated and untreated fruits respectively at day 12 (the end stage of untreated controls). Even at the end stage of treated fruits which occurred 3 days later, the fruits ascorbic acid content was slightly higher (53.2 mg/100ml) to that of untreated fruits. In Embu fruits, the ascorbic acid content of treated fruits was 66.7 mg/100ml at day 10 which was the end stage of untreated fruits. This was 26.5% higher relative to untreated fruits' 49.0 mg/100ml on the

same day. In fruits harvested at S2, 1-MCP treatment effect was evident in Embu fruits. In fruits from Makueni, ascorbic acid content reduced from initial value of 106.3 mg/100ml to 74.9 and 63.2 mg/100ml for treated and untreated fruits respectively at the end stage (day 10) which was the end stage of control fruits. In Embu fruits, 1-MCP treated fruits retained significantly ($p<0.05$) higher ascorbic content (79.1 mg/100ml) at the end stage on day 7. This was 42.5% higher relative to untreated fruits' 45.5 mg/100ml on the same day.

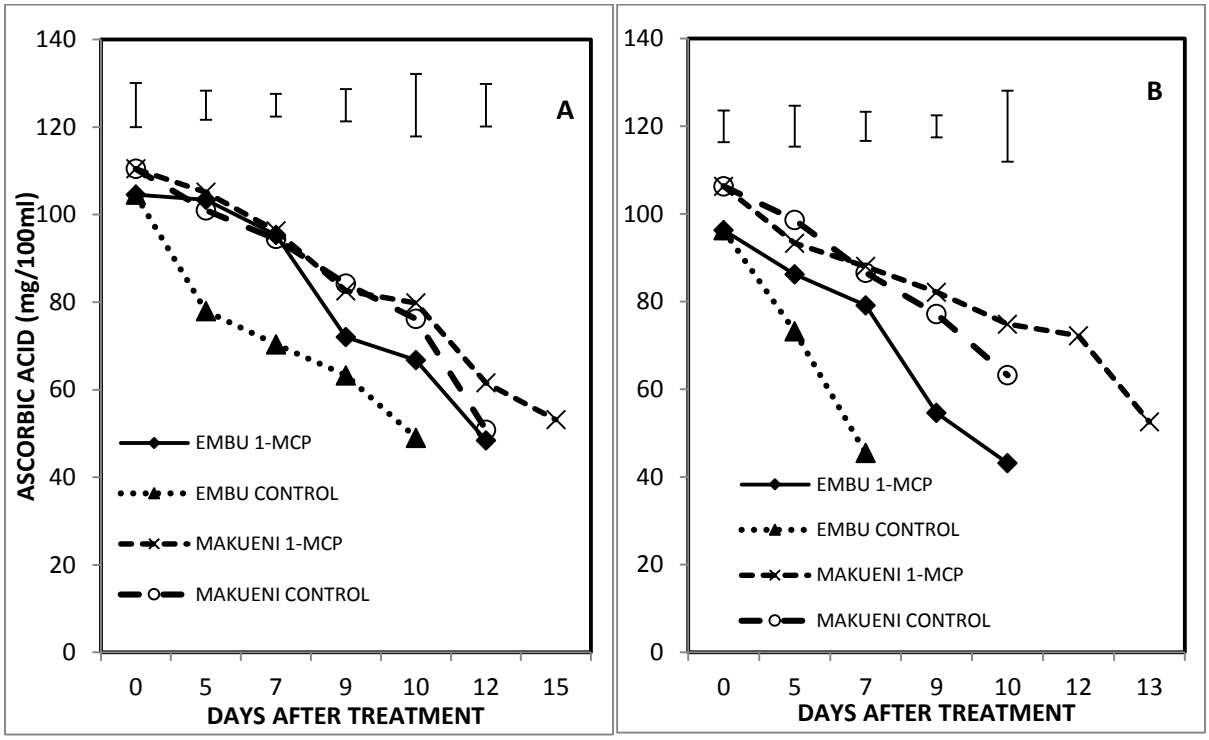

Figure 4.10: Changes in ascorbic acid of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p\leq0.05$for the four treatment means on each sampling day.

4.5.3.4 BETA-CAROTENE

The beta-carotene levels increased in all the fruits as ripening progressed (Figure 4.11 (A-B). The increase in beta-carotene level was significantly ($p<0.05$) slower in 1-MCP treated fruits compared to untreated controls irrespective of stage and location. Fruits' beta-carotene content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. At S1, beta-carotene levels of fruits from Makueni increased from initial 0.6 mg/100ml

to 5.5 and 6.6 mg/100ml for treated and untreated fruits respectively at day 12 (the end stage of untreated control fruits). In Embu fruits, the beta-carotene content of treated fruits was 5.6 mg/100ml at the end stage (day 9). This was 16.1% lower relative to untreated fruits' 6.5 mg/100ml on the same day. In S2 fruits, the increase in beta-carotene content was significantly ($p<0.05$) slowed down in 1-MCP treated fruits from Makueni (Figure 4.11B). In Makueni fruits, the beta-carotene content increased from initial 1.3 mg/100ml to 4.9 and 7.9 mg/100ml for 1-MCP treated and untreated fruits respectively at day 10 (the end stage of untreated controls). In Embu fruits, the untreated fruits' beta-carotene content was 5.5 mg/100ml at the end stage (day 7). This was 40% higher relative to treated fruits' 3.3 mg/100ml on the same day.

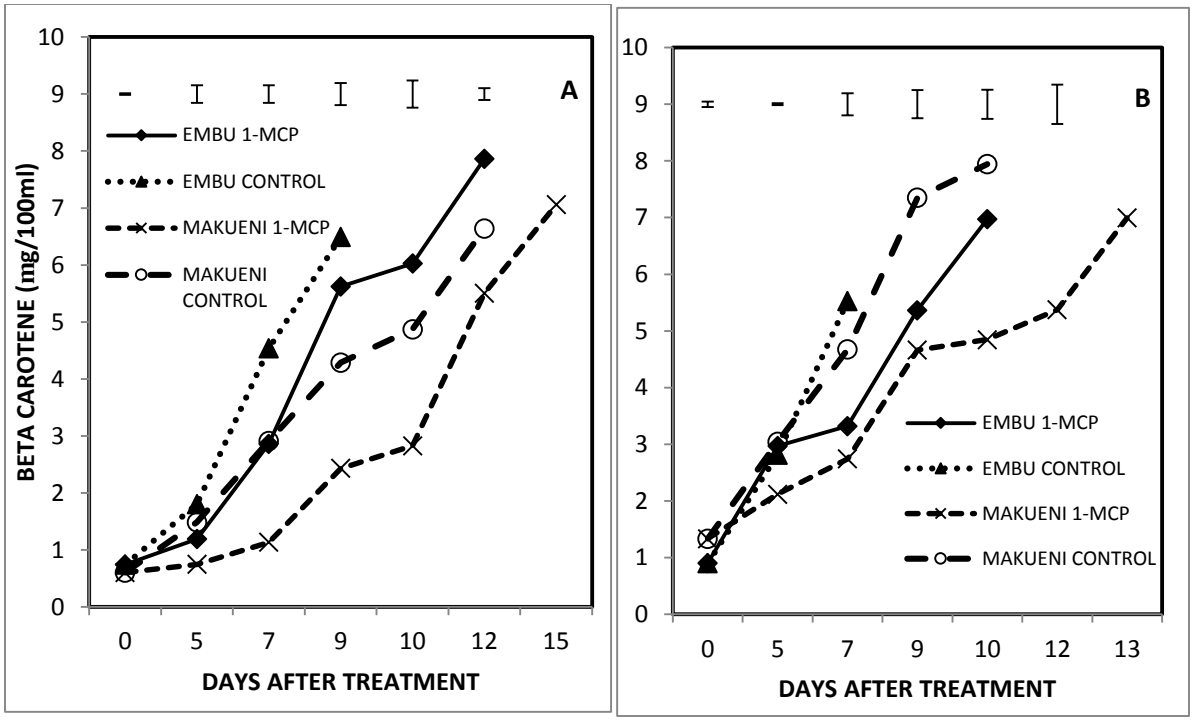

Figure 4.11: Changes in beta-carotene content of 'apple' mango harvested from Embu and Makueni at two stages of maturity; S1- mature green (A) and S2- advanced in maturity (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm). Bars above the graph represent LSD at $p\leq0.05$for the four treatment means on each sampling day.

4.5.4 CHANGES IN MAJOR SUGARS

4.5.4.1 FRUCTOSE

The level of fructose increased gradually to a peak level then declined with progress in fruit ripening. Treated fruits harvested from Makueni retained significantly ($p<0.05$) higher

fructose levels than treated fruits from Embu at both maturity stages. Fructose content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. At S1 in Makueni fruits, fructose level increased from initial 1.9 g/100ml to 7.7 and 8.0 g/100ml for treated and untreated fruits respectively at the end stage on day 12. In Embu fruits, the fructose level of untreated fruits was 5.1 g/100ml at the end stage (day 9). This was 29.4% lower compared to 1-MCP treated fruits' 6.6 g/100ml at the same day. At S2, 1-MCP treatment effect was noted in fruits harvested from Embu. In Makueni fruits, fructose level increased from initial 2.6 g/100ml to a peak value of 13 g/100ml then declined to 12.4 g/100ml for treated fruits and to a peak value of 11.9 g/100ml then declined to 11.7 g/100ml for untreated fruits. In Embu fruits, the fructose content of 1-MCP treated fruits was 5.1 g/100ml at the end stage (day 7). This was 43.1% lower relative to untreated fruits' 7.3 g/100ml on the same day.

Table 4.1: Changes in fructose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (control).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	13
EMBU TREATED	1.9a	4.3a	3.2c	3.6b	4.1b		
EMBU UNTREATED	1.9a	3.7b	3.4c				
MAKUENI TREATED	1.3b	2.2c	4.5b	5.7a	6.0a	6.6	5.8
MAKUENI UNTREATED	1.3b	2.3c	5.1a	5.5a	5.7a		
LSD	**0.49**	**0.52**	**0.58**	**0.39**	**0.5**		

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.2: Changes in fructose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	13
EMBU TREATED	2.1b	5.3b	5.1b	5.6c	6.7b		
EMBU UNTREATED	2.1b	6.3a	7.3a				
MAKUENI TREATED	2.6a	3.9c	8.4a	13.0a	12.4a	12.1	11.3
MAKUENI UNTREATED	2.6a	5.3b	8.1a	11.9b	11.7a		
LSD	**0.3**	**0.78**	**1.06**	**0.62**	**0.95**		

Means within column followed by different letter differ significantly at ($p<0.05$).

4.5.4.2 GLUCOSE

Glucose levels increased with fruit ripening irrespective of location, stage of maturity or treatment. Treated fruits retained relatively higher glucose levels than untreated fruits from both locations at both maturity stages. Fruits' glucose content was significantly ($p<0.05$) affected by the interaction between stage of maturity, location and treatment. In fruits harvested at S1 from Makueni, glucose content increased gradually from initial 1.2 g/100ml to 5.2 and 4.8 g/100ml for treated and untreated fruits respectively at day 12 (the end stage of untreated control fruits). Similarly, in Embu fruits, the increase in glucose content was from initial 0.9 g/100ml to 3.0 and 2.1 g/100ml for treated and untreated fruits respectively at the end stage (day 9) of untreated fruits. At S2 in Makueni fruits, the glucose content increased from initial 1.3 g/100ml to 6.0 and 5.7 g/100ml for treated and untreated fruits respectively at day 10 (the end stage of untreated fruits). In Embu fruits, the glucose content of untreated fruits was 3.4 g/100ml at the end stage (day 7). This was 5.9% higher relative to treated fruits' 3.2 g/100ml on that similar day.

Table 4.3: Changes in glucose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	15
EMBU TREATED	0.9a	1.3a	1.7c	3.0b	3.3c		
EMBU UNTREATED	0.9a	1.6a	1.1d	2.1c			
MAKUENI TREATED	1.2a	1.5a	2.9a	4.0a	4.8a	5.2a	5.3
MAKUENI UNTREATED	1.2a	0.9b	2.3b	3.9a	4.1b	4.8a	
LSD	**0.41**	**0.29**	**0.36**	**0.37**	**0.44**	**0.59**	

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.4: Changes in glucose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	13
EMBU TREATED	1.9a	4.3a	3.2c	3.6b	4.1b		
EMBU UNTREATED	1.9a	3.7b	3.4c				
MAKUENI TREATED	1.3b	2.2c	4.5b	5.7a	6.0a	6.6	5.8
MAKUENI UNTREATED	1.3b	2.3c	5.1a	5.5a	5.7a		
LSD	**0.49**	**0.52**	**0.58**	**0.39**	**0.5**		

Means within column followed by different letter differ significantly at ($p<0.05$).

4.5.4.3 SUCROSE

The sucrose levels increased gradually with progress in fruit ripening. The increase in sucrose content was significantly ($p<0.05$) slower in 1-MCP treated fruits than in untreated fruits. Sucrose content was not significantly affected by the interaction between stage of maturity, location and treatment. At S1 in Makueni fruits, sucrose content increased from initial 1.3 g/100ml

to 5.2 and 5.5 g/100ml for treated and untreated fruits respectively at day 12 (the end stage of untreated controls). In Embu fruits, the sucrose content of treated fruits was 4.1 g/100ml at the end stage (day 9). This was 29.2% higher compared to untreated controls' 2.9 g/100ml on the same day. At S2 in Makueni fruits, sucrose content increased gradually from initial 1.4 g/100ml to 9.5 and 9.2 g/100ml for 1-MCP treated and untreated fruits respectively at day 10 (the end stage of untreated fruits). At the end stage (day 13) of treated fruits, the sucrose content dropped 8.9 g/100ml. In Embu fruits, sucrose content of treated fruits was 6.7 g/100ml at the end stage on day 7. This was 10.4% higher relative to untreated fruits' 6.0 g/100ml on the same day.

Table 4.5: Changes in sucrose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	15
EMBU TREATED	1.2a	1.5b	1.7c	4.1b	4.3a		
EMBU UNTREATED	1.2a	1.4b	1.8c	2.9c			
MAKUENI TREATED	1.3a	1.5b	2.6b	2.7c	4.5a	5.2a	4.6
MAKUENI UNTREATED	1.3a	3.6a	4.5a	4.9a	4.7a	5.5a	
LSD	**0.24**	**0.34**	**0.45**	**0.23**	**0.58**	**0.59**	

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.6: Changes in sucrose content (g/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	13
EMBU TREATED	1.3a	3.1b	6.7a	8.7b	8.0b		
EMBU UNTREATED	1.3a	3.7b	6.0b				
MAKUENI TREATED	1.4a	3.1b	6.9a	9.2a	9.5a	9.0	8.9
MAKUENI UNTREATED	1.4a	4.7a	7.1a	9.5a	9.2a		
LSD	**0.26**	**0.65**	**0.61**	**0.57**	**0.6**		

Means within column followed by different letter differ significantly at ($p<0.05$).

4.5.5 CHANGES IN SELECTED MINERAL NUTRIENTS IN FRUIT TISSUE

4.5.5.1 MAGNESIUM

The reduction in Magnesium (Mg) content was non-linear during ripening fruit ripening. Fruits harvested at S1 had relatively higher initial Mg content compared to fruits at S2 from both locations. Fruits harvested from Makueni had significantly ($p<0.05$) higher Mg content than fruits from Embu. Fruit Mg content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. In S1 fruits, the reduction in Mg content was significantly ($p<0.05$) slowed down following 1-MCP treatment in fruits from Makueni compared to fruits from Embu. In Makueni fruits, Mg levels reduced non-linearly from the initial 20.5 mg/100ml to 14.7 and 8.8 mg/100ml for 1-MCP treated and untreated fruits respectively at day 12 which was the end stage of untreated fruits. In Embu fruits, the Mg content of treated fruits was 10.6 mg/100ml at the end stage on day 9. This was 46.2% higher compared to untreated fruits' 5.7 mg/100ml on the same day. The Mg content of treated fruits was 5.3 mg/100ml at the end stage (day 12). In fruits harvested at S2 from Makueni, Mg content reduced no-linearly from initial 17.9 mg/100ml to 4.4 and 2.2 mg/100ml for treated and untreated control fruits respectively at day 10 (the end stage of untreated fruits). The Mg content of treated fruits was 1.4 mg/100ml at the end stage which occurred 3 days later. In fruits from Embu, the Mg content of treated fruits was 8.4 mg/100ml at the end stage (day 7). This was 51.2% higher relative to untreated controls' 4.1 mg/100ml on that similar day.

Table 4.7: Changes in magnesium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	15
EMBU TREATED	14.0b	9.7c	9.2b	10.6b	7.1b	5.3c	
EMBU UNTREATED	14.0b	7.30d	9.5b	5.7c			
MAKUENI TREATED	20.5a	31.3a	26.7a	18.5a	13.8a	14.7a	6.9
MAKUENI UNTREATED	20.5a	15.7b	10.6b	5.3c	14.1a	8.8b	
LSD	**1.06**	**0.96**	**1.15**	**0.99**	**3.57**	**1.27**	

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.8: Changes in magnesium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT					
LOCATION*TREATMENT	0	5	7	9	10	13
EMBU TREATED	13.0b	12.5b	8.4b	10.3b	4.3a	
EMBU UNTREATED	13.0b	6.2c	4.1c			
MAKUENI TREATED	17.9a	3.1d	1.8d	6.8c	4.4a	1.4
MAKUENI UNTREATED	17.9a	16.7a	10.5a	12.5a	2.2b	
LSD	**1.07**	**0.75**	**1.5**	**2.06**	**0.79**	

Means within column followed by different letter differ significantly at ($p<0.05$).

4.5.5.2 CALCIUM

A reduction in Ca level was observed with advancement in fruit ripening. Relatively higher Ca levels were noted in fruits harvested at S1 than fruits at S2. Fruits from Embu had significantly ($p<0.05$) higher initial Ca levels compared to fruits from Makueni at both maturity

stages. Fruit Ca content was significantly ($p<0.05$) affected by the interaction between stage of maturity, location and treatment. In fruits harvested at S1, treated fruits from Embu retained significantly ($p<0.05$) higher Ca levels than treated fruits from Makueni up to day 7. In Makueni fruits, Ca content of treated fruits reduced from 4.1 mg/100ml to 2.6 mg/100ml at the end stage (day 12) of the untreated fruits. Ca content of untreated fruits reduced from initial 4.1 mg/100ml to 1.3 mg/100ml at day 12 (the end stage of untreated fruits). In Embu fruits, the Ca content of treated fruits was 4.0 mg/100ml at the end stage (day 9) for untreated fruits. This was 53% higher relative to untreated fruits' 1.9 mg/100ml on the same day. In fruits harvested at S2, the reduction in Ca levels was significantly ($p<0.05$) slowed down in 1-MCP treated fruits from Makueni. In fruits harvested from Makueni, Ca content reduced gradually from initial 3.5 mg/100ml to 3.2 and 2.9 mg/100ml for 1-MCP treated and untreated fruits respectively at day 10 (the end stage of untreated fruits). Treated fruits had 9.3% higher Ca content relative to the untreated fruits at the end stage (day 10). In Embu fruits, the reduction in Ca content was from initial 5.4 mg/100ml to 4.2 and 5.3 mg/100ml for treated and untreated fruits respectively at the end stage on day 7.

Table 4.9: Changes in calcium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	15
EMBU TREATED	7.1a	6.7a	5.2a	4.0a	3.0a	1.5b	
EMBU UNTREATED	7.1a	4.6b	2.3c	1.9b			
MAKUENI TREATED	4.1b	4.2b	4.8b	4.6a	3.7a	2.6a	1.7
MAKUENI UNTREATED	4.1b	6.2a	4.6b	4.3a	2.3b	1.3b	
LSD	**1.22**	**1.61**	**0.68**	**0.7**	**0.92**	**0.66**	

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.10: Changes in calcium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT					
LOCATION*TREATMENT	0	5	7	9	10	13
EMBU TREATED	5.4a	6.0a	4.2c	1.9c	1.6b	
EMBU UNTREATED	5.4a	5.2b	5.3b			
MAKUENI TREATED	3.5b	6.4a	5.9a	3.6a	3.2a	1.8
MAKUENI UNTREATED	3.5b	5.9a	3.3d	2.5b	2.9a	
LSD	**0.91**	**0.58**	**0.59**	**0.49**	**0.69**	

Means within column followed by different letter differ significantly at ($p<0.05$).

4.5.5.3 POTASSIUM

A non-linear reduction in K content was observed with progress in fruit ripening. Fruits harvested at S1 had higher initial K content than fruits at S2 from both locations. Fruits from Embu had significantly ($p<0.05$) higher K content compared to fruits from Makueni. Fruits from Embu at S1 retained significantly ($p<0.05$) higher K content than fruits from Makueni at S1. Treated fruits harvested at S1 from both locations had significantly ($p<0.05$) high K content compared to treated fruits at S2 from both locations. Fruit K content was significantly ($p<0.001$) affected by the interaction between stage of maturity, location and treatment. In S1 fruits, treated fruits retained relatively higher K levels than untreated fruits from both locations. In fruits harvested from Makueni, the K content reduced from initial 95.1 mg/100ml to 55 and 15 mg/100ml for treated and untreated fruits respectively at day 12 which was the end stage of untreated fruits. In Embu fruits, the K content of treated fruits was 86.8 mg/100ml at the end stage on day 9. This was 38.0% higher compared to untreated fruits' 53.8 mg/100ml on the same day. In fruits harvested at S2, untreated fruits from both locations retained relatively higher K levels compared to the treated fruits from Embu and Makueni. In Makueni fruits, the reduction in K content was from initial 80.1 mg/100ml to 48.8 and 72.7 mg/100ml for 1-MCP treated and untreated fruits respectively at the end stage (day 10) of untreated control. In Embu fruits, K content reduced from initial 195.1 mg/100ml to 56.3 and 88.8 mg/100ml for treated and untreated fruits respectively at the end stage (day 7).

Table 4.11: Changes in potassium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 1 (mature green) (A) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT						
LOCATION*TREATMENT	0	5	7	9	10	12	15
EMBU TREATED	281.4a	92.6b	94.0a	86.8a	76.3a	46.3a	
EMBU UNTREATED	281.4a	68.8b	86.8a	53.8b			
MAKUENI TREATED	95.1b	112.6a	57.5c	84.1a	75.4a	55.0a	33.4
MAKUENI UNTREATED	95.1b	76.3b	73.4b	84.2a	93.8a	15b	
LSD	**16.82**	**18.69**	**12.34**	**16.43**	**18.17**	**28.6**	

Means within column followed by different letter differ significantly at ($p<0.05$).

Table 4.12: Changes in potassium content (mg/100ml) of 'apple' mango harvested from Embu and Makueni at stage 2 (advanced in maturity) (B) and treated with 1-MCP (1 ppm) for 24 hours or left untreated (0 ppm).

	DAYS AFTER TREATMENT					
LOCATION*TREATMENT	0	5	7	9	10	13
EMBU TREATED	195.1a	61.3b	56.3b	68.8a	77.6a	
EMBU UNTREATED	195.1a	118.8a	88.8a			
MAKUENI TREATED	80.1b	45.0c	57.5b	59.3a	48.8b	52.5
MAKUENI UNTREATED	80.1b	66.3b	86.3a	74.4a	72.7a	
LSD	**12.57**	**18.01**	**16.1**	**12.32**	**23.44**	

Means within column followed by different letter differ significantly at ($p<0.05$).

4.6 DISCUSSION

Climacteric fruits such as mango have a short shelf life due to their high perishability which is partly attributed to the effects of ethylene, the ripening hormone. Therefore ethylene management in postharvest storage systems is one strategy that is deployed to extend the shelf life and hence marketing period of climacteric fruits. In the present study, the efficacy of 1-Methylcyclopropene (1-MCP), a postharvest technology that has been shown to slow down deleterious effects of ethylene was established in 'apple' mango fruits.

Studies in some commodities show that the efficacy of 1-MCP is affected by preharvest production conditions such as light, temperature, rainfall, soils and agronomic practices. Additionally commodity factors such as species, variety and stage of maturity have been reported to affect 1-MCP effects. Therefore, the fruits used in the present study were harvested from two different agro-ecological conditions; a high potential AEZ, (Embu) and a low potential AEZ, (Makueni). The fruits were harvested at two stages of maturity; mature green (S1) and advanced maturity (S2).

The results revealed that production location, stage of maturity and the interaction between the two factors affected the changes in the fruits' physicochemical parameters during ripening and their response to 1-MCP treatment. Overall, 1-MCP treated fruits harvested at S1 and S2 had relatively longer shelf life of (15 and 13 days) and (12 and 10 days) respectively for Makueni and Embu locations. In comparison, untreated fruits at S1 and S2 had a shelf life of (12 and 10 days) and (9 and 7 days) respectively, for Makueni and Embu locations.

Although ethylene evolution was erratic with no clear trend in all the fruits, the effect of its inhibition was evident in the treated fruits where the ripening related changes, which are known to be triggered by ethylene, progressed in slower rates. In general, lower ethylene levels were observed in 1-MCP treated fruits. The mode of action of 1-MCP is through binding ethylene receptors in the fruits' tissue. Failure of ethylene to bind consequently inhibits its action in the treated commodities. As a result, ripening related changes which are known to be mediated or triggered by ethylene are slowed or inhibited in 1-MCP treated fruits (Watkins, 2002).

Respiration is one of the postharvest metabolic processes that determine the longevity of perishable commodities. Respiratory activity often mirrors the rates of other ripening related changes and is therefore used to gauge the rate of metabolism in the commodity. In the present study, the trend in respiration rate was mirrored in the other ripening changes in the mango fruits.

The efficacy of 1-MCP in slowing down ripening was reflected in reduced rates of respiration in treated fruits from both locations. The effect was most significant in fruits harvested at early maturity, S1. The treated fruits had lower respiration rates and the respiratory climacteric peak was delayed by 3 days compared to the untreated controls. These results are in concurrence with findings of previous studies in mango (Ricardo, 2004; Githiga, 2011) and other climacteric fruits such as banana, avocado, tomato, apples (Jiang and Joyce, 2002; Mattheis *et al.,* 2005). Contrary to the results of the present study, Bower *et al.,* (2003) found higher respiration rates in 1-MCP treated strawberry and attributed it to earlier decay. Increase in respiration during ripening is characteristic of climacteric fruits (Thompson, 2003). Preharvest production conditions have been reported to affect respiratory activity of fruits after harvest due. In banana (Ambuko *et al.,* 2008) and passion (Baraza *et al.,* 2013), fruits produced under dry agro-climatic conditions or season were reported to exhibit lower respiratory activity compared to those produced under more humid or wet agro-climatic conditions or season. In the present study, fruits from Makueni exhibited lower respiratory activity compared to Embu fruits. This could be attributed to the effect of the growing conditions on the fruits' physiological status, and consequently their response to 1-MCP treatment.

The rates and trends in other ripening changes that occurred in the fruits correlated positively with respiratory activity. In 1-MCP treated fruits where respiratory activity was slow, the changes occurred at slower rates relative to the untreated controls.

The peel and flesh hue angles reduced progressively with ripening in all the fruits but this was slowed down in 1-MCP treated fruits. The peel color change from green to yellow-orange in ripening mango fruits is attributed to chlorophyllase enzyme mediated breakdown of chlorophyll and also accumulation of color pigments, anthocyanin and carotenoids. The delayed reduction in hue angle in 1-MCP treated fruits could be attributed to reduced activity of chlorophyllase enzyme. Hershkovitz *et al.,* (2005) attributed the delayed degreening in avocado to reduced activity of chlorophyllase. Previous studies found that 1-MCP inhibited anthocyanin increase in strawberry fruit (Jiang *et al.,* 2001) and plum (Menniti *et al.,* 2004). In the present study, color changes were delayed in treated fruits. However, at the end of storage the treated fruits attained the desirable yellow-orange color similar to that of untreated fruits'. The delayed reduction in flesh color of treated fruits positively correlated with the changes observed in the levels of beta-carotene content. This observation could be attributed to delayed synthesis of carotenoids which lead to the

flesh color change from cream-white to yellow-orange (Marty *et al.,* 2005). 1-MCP treated fruits maintained significantly lower levels of beta-carotene compared to the untreated fruits. The inhibition of ethylene action due to 1-MCP application could have interfered with the carotenoid accumulation during ripening (Mercadante *et al.,* 1998). Differences observed in hue angle and carotenoids changes for Makueni and Embu fruits could be attributed to the variation in production conditions as previously reported in passion fruits (Baraza *et al.,* 2012).

Fruit softening is one of the changes associated with fruit ripening that renders an otherwise inedible fruit palatable. However, softening predisposes the fruits to mechanical injuries thus making postharvest handling difficult. Generally, firmness reduced gradually in all the fruits as the storage time progressed. However, 1-MCP treated fruits from both locations and stages of maturity remained relatively firmer compared to untreated control indicative of slow progression of the softening process. This 1-MCP mediated delay in softening has been similarly reported in mango (Ricardo *et al.,* 2004; Githiga, 2011; Ambuko *et al.,* 2012) and also in other tropical fruits including papaya (Jacomino *et al.,* 2002), red guava (Jacomino *et al.,* 2000) and avocado (Hershkovitz *et al.,* 2005; Woolf *et al.,* 2005). Delayed softening is attributed to reduced activities of the enzymes involved in cell wall metabolism including pectin methylesterase (PME), polygalacturonase (PG), endo-β-1,4-glucanase (EGase) and pectate lyase activities (Lohani *et al.,* 2004). Production location had an effect on the efficacy of 1-MCP as Makueni fruits retained relatively high peel and flesh firmness compared to those from Embu. This could be attributed to variation in production factors which impacted the fruits' physiological status of the fruits as reflected in the differences in respiration and ethylene evolution rate. This may have affected the fruits' response 1-MCP treatment.

Increased weight loss during ripening accelerates deterioration in postharvest fruit quality. According to Rathore *et al*., (2007), increased levels of respiration with fruit ripening contribute significantly to postharvest deterioration. In the present study, 1-MCP treated fruits at both maturity stages retained a relatively higher percentage of their initial weight compared to the untreated fruits. Previous studies have reported mixed findings on the effect of 1-MCP on weight loss in different fruits. In avocado (Jeong *et al.,* 2002) and plum (Valero, 2003), 1-MCP treatment was reported to result reduced weight loss compared to untreated control. On the contrary, Chaiprasart *et al.,* (2009) and Colleli *et al.,* (2003) reported that 1-MCP application did not affect weight loss in mango and tomato respectively. The reduction in the rate of weight loss in treated

fruits could be attributed to reduced metabolic activities resulting from lower respiration rates and ethylene production (Alves *et al.,* 2004). The variation in production factors could have affected the respiratory behavior of fruits from the different locations and response to 1-MCP application.

As the fruits ripened, an increase in TSS content and a decrease in TTA content was reported in all the fruits irrespective of production location, maturity stage and treatment. The increase in TSS levels and decrease in TTA levels was delayed by 1-MCP treatment. The increase in TSS levels could be attributed to the breakdown of stored carbohydrates during respiration into simple sugars (Zhong *et al.,* 2006). On the other hand the decrease in TTA levels is due to reduction in the organic acids or their conversion to respiratory substrates (Alves *et al.,* 2004; Abbasi *et al*., 2009). The observed slow progression of changes in TTA and TSS correlated with respiratory activity. In 1-MCP treated fruits where respiratory activity was significantly reduced, the increase in TSS and reduction in TTA was slower. The delayed change in TSS and TTA levels in 1-MCP treated fruits has been previously reported in nectarine and peach (Liu *et al.,* 2005), plum (Valero *et al.,* 2004) and passion fruit (Yumbya, 2012).

In the present study, ascorbic acid content reduced gradually with fruit ripening. 1-MCP treated fruits from both locations and stages of maturity retained higher ascorbic acid levels than untreated fruits at the end stage. The decrease in ascorbic acid during ripening is attributed to its oxidative degradation during respiration or its transformation to other metabolites like sugars and amino acids (Appiah *et al.,* 2011). Ascorbate oxidase has been proposed to be the major enzyme responsible for enzymatic degradation of ascorbic acid (Lee and Kader, 2000). As with other enzymes associated with fruit ripening, 1-MCP treatment may have resulted in reduced activity of ascorbate oxidase thereby resulting in the observed slow reduction of ascorbic acid. Additionally, reduced respiratory activity may have also contributed to the slow reduction in ascorbic acid as reported by Weston and Barth (1997). The finding of the present study concur with the findings of Vilaplana *et al.,* (2006), Ambuko *et al.,* (2012) and Yumbya (2012) who reported a delay in loss of ascorbic acid in 1-MCP treated pears, mango and passion fruits respectively.

Mango fruit ripening is accompanied by increases in the soluble sugars (fructose, glucose and sucrose). This increase in sugar levels is attributed to the hydrolysis of starch into soluble sugars to provide substrates for the respiring fruits (Nunes, 2008). In the present study, the increase in sugars progressed at a slower rate in 1-MCP treated fruits. The hydrolysis of stored carbohydrates into soluble sugars is mediated by enzymes (mainly amylases) whose activities may

have been slowed down by 1-MCP treatment. The initial level of sugars and the changes thereof in response to 1-MCP treatment was affected by production location. The 1-MCP treatment effects were more pronounced in Makueni fruits compared to Embu fruits. This could be attributed to variation in production factors especially high temperatures and reduced moisture availability during fruit growth and maturation affecting accumulation of sugar content in the fruits (Lechaudel, 2002).

The levels of mineral nutrients magnesium (Mg), calcium (Ca) and potassium (K) in the flesh tissue reduced in all the fruits as they ripened. This could be attributed to increased respiratory activities leading to increased utilization of these minerals in secondary metabolism during ripening (Cutting *et al.,* 1992). 1-MCP treatment had some effect on the changes in these mineral nutrients, although the trend was not consistent. Overall, 1-MCP treated fruits retained relatively higher Mg and Ca levels compared to untreated controls, an effect that was more evident in Makueni fruits. The reduction in Mg levels is attributed to the degradation of chlorophyll content as ripening progressed (Medlicott *et al.,* 1986). Similarly, the reduction in Ca levels can be attributed to its solubilization since it is a component of the cell wall. Consequently, 1-MCP treated fruits which retained higher Ca levels had a relatively longer shelf life compared to untreated control fruits. This 1-MCP effect on mineral nutrients' content has also been reported in avocado (Hofman *et al.,* 1994), mango (Githiga, 2011) and passion fruit (Yumbya, 2012).

4.7 CONCLUSION

1-MCP treatment at a concentration of 1 ppm effectively suppressed ethylene production and respiratory activity, thereby slightly prolonging the shelf life of treated fruits by 2 to 3 days. Fruits harvested from Makueni were more responsive to 1-MCP treatment with relatively longer shelf life compared to Embu fruits. Although 1-MCP treatment was effective in fruits from both stages of maturity, the effect was more pronounced in stage 1 fruits. Despite the relatively longer shelf life, 1-MCP treated fruits retained good nutritional quality attributes. Therefore 1-MCP treatment can be recommended for application in postharvest handling of 'apple' mango fruits to prolong the fruits' shelf life and their marketing period, thereby reducing the postharvest losses.

CHAPTER 5: GENERAL DISCUSSION AND RECOMMENDATIONS

5.1 GENERAL DISCUSSION

The horticulture industry is among the leading foreign exchange earners and a major contributor to food security in Kenya. The sub-sector contributes approximately 36% to the agricultural GDP and grows at a rate of 15-20% per year (HCDA, 2011). The sub-sector is also a source of livelihood to the majority of rural population who produce a wide range of horticultural commodities including fruits, flowers and vegetables. The sub-sector is dominated by small-scale famers who account for 75% of total agricultural production and 70% of marketed agricultural produce which is mostly carried out on small farm holdings averaging 2-3 hectares for both subsistence and commercial purposes. For these small holder horticultural farmers, their food security is pegged on their ability to optimize profits from their enterprises for economic empowerment to access food.

Over the years, more efforts have concentrated on increased productivity through improved crop varieties and good agronomic packages including integrated pest and nutrient management strategies. However, little attention has been given to ensuring that the yields and quality realized at harvest is delivered to the end user. As a result, a high volume of food produced never reaches the end consumer. Based on studies by the Food and Agriculture Organization of the United Nations (FAO), this loss amounts to about 1.3 billion metric tons per year, or roughly, one third of food produced for human consumption (FAO, 2011). While much attention has focused on increasing productivity as the primary solution to feeding nine billion people by 2050, an important part of the solution must also be reducing the inefficiencies that create such huge losses in our food system. These losses not only result in lost profits for the farmers but it also means that huge amounts of the resources (land, labor, fertilizer, water) used in food production are wasted. In highly perishable horticultural commodities such as fruits, these losses are even higher among the small holder farmers who dominate the horticultural sector.

Many studies show that both preharvest and postharvest factors contribute to the postharvest losses incurred along the supply chain. In developing countries like Kenya, most of the postharvest losses occur during the early stages of the supply chain and are mainly due to managerial, financial and technical limitations in production techniques, harvesting techniques, storage facilities, infrastructure and disorganized marketing systems (FAO, 2012). Preharvest

production factors including differences in climatic conditions (rainfall, temperature, light, soils), farmers agronomic practices (fertilization, irrigation, pruning, pest/disease control) and commodity factors (fruit variety/cultivar and maturity stage at harvest) determine fruit quality at harvest and their storability. This means that the choice of crop variety for a given location, crop husbandry practices used to produce the chosen crop, and thereafter the harvesting and postharvest handling practices all contribute towards the quality and quantity that is delivered to the end user. Therefore postharvest loss management is not limited to addressing the causative factors in the postharvest continuum but rather a systems approach that takes cognizance of predisposing factors in the preharvest environment.

The present study sought to establish the effect of production location and harvest maturity stage on the shelf life and the postharvest quality attributes of 'apple' mango fruits based on instrumental (objective) analyses and consumer perception (subjective). Additionally, the response of these fruits to 1-Methylcyclopropene (1-MCP), one of the postharvest technologies used to maintain quality after harvest by countering the deteriorative effects of ethylene as affected by the same preharvest and commodity factors was established. The findings revealed that while mango is produced in most of the AEZs in Kenya because of its wide adaptability, choice of location is a factor that contributes significantly to the quality at harvest, shelf life and the fruits response to postharvest treatments.

In the first study, the effect of preharvest agro-ecological conditions (AEZ) on shelf life and postharvest quality of 'apple' mango fruits harvested at two maturity stages (S1; mature green and S2; advanced maturity) was investigated. The fruits were harvested from two different AEZs of Kenya; Makueni (low potential zone) and Embu (high potential zone). The results show that fruits harvested at S1 had relatively longer shelf life (3 days more) compared to fruits harvested at S2. Similarly, fruits harvested from Makueni had relatively longer shelf life and lower respiration rate compared to Embu fruits. The fruits from Makueni had higher peel/flesh hue angle and firmness with minimal weight loss. The chemical composition of the fruits harvested from the two locations also differed significantly. Makueni fruits had significantly ($p<0.05$) high total soluble solids, ascorbic acid, beta-carotene, soluble sugars and minerals (Mg and Ca) while fruits from Embu had significantly ($p<0.05$) high titratable acidity and K content. The level of titratable acidity, ascorbic acid, Mg and Ca was significantly ($p<0.05$) high in S1 fruits while fruits at S2 contained

significantly high TSS, beta-carotene, sugars and K. The sensory evaluation done on tree-ripe fruits from these two locations positively correlated with the instrumental results on chemical parameters during ripening. Generally, fruits from Makueni scored high for most of the parameters evaluated including sweetness, mouth feel and general acceptability.

The results of this study clearly show how variations in preharvest production factors affect overall fruit quality. Similar findings have previously been reported in banana (Ambuko *et al.*, 2006) and passion fruit (Baraza *et al.,* 2012). The differences in quality not only affect the consumer perception but are of great interest for processors. The differences in quality at harvest can be traced in processed products such as juices, jams and dried products. When fruits of mixed quality are batched together for processing, the consistency of quality attributes such as TSS, TTA and nutritional attributes cannot be assured. Lack of consistency in these processed products is a factor limiting access to export market which requires strict adherence to set standards. The differences in physiological characteristics (such as respiration, ethylene evolution) of the fruits from different locations and of different maturities are of importance in postharvest handling of the fruits. Mixing of the fruits with different physiological characteristics is one of the factors contributing to aggravated deterioration. For example, when fruits which produce high ethylene and have high respiration rates are mixed with those that produce low ethylene in packing or storage areas, deterioration in the latter is aggravated (Kader, 2005). Therefore knowledge of these physiological differences should be used to ensure that the fruits are appropriately sorted and separated during packing and storage.

In the second experiment, the response of 'apple' mango fruits harvested at different maturities from the two locations (Makueni and Embu) to 1-MCP was evaluated. 1-MCP is one of the postharvest technologies widely adopted in some countries to manage ethylene and its deteriorative effects in perishable commodities including fruits, vegetables and flowers. Although it has not been adopted commercially in Kenya, it has potential for application in a wide range of horticultural commodities. Commercialization of 1-MCP application requires extensive studies to establish optimal application conditions and commodity responses. The mode of action of 1-MCP is physiological; by inhibiting ethylene perception in the treated commodities' tissue. It is therefore imperative that the physiological status of the treated commodity would have an effect on its response to the treatment (Watkins, 2006). In the present study, differences in the preharvest production conditions and stage of maturity showed a clear effect on the physiological status of

the fruits as evidenced by differences in ethylene evolution, respiration and other physical parameters such as firmness, color, cumulative weight loss. Consequently, these differences in the physiological status were reflected in the fruits' response to 1-MCP treatment. Although fruits harvested from both locations (Embu and Makueni) and stages of maturity responded positively to 1-MCP treatment, the effect was more pronounced in fruits from Makueni and those harvested at earlier maturity. Similar results on effect of production conditions on response to 1-MCP have been previously reported in passion fruits, where fruits from a dry production location responded more positively to 1-MCP treatment (Baraza *et al.,* 2012). The results also revealed that fruits harvested at earlier maturity were more responsive to 1-MCP treatment compared to those of advanced maturity. Stage of maturity has been reported to significantly affect the efficacy of 1-MCP in fruits such as passion fruit (Yumbya, 2012) and mango (Githiga, 2012; Ricardo *et al.*, 2004). The differences in response as affected by the stage of maturity is attributed to autocatalytic (system II) ethylene production. It is reported that once autocatalytic ethylene is triggered, efficacy of postharvest technologies whose action is based on inhibition of its perception, is greatly hindered (Paul and Kays, 2004). This implies that the timing of harvest maturity where treatments such as 1-MCP can be beneficial is critical. Stage 1 fruits are usually targeted for export market and could benefit greatly from 1-MCP treatments. However, fruits harvested at advanced maturity for the domestic market may not be the best candidates for 1-MCP treatment and therefore alternative technologies to maintain postharvest quality can be explored.

In conclusion, the findings show a significant effect of production location (AEZ) and the harvest maturity on fruits' shelf-life and postharvest quality as evidenced in instrumental analyses and corroborated by sensory evaluation. Production location and maturity stage should therefore be put into consideration in postharvest handling of mango fruits and also in the processing of high quality mango products. Additionally the results show that response to postharvest treatments such as 1-MCP is affected by production location and harvest maturity of the fruits. Therefore in designing postharvest treatment regimes, the production location and maturity stage of the fruits should be considered.

5.2 RECOMMENDATIONS

- Fruits harvested from Makueni had better quality attributes than those from Embu and are recommended for processing of products that require attributes such high TSS and low TTA.

Such fruits and their value-added products can also be marketed as prime products that would fetch a better price for farmers in low potential AEZs.

- Significant differences observed in the shelf life of 'apple' mango fruits as affected by production location and maturity stage highlight the effect of preharvest and commodity factors on the fruits' physiological status, despite their physical similarity. It is therefore recommended that the fruits from different locations and stage of maturity are separated during packing, transporting and storage.
- Due to the observed differences in the quality attributes of fruits from the two locations, it is recommended that the processors should endeavor to process them separately to ensure consistency in processed products.
- 1-MCP treatment at a concentration of 1ppm was effective in inhibiting ethylene action and extending shelf life of mango fruits harvested from Makueni and Embu at both maturity stages. Although fruits harvested at both maturity stages responded positively to 1-MCP treatment, 1-MCP treatment effect was more evident in fruits at mature green stage. 1-MCP treatment can therefore be recommended in fruits harvested at S1. Alternative postharvest technologies such as cold storage and modified atmosphere packaging are recommended for fruits harvested at advanced maturity.
- Although fruits harvested from both locations responded positively to 1-MCP treatment, Makueni fruits were more responsive to 1-MCP treatment. It is recommended that further studies be conducted to establish the response to 1-MCP treatment by the many commercial mango varieties produced across different AEZs in Kenya. This will facilitate guided recommendation for 1-MCP treatment for the different varieties and production locations.
- Overall, the results reveal the potential of 1-MCP application in postharvest storage systems to manage ethylene and extend the shelf life of perishable commodities. However, the method used to generate the 1-MCP gas from SmartFresh^{TM} powder in the laboratory was tedious and therefore its commercialization will require commercially feasible application systems that can be easily adopted by stakeholders handling perishable commodities.

REFERENCES

1. Abbasi, N. A., Zafar I., Maqbool M. and Hafiz I. A. (2009). Postharvest quality of mango (*Mangifera indica* L.) fruit as affected by chitosan coating. *Pakistan Journal of Botany*, 41(1): 343-357
2. Abbott, J. A. (1999). Quality measurement of fruits and vegetables. *Journal of Postharvest Biology and Technology*, 15:207-225.
3. Abu-Goukh, A. A. and Bashir, H. A. (2003). Changes in pectic enzymes and cellulase activity during guava fruit ripening. *Journal of Food Chemistry,* 83: 32-218.
4. Abu-Goukh, A. A, Ibrahim, K.E. and Yusuf, K.S. (1995). A comparative study of banana fruit quality and acceptability under different ripening conditions in Sudan. University of Khartoum *Journal of Agricultural Sciences,* 3(2): 32- 48.
5. Abu-Goukh, A. A. and Abu-Sarra, A. F. (1993). Compositional changes during mango fruit ripening. University of Khartoum *Journal of Agricultural Sciences,* 1(1): 32-51.
6. Abu-Sarra, A. F. and Abu-Goukh, A. A. (1992). Changes in pectinesterase, polygalacturonase and cellulase activity during mango fruit ripening. *Journal of Horticultural Science,* 67(4): 561-568.
7. Alves, R. E., Filgueiras, H. A. C. Pereira, M. E. C. Cocozza, F. M. and Jorge J. T. (2004). Postharvest ripening of 'Tommy Atkins' mangoes on two maturation stages treated with 1-MCP. *Acta Horticulturae,* 645: 627–632.
8. Amarante, C. and Banks N. H (2004). Postharvest physiology and quality of coated fruits and vegetables. *Horticulture review,* 26: 161-234.
9. Ambuko, J., Githiga, R.W., Hutchinson, M.J., Gemma, H. and Owino, W.O. (2012). Effect of maturity stage and variety on the efficacy of 1-MCP treatments in mango fruits. *Acta Horticulturae,* 934: 719-726.
10. Ambuko, J.L., Sekozawa, Y., Sugaya, S., Itoh, F., Nakamura, K. and Gemma, H. (2006). Effect of seasonal variation, cultivar and production system on some postharvest characteristics of the banana. *Acta Horticulturae,* 712: 505-510

11. Appiah, F., Kumah P. and Idun I. (2011).Effect of ripening stage on composition, sensory qualities and acceptability of keitt mango (*Mangifera indica* L.) chips. *African Journal of Food, Agriculture, Nutrition and Development,* 11: 5-10

12. Aremu, C.Y and Udoessien E.I (1990). Chemical estimation of some inorganic elements in selected tropical fruits and vegetables. *Food Chemistry*, 37: 229–234.

13. Asif, M. H., Pathak N., Solomos T., Trivedi P. K. (2009). Effect of low oxygen, temperature and 1- Methylcyclopropene on the expression of genes regulating ethylene biosynthesis and perception during ripening in apple. *South African Journal of Botany,* 75(1): 137-144.

14. Austin, P.T., Hall A. J., Gandar P.W., Warrington I.J., Fulton T.A., Halligan E. A (1999). Compartment model of the effect of early-season temperatures on potential size and growth of 'Delicious' apple fruits. *Annals of Botany*, 83: 129-143.

15. Azzolini, M., Jacomino, A. P., Bron, I.U., Kluge, R. A. and Schiavinato, M. A. (2005). Ripening of 'Pedro Sato' guava: study on its climacteric and non-climacteric nature. *Brazilian Journal of Plant Physiology*, 17: 87-95

16. Baldwin, E. (2005). Edible coatings. In: Environmentally friendly technologies for agricultural produce quality. Ben-Yehoshua, S. Ed. Taylor and Francis Group. Boca Raton, USA. Chapter 10.

17. Baldwin, E. A., J. K. Burns, W. Kazokas, J. K. Brecht, R. D. Hagenmaier, R. J. Bender, and E. (2004). Postharvest ripening of Tommy Atkins mangoes on two maturation stages treated with 1-MCP. *Acta Horticulturae*, 645: 627-632.

18. Baraza, A., Ambuko, J., Kubo, Y. and Owino, W.O. (2012). Effect of 1-MCP in extending postharvest life of purple passion fruit. *Acta Horticulturae*, 1007: 73-80.

19. Baritelle, A. L., Hyde G. M., Fellman J. K., Varith J. (2001). Using 1-MCP to inhibit the influence of ripening on impact properties of pear and apple tissue. *Postharvest Biology and Technology*, 23:153–60.

20. Behboudian, M. H. and Mills, T. M. (1997). 'Deficit irrigation in deciduous orchards '*Horticultural Reviews'* 21: 105–131.

21. Bender, R.J., J.K. Brecht, S.A. Sargent and D.J. Huber (2000a). Mango tolerance to reduced oxygen levels in controlled atmosphere storage. *Journal of America Society Horticulture Science,* 125:707-713.

22. Bender, R.J., J.K. Brecht, S.A. Sargent and D. J. Huber. (2000b). Low temperature controlled atmosphere storage for tree-ripe mangoes (Mangifera indica L.). *Acta Horticulturae*, 509: 447-458.

23. Bender, R. J., J. K. Brecht, and S. A. Sargent. (1995). Inhibition of ethylene production in mango fruit by elevated CO2 and recovery during subsequent air storage. *Horticultural Science*, 108: 279-285.

24. Bender, R. J., J. K. Brecht, and C. A. Campbell (1994). Responses of Kent and Tommy Atkins mangoes to reduced O2 and elevated CO2. *Horticultural Science,* 107: 274- 277.

25. Ben-Yehoshua, S., R. M. Beaudry, S. Fishman, S. Jayanty, and N. Mir. (2005). Modified atmosphere packaging and controlled atmosphere storage. **In**: Environmentally friendly technologies for agricultural produce quality. Ben-Yehoshua, S. Ed. Taylor and Francis Group. Boca Raton, USA. Chapter 4.

26. Blankenship, S. M., and Dole J. M. 1-methylcyclopropene (2003): a review. *Postharvest Biology Technology*, 28:1-25.

27. Burdon, J. N. (1997). Postharvest Handling of Tropical and Subtropical Fruits for Export. **In**: Mitra, S.K. Postharvest Physiology and Storage of Tropical and Subtropical Fruits. CAB International, New York, page 1-19.

28. Bower, J. H., Blasi W. V. and Mitcham E. J. (2003). Effects of ethylene and 1-MCP on the quality and storage life of strawberries. *Postharvest Biology Technology*, 28: 417–423

29. Calvo, G., and Sozzi G. O (2004). Improvement of postharvest storage quality of 'Red Clapp's' pears by treatment with 1-methylcyclopropene at low temperature. *Journal of Horticulture Science and Biotechnology*, 79: 930–934.

30. Campbell, C. W. and S. E. Malo. (1969). The effect of 2-chloroethylphosphonic acid on ripening of mango fruits. *American Society Horticultural Science*, 13: 221-226.

31. Carrillo, L. A., F. Ramirez-Bustamante, J. B. Valdez-Torres, R. Rojas-Villegas and E. M. Yahia (2000). Ripening and quality changes in mango fruit as affected by coating with an edible film. *Journal of Food Quality*, 23: 479-486.

32. Castrillo, M., Kruger N. J, and Whatley F. R (1992). Sucrose metabolism in mango fruit during ripening. *Plant Science,* 84: 45-51.

33. Chaiprasart, P. and Hansawasdi, C. (2009). "Effect of 1-methylcyclopropene on the shelf life of mango (*Mangifera indica* L.) cv. Nahm-dawg-maisri- tong," *Acta Horticulturae*, 820:725-729

34. Chris B. Watkins (2006).Use of 1-MCP on fruits and vegetables. **In**: *Biotechnology Advances*, 24: 389-409

35. Chun, T. W. (2010). An overview of postharvest biology and technology of fruits and vegetables. AARDO workshop on technology on reducing postharvest losses and maintaining quality of fruits and vegetables. page 2-11.

36. Cocozza, F. M., Alves, R. E., Filgueiras, H. A. C., Almeida, A. S., Pereira, M. E. C. and Jorge, J. T. (2004). Respiration rate and chemical characteristics of cold stored 'Tommy Atkins' mangoes influenced by 1-MCP and modified atmosphere packaging. *Acta Horticulturae* ISHS 645: 645-650. **In**: Proceedings of the Seventh International Mango Symposium, Recife, Brazil, 1/2/2004.

37. Cocozza, F. M., J. T. Jorge, R. E. Alves, H. A. C. Filgueiras, D. Santos, and M. E .C. Pereira. (2004). Sensory and physical evaluations of cold stored 'Tommy Atkins' mangoes influenced by 1-MCP and modified atmosphere packaging. *Acta Horticulturae*, 645: 655–661.

38. Colelli, G., Sánchez M. T, and Torralbo F. J (2003). Effects of treatment with 1-methylcyclopropene (1-MCP) on tomato. *Alimentaria*, 342: 67–70.

39. Crisosto, C. H. and Ganer, D. (2001). 1-MCP inhibits Kiwifruit softening during storage. *Perishables handling quarterly*, 108: 19-20.

40. Crisosto, C. H., Mitchell, F. G., and Johnson, S., (1995). Factors in fresh market stone fruit quality. *Postharvest News Information*. 6 (2): 17–21.

41. Crisosto, C. H., (1994). Stone fruit maturity indices: a descriptive review. *Postharvest News Information.* 5 (6): 65–68.

42. Curry, E. (2008). Effects of 1-MCP applied postharvest on epicuticular wax of apples (*Malus Domestica*) during storage. *Journal of Food Science and Agriculture,* 88(6): 996-1006.

43. Cutting, J. M., Wolstenholme, B. N. and Hardy, J. (1992). Increasing relative maturity alters the base mineral composition and phenolic concentration of avocado fruit. *Horticultural Science,* 67: 761–768.

44. Dauny, P. T, and Joyce D. C (2002). 1-MCP improves storability of ‘Queen Cox’ and ‘Bramley’ apple fruit. *Horticultural Science*, 37: 1082–1085.

45. Davenport, T. L. and R. Nunez-Elisea (1997). **In**: Reproductive physiology of mango.

46. Day, B. (1993). Fruits and vegetables. **In**: Parry, R. T. (Ed.). *Principles and Applications of MAP of Foods*. Blackie Academic and Professional. New York, USA.

47. DeEll, J. R., Murr, D. P., Porteous, M.D., and Dupasinghe, H.P. (2002). Influence of temperature and duration of 1-methylcyclopropene (1-MCP) treatment on apple quality. *Postharvest Biology and Technology*, 24: 349– 353

48. Dı´az-Mula, H. M., Zapata, P. J., Guille´, F., Castillo, S., Martinez-Romero, D., Valero, D., and Serrano, M., (2008). Changes in physicochemical and nutritive parameters and bioactive compounds during development and on-tree ripening of eight plum cultivars: a comparative study. *Journal of Food Science and Agriculture*, 88:2499–2507.

49. Diczbalis, Y., Hofman P., Landrigan M., Kulkarni V., and Smith L. (1995). Mango irrigation management for fruit yield, maturity and quality. **In**: Proceedings of Mango 2000 marketing seminar and production workshop. Brisbane, Australia, 85-90.

50. Dong, L., Lurie, S. and Zhou, H., (2002). Effect of 1-methylcyclopropene on ripening of ‘Canino’ apricots and ‘Royal Zee’ plums. *Postharvest Biology and Technology*, 24: 135-145

51. Doreyappy-Gowda, I. N. D and Huddar A. G. (2001). Studies on ripening changes in mango *(Mangifera indica* L.) fruits. *Journal of Food Science and Technology Mysore*, 38: 135-137.

52. E. P.A. Environmental Protection Agency (2002). *Federal Register* 67 (48): 796–800.

53. Engelkes, C. A, Widders, I., and Price, H., (1990). Ontogenetic changes in calcium concentration and content in pickling cucumber fruit as influenced by genotype and environment. *Journal of America Society Horticulture Science* 115: 555–558.

54. Fabi, J. P, Cordenunsi, B. R, de Mattos Barreto, G.P, Mercadante, A. Z, Lajolo, F. M, Oliveira and Nascimento, J. R. (2007). Papaya fruit ripening: response to ethylene and 1-methylcyclopropene (1-MCP). J*ournal of Agriculture and Food Chemistry* 55: 6118-6123.

55. Fan, X., Argenta, L., and Mattheis, J. P (2002). Interactive effects of 1-MCP and temperature on ‘Elberta’ peach quality. *Horticulture Science*, 37: 134–138.

56. Fan, X. T, Mattheis J. P, and Roberts R. G (2000). Biosynthesis of phytoalexin in carrot root requires ethylene action. *Physiology Plant,* 110: 450–454.

57. Fan, X. T., S. M. Blankenship, and J. P. Mattheis. (1999). 1-Methylcyclopropene inhibits apple ripening. *Journal of American Society Horticulture Science,* 124: 690–695.

58. FAO (Food and Agriculture Organization of the United Nations) (2010). Statistical Yearbook - Agricultural Production, available at: http://www.fao. Accessed on 4/7/2012

59. FAO (Food and Agriculture Organization of the United Nations) (2009). Statistical Yearbook - Agricultural Production, available at: http://www.fao. Accessed on 3/6/2012

60. FAOSTAT (2006). FAO Statistics, Food and Agriculture Organization of the United Nations. http://faostat.fao.org/. Accessed on 27/7/2011

61. FAO (Food and Agriculture Organization of the United Nations), (2003). FAOSTAT 2001 database. Rome, Italy: Food and Agriculture Organization of the United Nations. Accessed on 13/7/2011.

62. Feng, X. Q., Apelbaum A., Sisler E. C., Goren .R. (2000). Control of ethylene responses in avocado fruit with 1-methylcyclopropene. *Postharvest Biology and Technology,* 20:143–150.

63. Ferguson, I. B. and Boyd, L.M. (2002). 'Inorganic nutrients and fruit quality', in M. Knee (Ed.) Fruit Quality and its Biological Basis, England: Sheffield Academic Press, 15–45.

64. Ferguson, I., Volz, R. and Woolf, A. (1999). 'Preharvest factors affecting physiological disorders of fruit', *Postharvest Biology and Technology*, 15: 255–262.

65. Feygenberg, O., V. Hershkovitz, R. Ben-Arie, S. Jacob, E. Pesis, and T. Nikitenko (2005). Postharvest use of organic coating for maintaining bio-organic avocado and mango quality. *Acta Horticulturae.* 682: 507-512.

66. Frean, R. T. (1991). Mango diseases, Leaflet Mangoes H. 1, Nelspruit, South Africa.

67. Gal, S., S. Alkalai-Tuvia, Y. Elkind, and E. Fallik. (2006). Influence of different concentrations of 1-methylcyclopropene and times of exposure on the quality of 'Galia'-type melon harvested at different stages of maturity. *Journal Horticulture Science and Biotechnology,* 81:975–982.

68. Garcia, M. A., M. N. Martino, and N. E. Zaritzky (1998a). Plasticized starch-based coatings to improve strawberry quality and stability. *Journal of Agriculture and Food Chemistry*, 46: 3758-3767.

69. Gathambiri, C. W., Muchui, M. N., Njuguna, J. K., Wephukulu, S. B., Kiiru, S. N., Wanjala S. N., and Kariuki, D. N. (2010). Evaluation of postharvest characteristics of mango (*Mangifera indica* L.) fruit varieties. Proceeding of the 10th Biennial Scientific Conference 2006.Volume II. Kenya Agricultural Research Institute. Nairobi, Kenya.

70. Githiga, R. W. (2012). Effect of 1-Methylcyclopropene and Activebag packaging on the postharvest characteristics of mango fruit (*Mangifera Indica* L) cultivar Tommy Atkins. Master of Science Thesis. University of Nairobi, Kenya.

71. Golding J. B, Shearer D, Wyllie S. G, and McGlasson W. B (1998). Application of 1-MCP and propylene to identify ethylene-dependent ripening processes in mature banana fruit. *Postharvest Biology and Technology*,14: 87–98.

72. Gomer-Lim, M. A. (1997). Postharvest physiology. **In**: The Mango: Botany, Production and Uses. (Eds.): R.E. Litz. 425-446, CAB International, New York.

73. Gong, Y., Fan, X., and Mattheis, J. P. (2002). Responses of 'Bing' and 'Rainier' sweet cherries to ethylene and 1-methylcyclopropene. *American Society of Horticultural science,* 127: 831-835.

74. Gossinger, M., F. Mayer, N. Radocha, M. Höfler, A. Boner, E. Groll, E. Nosko, R. Bauer and E. Berghofer. (2008). Consumer's color acceptance of strawberry nectars from puree. *Journal of Sensory Studies*, 24:78-92.

75. Griesbach, J. (2003). Mango Growing in Kenya. International Center for Research in Agroforestry, Nairobi, Kenya.

76. Griesbach, J. (1997). A guide to propagation and cultivation of fruit trees in Kenya. Schriftenreiheder GTZ number 230.Eschborn, Germany. Page 180.

77. Guerra, M., and Casquero, P. A. (2009). Influence of delayed cooling on storability and postharvest quality of European plums. *Journal of Food Science and Agriculture*, 89: 1076–1082.

78. Guillen, F., S. Castillo, P. J. Zapata, D. Martinez- Romero, D. Valero, and M. Serrano. (2006). Efficacy of 1-MCP treatment in tomato fruit. 2. Effect of cultivar and ripening stage at harvest. *Postharvest Biology and Technology,* 42: 235–242.

79. Gutierrez, M. S., Gustaro D., Ana M. and Gabriel O. S. (2008). Different responses of golden berry fruit treated at four maturity stages with the ethylene antagonist 1-MCP. *Postharvest Biology and Technology*, 48: 199-20

80. Harris, D. R, Seberry J. A, Wills R. B .H, and Spohr L .J (2000). Effect of fruit maturity on efficiency of 1-methylcyclopropene to delay the ripening of bananas. *Postharvest Biology Technology*. 20:303-308.

81. Herianus, J. D., L. Z. Singh and S. C. Tan. (2003). Aroma volatiles production during fruit ripening of Kensington Pride mango. *Postharvest Biology and Technology,* 27: 323-336.

82. Hershkovitz, V., Saguy S.I, and Pesis E. (2005). Postharvest application of 1-MCP to improve the quality of various avocado cultivars. *Postharvest Biology and Technology* 37: 252–264.

83. Hewett, E. W. (2006). An overview of preharvest factors influencing postharvest quality of horticultural products. *International Journal of Postharvest Technology and Innovation*, 1:4-15.

84. Hewett, E. W. (1997). 'Fruit quality and tree nutrition', in L.D. Currie and P. Loganathan (Eds.) Proceedings of Workshop Nutritional Requirements of Horticultural Crops, Massey University Fertilizer and Lime Research Centre, Occasional Report Number. 10: 159–171.

85. Hewett, E. W. and Watkins, C. B. (1991). 'Bitter pit control by sprays and vacuum infiltration of calcium in Cox's Orange Pippin apples', *Horticulture Science*, 26: 284–286.

86. Hofman, P. J., Vuthapanich, S., Whiley, A. W., Klieber, A., and Simons, D. H., (2002). Tree yield and fruit minerals concentrations influence 'Hass' avocado fruit quality. *Acta Horticulturae*. 92: 113–123.

87. Hofman, P. J, Jobin-Decor M, Meiburg G. F, Macnish A. J, and Joyce D. C (2001). Ripening and quality responses of avocado, custard apple, mango and papaya fruit to 1-methylcyclopropene. *Australia Journal of Agriculture,* 41:567–572.

88. Hofman, P. J., Smith L. G, Joyce D. C, Johnson G. I and Meiburg .G (1997). Bagging of mango (Mangifera indica cv. 'Keitt') fruit influences fruit quality and mineral composition. *Postharvest Biology and Technology* 12: 83-91.

89. Hofman, P. J., Smith L. G, Holmes .R, Campbell T, Meiburg .G (1995) Mango fruit quality at harvest is affected by production conditions. **In**: Proceedings of Mango 2000 marketing seminar and production workshop. Brisbane, Australia, 199-208.

90. Hollinger, D.Y. (1996). Optimality and nitrogen allocation in a tree canopy. *Tree Physiology*.

16: 627-634.

91. Horticultural Crops Development Authority H.C.D.A (2011). Horticultural Data 2011. Validation Report. HCDA, Nairobi, Kenya. Accessed on 24/3/2012.
92. Horticultural Crops Development Authority H.C.D.A (2010). Export Statistics. Website: http://www.hcda.or.ke/ accessed on 6/8/2012.
93. Horticultural Crops Development Authority H.C.D.A (2009). Export Statistics. Website: http://www.hcda.or.ke/ accessed on 4/9/2011. Accessed on 12/8/2012.
94. Horticultural Crops Development Authority H.C.D.A (2008). Horticultural Data 2005-2007. Validation Report. H.C.D.A, Nairobi, Kenya. Accessed on 4/5/2012.
95. Horticultural Crops Development Authority H.CD.A (2007). Horticultural Data 2005-2007. Validation Report. H.C.D.A, Nairobi, Kenya. Accessed on 26/8/2011.
96. Horticultural Crops Development Authority H.C.D.A (2006). Horticultural Data 2005-2007. Validation Report. HCDA, Nairobi, Kenya. Accessed on 17/3/2011.
97. Horticultural Crops Development Authority H.C.D.A (2005). Horticultural Data 2005-2007. Validation Report. H .C.D.A, Nairobi, Kenya. Accessed on 4/06/2012.
98. Howard, L. R., Smith, R. T., Wagner, A. B., Villalon, B. and Burns, E. E., (1994). Pro-vitamin A and ascorbic acid content of fresh pepper cultivars (*Capsicum annuum*) and processed jalapenos. *Journal of Food Science*, 59: 362–365.
99. Hubbard, N. L., Pharr D. M, Huber S. C (1990). Sucrose metabolism in ripening muskmelon fruit as affected by leaf area. *Journal of American Society Horticulture Science*, 115:798-802.
100. Jacobi, K. K., Macrae, E. A. and Hetherington, S. E. (1998). Early detection of abnormal skin ripening characteristics of 'Kensington' mango (*Mangifera indica* L). *Horticulture Science, 72*: 215–225.
101. Jacobi, K. K., Wong, L. S. and Giles, J. E. (1995). Effect of fruit maturity on quality and physiology of high-humidity hot air-treated 'Kensington' mango (*Mangifera indica* L.) *Postharvest Biology and Technology 5*: 149–159.
102. Jacomino, A.P., Kluge R.A., and Brackmann A. (2002). Ripening and senescence of papaya with 1-methylcyclopropene. *Agricultural Science*, 59: 303–308.

103. Jacomino, A.P., Bassetto E., Pinheiro A.L., and Kluge R.A. (2000). Delay of ripening of 'Pedro Sato' guava with 1-methylcyclopropene. *Postharvest Biology and Technology,* 35 (3): 303-308.

104. Jaetzold, R. and H Schmidt (Eds), (1983). Farm management handbook of Kenya. Volumes A, B, and C. Nairobi, Kenya: Ministry of Agriculture, Nairobi, Kenya/Germany: German Agency for Technical Cooperation (GTZ)

105. Jeong, J. and Huber D. J. (2004). Suppression of avocado (Persea Americana Mill.) fruit softening and changes in cell wall matrix polysaccharides and enzyme activities: differential responses to 1- MCP and delayed ethylene application. *Journal of America Society Horticulture Science,* 129: 752–759.

106. Jha, S. N., Chopra S, and Kingsly A. R. P (2007). Modeling of color values for nondestructive evaluation of maturity of mango. *Journal of Food Engineering* 78:22-26.

107. Jiang, Y.M., Joyce D.C, and Terry L.A (2001). 1-methylcyclopropene treatment affects strawberry fruit decay. *Postharvest Biology and Technology,* 23: 227–32.

108. Jiang, Y. and Joyce, D.C. (2000).Effect of 1-methylcyclopropene alone or in combination with polyethylene bags on the postharvest life of mango fruit. *Annals of Applied Biology,* 137: 321-327.

109. Jongen, W. M. F. (2000). 'Food supply chains: from productivity toward quality', in R.L. Shewfelt and B. Bruckner (Eds.*)* Fruit and Vegetable Quality: An Integrated View, Lancaster, USA: Technomic Publishing Company 3–20.

110. Kader, A. and B. Mitcham. (2008). Optimum Procedures for Ripening Mangoes. **In**: Fruit Ripening and Ethylene Management: 47-48. University of California. Postharvest Technology Research and Information Center Publication Series number 9.

111. Kader, A. A. (2008). Fresh-cut mangos as a value-added product; Postharvest Horticulture Consultant, Kader Consulting Service

112. Kader, A.A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. *Acta Horticulturae,* 682: 2169-2175

113. Kader, A. A. (1995). Regulation of fruit physiology by controlled/ modified atmospheres. *Acta Horticulturae*, 398: 59–70.

114. Kays, S. J. (1999). 'Preharvest factors affecting quality', *Postharvest Biology and Technology,* 15: 233–247.

115. Kays, S. J. (1991). Postharvest physiology of perishable plant products; Vas Nostrand Rein Hold Book, AVI Publishing Company. Page 149-316.

116. Kenya Agricultural Research Institute (KARI), (2009). Agricultural information resources in Kenya: generation, access and management frameworks.

117. Khan, A. S., and Singh, Z. (2009). 1-MCP application suppresses ethylene biosynthesis and retards fruit softening during cold storage of 'Tegan Blue' Japanese plum *Plant Science*, 176: 539-544

118. Kluge, R. A., Bilhalva, A. B., and Cantillano, R. F., (1996). Cold storage of 'Reubennel' plums (*Prunus salicina*.): effects of ripening stages and polyethylene packing. *Agriculture Science,* 53 (2/3): 226–231.

119. Krall, S. M., and McFeeters, R. F., (1998). Pectin hydrolysis: effect of temperature, degree of methylation, pH and calcium on hydrolysis rates. *Journal of Agriculture and Food Chemistry,* 46: 1311–1315.

120. Kumar, R., and Selvaraj Y. (1994). Fructose-1, 6-bisphosphatase in ripening mango fruit. *Indian Journal Biology*, 28:284-286

121. Lalel, H. J. D, Singh Z., and Tan S. C (2003a). The role of ethylene in mango fruit aroma volatile biosynthesis. *Journal of Horticultural Science and Biotechnology,* 78: 485-495.

122. Lalel, H. J. D, Singh Z., and Tan S. C (2003b). The role of ethylene in mango fruit aroma volatiles biosynthesis. *Journal of Horticultural Science Biotechnology,* 78:485-496.

123. Lang, A., and Volz R. K (1998). Spur leaves increase calcium in young apples by promoting xylem inflow and outflow. *Journal of American Society Horticultural Science,* 123:956-960.

124. Lazan, H., Ali L. M, Soh and Talkan Z (1993). The biochemical basis of differential ripening in mango. *Acta Horticulture,* 341: 500-509.

125. Léchaudel, M., and Joas J. (2006). Quality and maturation of mango fruits of cv. Cogshall in relation to harvest date and carbon supply. *Australia Journal of Agriculture and Research,* 57:419-426.

126. Léchaudel, M., Génard M, Lescourret F, Urban L and Jannoyer M. (2005a). Modeling effects of weather and source sink relationships on mango fruit growth. *Tree Physiology*, 25:583-597.

127. Léchaudel, M., Joas J., Caro Y., Génard M., and Jannoyer M. (2005b). Leaf: fruit ratio and

irrigation supply affect seasonal changes in minerals, organic acids and sugars of mango fruit. *Journal of Food Science and Agriculture*, 85:251-260.

128. Léchaudel, M., Génard M, Lescourret F, Urban L, and Jannoyer M. (2002). Leaf-to-fruit ratio affects water and dry matter content of mango fruit. *Journal of Horticulture Science and Biotechnology,* 77:773-777.

129. Lee, S. K. and Kader A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology,* 20: 207-220.

130. Lelièvre, J. M., Latché A., Jones B., Bouzayen M., and Pech J. C. (1997). Ethylene and fruit ripening. *Plant Physiology,* 101:727-739.

131. Liguori, G., Weksler A., Zutahi Y., Lurie S., and Kosto I. (2004). Effect of 1-methylcyclopropene on ripening of melting flesh peaches and nectarines. *Postharvest Biology Technology*, 31: 263–268.

132. Lin, Z., Zhong S. and Grierson, D. (2009). Recent advances in ethylene research. *Journal of Botany,* 60:3311–3336.

133. Litz, R. E. (Ed.) (1997). The Mango; Botany, Production and Uses, 1st edition. CAB International, Wallingford, UK.

134. Liu, H. X., W. B. Jiang, L. G. Zhou, B. G. Wang, and Y. B. Luo. (2005). The effects of 1-methylcyclopropen on peach fruit (*Prunus persica* L. cv. Jiubao) ripening and disease resistance. *International Journal Food Science and Technology*, 40: 1–7.

135. Lizada, C. (1993). Mango, 255–271. **In**: B. Seymour, J.E. Taylor, and G.A. Tucker (Eds.). Biochemistry of fruit ripening. Chapman and Hall, New York.

136. Lohani, S., Trivedi P. K and Nath P. (2004). Changes in activities of cell wall hydrolases during ethylene-induced ripening in banana: effect of 1-MCP, ABA and IAA. *Postharvest Biology and Technology*, 31:119–126.

137. Lu, C. W., Cureatz, V., and Toivonen, P. M. A. (2009). Improved quality retention of packaged 'Anjou' pear slices using a 1-methylcyclopropene (1-MCP) co-release technology. *Postharvest Biology and Technology,* 51: 378-383

138. Mabberly, D. J. (1997). The plant book. Cambridge, UK: Cambridge University Press.

139. Mahayothee, B., W. Muhlhauer, S. Neihart, M. Leitenberger, and R. Carle (2004). Nondestructive determination of maturity of Thai mangoes by near-infrared spectroscopy. *Acta Horticulturae.* 645:581-588.

140. Mamiro, P., L. Fweja, B. Chove, J. Kinabo, V. George and K. Mtebe. (2007). Physical and chemical characteristics of off vine ripened mango (*Mangifera indica* L.) fruit (Dodo). *African Journal of Biotechnology*, 6: 2477-2483.

141. Marsh, K. B., Richardson A. C., Macrae E. A. (1999). Early- and mid-season temperature effects on the growth and composition of satsuma mandarins. *Journal of Horticulture Science and Biotechnology,* 74: 443-451.

142. Martínez-Romero, D., Bailén G., Serrano, M., Guillen F., Valverde, J.M., Zapata P, Castillo S, Valero D. (2007). Tools to maintain postharvest fruit and vegetable quality through the inhibition of ethylene action. *Critical Reviews Food Science and Nutrition*, 45:543–560.

143. Marty, I., Bureau S., Sarkissian G., Gouble B., Audergon J. M., Albagnac G. (2005). Ethylene regulation of carotenoid accumulation and carotenogenic gene expression in color-contrasted apricot varieties (*Prunus armeniaca*). *Journal of Botany*,56:1877–1886.

144. Mattheis, J. P. and Fellman, J. K. (1999). 'Preharvest factors influencing flavor of fresh fruit and vegetables', *Postharvest Biology and Technology*, 15: 227–232.

145. Medlicott, A. P. (1990). Ripening of mangoes following low temperature storage. *Journal of America Society Horticulture Science*, 15: 115-430.

146. Medlicott, A. P. and Thompson, A. K. (1985). Analysis of sugars and organic acids in ripening of mango fruit (*Mangifera indica* L. var. 'Keitt') by high performance liquid chromatography. *Journal of Food Science and Agriculture*, 36: 561-566.

147. Menniti, A. M., Gregori .R, Donati .I (2004). 1-methylcyclopropene retards postharvest softening of plums. *Postharvest Biology Technology,* 31: 269–275.

148. Mercadante, A. Z., Rodriguez-Amaya D. B., Britton G. (1997). HPLC and mass spectrophotometric analysis of carotenoids from mango. *Journal of Agriculture and Food Chemistry*, 45: 120-123.

149. Mills, T. M., Behboudian M. H, Clothier B. E (1997). The diurnal and seasonal water relations, and composition, of 'Braeburn' apple fruit under reduced plant water status. *Plant Science*, 126:145-154.

150. Ministry of Agriculture and Deutsche GesellschaftfürTechnischeZusammenarbeit (GTZ) (2006). Report on the Mango Value Chain Stakeholder Workshop, Nairobi/ Thika, 6-8 March 2006. Promotion of Private Sector Development in Agriculture (PSDA) Project

GTZ, Nairobi, Kenya. Accessed on 27/4/2011.

151. Ministry of Agriculture. (2002). Horticulture annual report 2001. Nairobi, Kenya: Ministry of Agriculture. Accessed on 3/7/2011.

152. Mir, N., Canoles M., Beaudry R., Baldwin E. and Pal Mehla C. (2004). Inhibiting tomato ripening with 1-methylcyclopropene. *Journal of America Society Horticulture Science*, 129:112–120

153. Mir, N. A., Curell, E., Khan, N, Whitaker, M., and Beaudry, R. M. (2001). Harvest maturity, storage temperature, and 1-MCP application frequency alter firmness retention and chlorophyll fluorescence of 'Redchief Delicious' apples. *American Society of Horticultural Science,* 126: 618–24.

154. Mitra, S. K. and Baldwin, E. Z. (1997). Mango. **In**: Postharvest Physiology and Storage of Tropical and Subtropical Fruits (Mitra S.K., Eds), page 85- 122. CAB International, West Bengal, India.

155. Montalvo, E., Garcia .H. S., Tovar .B, and Mata .M. (2007). Application of exogenous ethylene on postharvest ripening of refrigerated 'Ataulfo' mangoes. *Journal Food Science Technology,* 40: 1466-1472

156. Moodley, R. S., Govinden, R., and Odhav, B. (2002). The effect of modified atmospheres and packaging on patulin production in apples. *Journal of Food Protection,* 65(5): 867–871.

157. Mootoo, A. (1991). Effect of post-harvest calcium chloride dips on ripening changes. **In**: Julie Mtebe, K., P. Mamiro and L. Fweja. (2006). Sensory attributes, microbial quality and aroma profiles of off vine ripened mango (*Mangifera indica* L.) fruit. *African Journal of Biotechnology*, 5: 201-205.

158. Mukherjee, S. K. (1953). The mango, its botany, cultivation, uses and future improvement. *Botany.* 7(2): 130-162.

159. Narayana, C. K., R. K. Pal and S.K. Roy. (1996). Effect of pre-storage treatments and temperature regimes on shelf-life and respiratory behavior of ripe Baneshan mango. *Journal Food Science Technology,* 33: 79-82.

160. Nasrija, J. N. H (1993). Effect of storage temperature on pectin depolymerization and softening of mango fruit. BSc thesis, Department of Botany, University Kebangsaan, Bangi, Malaysia.

161. Ninio, E., Lewinsohn, Y. Mizrahi and Sitrit, Y. (2003). Changes in sugars, acids and volatiles

during ripening of Koubo (*Cereus Peruvianus* (L) Miller) fruit. *Journal of Agriculture and Food Chemistry,* 51:425-429.

162. Nunes, M. C., J. K. Brecht, A.M. Morais and S. A. Sargent. (1998). Controlling temperature and water loss to maintain ascorbic acid levels in strawberries during postharvest handling. *Journal of Food Science*, 63(6): 1033-1036

163. Nyambo, B., Varela, A.M. and Seif, A.A. (2006). A modified Farmer Field School on Integrated Pest Management of Mango Production in Smallholder Systems in Kenya. International Centre of Insect Physiology and Ecology, page 1-25.

164. Oosthuyse, S .A. Subhadrabandhu, S. and Pichakum, A. (2000). Effect of cool storage on the extent of ripening during and fruit quality after cool- storage. *Acta Horticulture,* 509: 395-400.

165. Oosthuyse, S.A. (1994). Quality of mature zill mangoes after long-term refrigerated storage as determined by pre-storage ripeness and cold storage regime. *South African Mango Growers Association Yearbook*., 14: 37-42.

166. Oosthuyse, S.A. (1993a). Effect of spray application of KNO_3, urea and growth regulators on the yield of Tommy Atkins mango. *South African Mango Growers' Association Yearbook*, 13: 58-62.

167. Opiyo, A. M. and T. J. Ying. (2005). The effects of 1- Methylcyclopropene treatment on the shelf life and quality of cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*) fruit. *International Journal Food Science and Technology,* 40: 665–673.

168. Pamplona-Roger, G.D. (2003). **In**: Healthy Foods. Editorial Safe Liz. Madrid.

169. Patterson, S.E and Bleecker A.B (2004). Ethylene- dependent and independent processes associated with floral organ abscission in Arabidopsis. *Plant physiology,* 134: 194-203.

170. Paull, R. E., and C. C. Chen (2004). Mango In: Gross K.C., Wang C.Y. and Saltveit M. (Eds), The Commercial Storage of Fruits, Vegetables and Florist and Nursery Stocks. A draft version of the forthcoming revision to USDA, Agriculture Handbook 66 on the website of USDA, Agricultural Research Service. Accessed on 9/1/ 2009.

171. Paull, R.E. (2001). Advances in Postharvest Technology for Tropical and Subtropical Fruits. Proceedings of the International Technical and Trade Seminar on Tropical and Subtropical Fruits. Kuala Lumpur.

172. Perez, K., J. Mercado and H. S. Valdez (2004). Effect of storage temperature on the shelf life of Hass avocado (*Persea americana*). *Food Science Technology International*, 10: 73-77.

173. Pesis, E. (1999). Effect of two coatings with different permeability characteristics on mango (Mangifera indica L.) ripening during storage. *Postharvest Biology and Technology*, 17:215-226.

174. Plotto, A., Bai, J., Baldwin, E.A. and Brecht, J.K. (2003). Effect of pre-treatments of intact 'Kent' and 'Tommy Atkins' mangoes with ethanol vapor, heat or 1-methylcyclopropene on quality and shelf life of fresh-cut slices. *Horticulture Science*, 116: 394-400.

175. Porat, R., B. Weiss, L. Cohen, A. Daus, R. Goren, and S. Droby. (1999). Effects of ethylene and 1-methylcyclopropene on the postharvest qualities of 'Shamouti' oranges. *Postharvest Biology Technology*, 15: 155–163

176. Prasanna, V., Prabha, T. N. and Tharanathan, R. N. (2007). Fruit ripening phenomenon – An overview *Critical reviews in food science and nutrition*. Tailor and Francis group, LLC. 47: 1-19.

177. Pretel, M. T., Souty, M., and Romojaro, F. (2000).Use of passive and active modified atmosphere packaging to prolong the postharvest life of three varieties of apricot (*Prunus armeniaca* L.). *European Food Research and Technology*, 211(3): 191–198.

178. Qin, G. Z., Meng, X. H., Wang, Q., and Tian, S. P. (2009). Oxidative damage of mitochondrial proteins contributes to fruit senescence: a redox proteomics analysis. *Journal of Proteome Research*, 8: 2449-2462.

179. Rathore, H. A., Masud T., Sammi, S. and Soomro, H. A. (2007). Effects of storage on physico-chemical composition and sensory properties of mango (*Mangifera indica* L.) var. Dosehari. *Pakistan Journal of Nutrition*, 6: 143-148.

180. Rato, A. E., Agulheiro, A. C., Barroso, J.M., Riquelme, F., (2008). Soil and rootstock influence on fruit quality of plums (*Prunus domestica* L.). *Horticulture Science.* 118: 218–222.

181. Ricardo, E. A., Heloisa, A. C. and Adriano da Silva, A. (2004). Postharvest ripening of 'Tommy Atkins' mangoes on two maturation stage treated with 1-MCP. *Acta Horticulturae,* 645: 627-632

182. Rodriguez-Amaya, D. B (1999). Changes in carotenoids during processing and storage of foods. *Journal Latino America Nutrition*, 49:38-47.

183. Romero-Rodriguez, M. A, Vazquez-Oderiz M .L, Lopez-Hernandez J. and Simal- Lozano J. (1994). Composition of babaco, feijoa, passion fruit and tamarillo produced in Galicia (north-west Spain) *Food Chemistry,* 49: 23-27.

184. Rupasinghe, H.P., Murr, D.P., Paliyath, G., and Skog, L. (2000). Inhibitory effect of 1-MCP on ripening and superficial scald development in 'McIntosh' and 'Delicious' apples. *Horticultural Science and Biotechnology,* 75: 271–276.

185. Rupinder, S. and Upendra, N. D. (2008). Effect of Ethrel and 1-methylcyclopropene (1-MCP) on antioxidants in mango (Mangifera indica var. Dashehari) during fruit ripening. *Food Chemistry,* 111: 951–956

186. Sabir, K. F. and Agar, T. (2011). Influence of different concentrations of 1-MCP on quality of tomato harvested at different maturity stages. Published online on Wileyonlinelibrary.com

187. Saks, Y., Hofman, P. J. and Meiburg, G. F. (1999). Potential for improvement of mango skin color during storage. *Acta Horticulturae*, 485: 325–329.

188. Salim, A.S., Simons A.J, Orwa C, Chege J, Owuor. B, Mutua A (2002). Agroforestry database **In**: a tree species reference and selection guide. Version 2.0 CD-ROM. Nairobi, Kenya*:* International Centre for Research in Agroforestry

189. Salvador, A., J. Cuquerella, and J.M. Martinez-Javega. (2003). 1-MCP treatment prolongs postharvest life of 'Santa Rosa' plums. *Journal Food Science*, 68: 1504–1510.

190. Sams, C. (1999). Preharvest factors affecting postharvest texture. *Postharvest Biology Technology,*15: 249–254.

191. Saranwong, S., Sornsrivichai, J. and Kawano, S. (2003). Performance of a portable NIR instrument for Brix value determination of intact mango fruit. *Journal of Near Infrared Spectroscopy*, 11**:** 175–181.

192. Saranwong, S., J. Sornsrivichai, and S. Kawano. (2001). **In**: Improvement of PI.S calibration for Brix value and dry matter of mango using information from MLR. *Journal of Near Infrared Spectroscopy* 9: 287-295.

193. Schaffer B, Whiley A.W, Crane J. H (1994). Mango. **In**: Schaffer B, Andersen PC (eds), CRC Handbook of Environmental Physiology of Fruit Crops, Subtropical and Tropical Crops, 165-197. Press, Boca Raton.

194. Selvarajah, S., Bauchot A. D, and John P. (2001). Internal browning in cold-stored pineapples is suppressed by a postharvest application of 1-methylcyclopropene. *Postharvest Biology Technology,* 23:167–170.

195. Selvaraj, J.Y., R. Kumar and D.K. Pal (1989). Changes in sugars, organic acids, amino acids, lipid constituents and aroma characteristics of ripening mango (*Mangifera indica* L.) fruit. *Journal of Food Science and Technology*, 26: 308-313.

196. Serek, M., Sisler, E. C., Reid, M. S., (1995a).Effects of 1-MCP on the vase life and ethylene response of cut flowers. *Plant Growth Regulator*, 16: 93–97.

197. Serek, M., Sisler, E. C., Reid, M. S., (1995b). 1-Methylcyclopropene, a novel gaseous inhibitor of ethylene action, improves the life of fruits, cut flowers and potted plants. *Acta Horticulture*, 394: 337–345.

198. Serek, M., Sisler, E. C., Reid, M. S., (1994). Novel gaseous ethylene binding inhibitor prevents ethylene effects in potted flowering plants. *Journal America Society Horticulture Science*, 119: 1230 – 1233.

199. Shinde, A. K, Dabke, D. J and Jadhar, B. B (2006). Effect of dose and source of potassium on yield and quality of 'alphonso' mango. *Indian Journal of Agricultural Science*, 76: 213-217

200. Silva, F. P., Silva, M. D., da Costa, A. A., Ramos, J. G., (2008). Productive performance of Japanese plum cultivars in Caldas, Minas Gerais State. *Agronomy*, 39 (2): 241-249.

201. Simmons, S. L, Hofman P. J, Whiley A. W, Hetherington S. E (1998a). Effects of leaf: fruit ratios on fruit growth, mineral concentration and quality of mango (*Mangifera indica* L. cv. Kensington Pride*). Journal of Horticulture Science and Biotechnology,* 73: 367-374.

202. Simmons, S. L, Hofman P. J, Whiley A. W, Hetherington S. E (1998b). Effects of preharvest calcium sprays and fertilizers, leaf: fruit ratios, and water stress on mango fruit quality. **In**: Coates LM, Hofman PJ, Johnson GI (eds), International Workshop on Disease Control and

Storage Life Extension in Fruit, 19-26. Australian Centre for International Agricultural Research.

203. Simmons, S. L, Hofman P. J, Hetherington S. E (1995). The effects of water stress on mango fruit quality. In: Proceedings of Mango 2000 marketing seminar and production workshop. Brisbane, Australia, 191-197.

204. Sisler, E. C. and Serek, M. (2003). Compounds interacting with the ethylene receptor in plants. *Plant Biology*, 5: 473- 480

205. Sisler, E. C. and Serek, M. (1997). Inhibitors of ethylene responses in plants at the receptor level. Recent developments. *Physiology of Plants*, 100: 577-582.

206. Sisler, E. C, Blankenship S. M (1996). Methods of counteracting an ethylene response in plants. *Physiology of Plants*, 145: 34-45.

207. Sombroek, W. C., Braun, H.M .H. and Van der Pour, B.J .A. (1982). Explanatory Soil Map and Agro-climatic Location Map of Kenya. Report E1. National Agricultural Laboratories, Soil Survey Unit, Nairobi, Kenya, 56.

208. Spreer, W., Nagle M., Neidhart S., Carle R., Ongprasert S., Müller J. (2007). Effect of regulated deficit irrigation and partial root location drying on the quality of mango fruits (*Mangifera indica* L., cultivar Chok Anan'). *Agriculture Water Management,* 88:173-180.

209. Srinivasa, P. C., R. Baskaran, M. N. Ramesh, K. V. H. Prashanth and R. N. Tharanathan, (2002). Storage studies of mango packed using biodegradable chitosan film. *European Food Research Technology*, 215: 504-508.

210. Stassen, P. J. C, Grove, H. G and Davie, S. J (1999). Tree shaping strategies for higher density mango orchards. *Journal of Applied Horticulture,* 1: 1-4

211. Suntharalingam, S. (1996). Postharvest treatment of mangoes with calcium. *Tropical Science, 36:14-17.*

212. Tharanathan, R. N., Yashoda, H. M. and Prabha. T. N. (2006). Mango *(Mangifera indica* L.), the king of fruits - an overview. *Food Reviews International*, 22: 95-123.

213. Thompson, A. K. (2003). **In**: Fruits and vegetables harvesting, handling and storage by Blackwell publishers limited

214. Tian, M. S, Prakash, S., Elgar, H. J., Young, H., Burmeister, D. M. and Ross, G.S. (2000). Responses of strawberry fruit to 1-methylcyclopropene (1-MCP) and ethylene. *Plant Growth Regulator,* 32: 83–90.

215. Tombesi, A., Antognozzi, E. and Palliotti, A. (1993). Influence of Light Exposure on Characteristics and Storage Life of Kiwifruit. *New Zealand Journal of Crop Horticulture Science*, 21: 87-92.

216. Tridjaja, N. O. and Mahendra, M. S. (2000). Maturity indices and harvesting practice of 'Arumanis' mango related to the target market. **In**: *Quality Assurance in Agricultural Produce*, (G. I. Johnson, and L.V. To, N. D. Duc and M. C. Webb, Eds.) 129–133. Australian Center for International Agricultural Research Proceedings 100, Sydney Australia (accessed on 25/7/2011).

217. Tsuda, T., K .Chachin and Y. Ueda (1999). Studies on keeping capacity of imported carabo mango fruit from the Philippines. *Journal of Japan Society Horticulture Science,* 69: 669-674.

218. Tucker, G. A. (1993). Introduction **In**: Seymour, G. B., Taylor, J. E. and Tucker, G. A. (Eds). Biochemistry of fruit ripening. Chapman and Hall, London, 1-51.

219. Ueda, M., Sasaki, K., Utsunomiya, N., Inaba, K. and Shimabayashi, Y. (2000). Changes in physical and chemical properties during maturation of mango fruit (Mangifera indica L. 'Irwin') cultured in plastic greenhouse. *Food Science and Technology Resources*, 6: 299-305.

220. Urban, L., Léchaudel M (2005). Effect of leaf-to-fruit ratio on leaf nitrogen content and net photosynthesis in girdled branches of *Mangifera indica* L. *Trees Structure and Function* 19:564-571.

221. Urban, L., Léchaudel M., Lu P. (2004). Effect of fruit load and girdling on leaf photosynthesis in (*Mangifera indica* L). *Journal of Botany*, 55:2075-2085.

222. Urban, L., Le Roux X, Sinoquet H, Jaffuel S, Jannoyer M (2003). A biochemical model of photosynthesis for mango leaves: evidence for the effect of fruit on photosynthetic capacity of nearby leaves. *Tree Physiology* 23:289-300.

223. USDA (United States Department of Agriculture) (2010). National Nutrient Database for standard reference, SR-23. Mango Fruit reports 2009 page 449.Accessed on 3/8/2012.

224. Valero, D. and Serrano, M. (2010). **In**: Postharvest biology and technology for preserving fruit quality. C.R.C Press. Taylor and Francis group, Boca Raton, London New York 162-173

225. Valero, D., Crisosto C. H., and Slaughter D. (2006). Relationship between nondestructive firmness measurements and commercially important ripening fruit stages for peaches, nectarines and plums. *Postharvest Biology and Technology*, 44:248-253.

226. Valero, D., Martinez-Romero, D., Valverde, J.M., Guillen, F., and Serrano, M. (2004). Could the 1-MCP treatment effectiveness in plum be affected by packaging? *Postharvest Biology and Technology*, 34: 295–303.

227. Valero, D., D. Martinez-Romero, J. M. Valverde, F. Guillen, and M. Serrano. (2003). Quality improvement and extension of shelf life by 1-methylcyclopropene in plum as affected by ripening stage at harvest. *Innovation Food Science Technology,* 4: 339–348.

228. Vangdal, E., Flatland, S., Nordbo, R., Børve, J. (2007). Different strategies for foliar applications of calcium in plums (*Prunus domestica* L.). *Acta Horticulturae*, 734:371–374.

229. Vangdal, E., Meland, M., Mage, F., Doving, A., (2005). Prediction of fruit quality of plums (*Prunus domestica* L.). *Acta Horticulturae,* 674: 613–617.

230. Vilaplana, R., Y. Soria, M.C. Valentines, and C. Larrigaudiere (2007). Specific response of apple skin and pulp tissues to cold stress and 1-MCP treatment. *Postharvest Biology and Technology,* 43: 215-220

231. Wagner, W. L., D. R. Herbst, and S. H. Sohmer. (1999). **In**: Manual of the Flowering Plants of Hawaii revised Edition. University of Hawaii Press, Honolulu.

232. Wang, B. G, W. B. Jiang, H.X. Liu, L. Lin, and J. H. Wang (2006). Enhancing the post-harvest qualities of mango fruit by vacuum infiltration treatment with 1-methylcyclopropene. *Journal Horticulture Science Biotechnology*, 81: 163–167.

233. Wang, Z., and Stutte, G. (1992). The role of carbohydrates in active osmotic adjustment in apple under water stress. *Journal of America Science Horticulture Science*, 117:816-823.

234. Watada, A. E., Abe, K., and Yamauchi, N. (1990). Physiological activities of partially processed fruits and vegetables. *Food Technology,* 44: 120–122.

235. Watkins, C. B. and Miller, W. B. (2009). **In**: A summary of physiological processes or disorders in fruits, vegetables and ornamental products that is delayed or decreased, increased, or unaffected by application of 1-methylcyclopropene (1-MCP). Accessed on 24/5/ 2011.

236. Watkins, C.B. (2006). Use of 1-MCP on fruits and vegetables. *Biotechnology Advances*, 24: 389-409.

237. Wenkam, N. S. (1979). Nutritional aspects of some tropical plant foods. **In**: Inglett, G. E., Charalambous, G. (Eds.), Tropical Foods: Chemistry and Nutrition, Academic Press, New York, 2: 341–350.

238. Weston, L. A. and Barth, M. M., (1997). Preharvest factors affecting postharvest quality of vegetables. *Horticulture Science,* 32: 812–816.

239. Whiley, A. W. (1994). Mango Tropical Tree Fruits for Australia. Queensland Department of Primary Industries, Brisbane, Australia.

240. White, P. J. (2002). Recent advances in fruit development and ripening: an overview. *Journal of Experimental Botany,* 53: 1995-2000.

241. Wills, R.B.H. and Ku, V.V.V. (2007). Use of 1-MCP to extend the time to ripen of green tomatoes and postharvest life of ripe tomatoes. *Postharvest Biology and Technology,* 26: 85-90.

242. Win, T. O., Heyes, J., Kyu, K. L. and Kanlaynarat, S. (2006). Effects of different concentrations of 1-MCP on the yellowing of West Indian lime (*Citrus aurantifolia*) fruit. *Postharvest Biology and Technology,* 42: 23–30

243. Woolf, A. B. and Laing, W. A. (1996). Avocado fruit skin fluorescence following hot water treatments and pretreatments. *Journal of America Society Horticulture Science,* 121: 147–151.

244. Yahia, E. M. (2006). Modified and controlled atmospheres for tropical fruits. Stewart Postharvest Review, 5: 6- 10.

245. Yumbya, P. M. (2012). Effect of different concentrations of 1-Methylcyclopropene and Active bag packaging on the postharvest shelf life and quality of purple passion fruits. Master of Science, Thesis. University of Nairobi, Kenya.

246. Zhang, Z., Tian, S., Zhu, Z., Xu, Y. and Qin, G. (2012). Effects of 1-methylcyclopropene (1-MCP) on ripening and resistance of jujube (*Zizyphus jujuba* cv. Huping) fruit against postharvest disease. *Food Science and Technology*, 45: 13-19.

247. Zhong, Q. P. and Xia, W. S. (2007). Effect of 1-methylcyclopropene and/or chitosan coating treatments on storage life and quality maintenance of Indian jujube fruit. *Food Science and Technology*, 40: 404-411.

APPENDICES

Appendix 1: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on the rate of respiration of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		295.364	295.364	197.44	<.001
LOCATION	1		92.994	92.994	62.16	<.001
TIME	8	(3)	11380.724	1422.591	950.95	<.001
STAGE.LOCATION	1	21.728	21.728	14.52	<.001	
STAGE.TIME	7	(4)	545.017	77.860	52.05	<.001
LOCATION.TIME	6	(5)	1087.932	181.322	121.21	<.001
STAGE.LOCATION.TIME	4	(7)	491.810	122.953	82.19	<.001
Residual	58	(38)	86.766	1.496		
Total	86	(57)	12970.739			

Appendix 2:Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on the peel hue angle of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		662.339	662.339	590.08	<.001
LOCATION	1		4.854	4.854	4.32	0.045
TIME	5	(3)	12943.473	2588.695	2306.26	<.001
STAGE.LOCATION1		3.392	3.392	3.02	0.091	
STAGE.TIME	4	(4)	541.167	135.292	120.53	<.001
LOCATION.TIME	3	(5)	900.811	300.270	267.51	<.001
STAGE.LOCATION.TIME	2	(6)	210.195	105.097	93.63	<.001
Residual	36	(36)	40.409	1.122		
Total	53	(54)	10842.149			

Appendix 3:Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on the peel firmness of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		3.357	3.357	1.59	0.216
TIME	5	(6)	1509.624	301.925	142.86	<.001
LOCATION	1		745.454	745.454	352.72	<.001
STAGE.TIME	4	(7)	107.723	26.931	12.74	<.001
STAGE.LOCATION	1		0.001	0.001	0.00	0.985
TIME.LOCATION	3	(8)	285.751	95.250	45.07	<.001
STAGE.TIME.LOCATION	2	(9)	25.904	12.952	6.13	0.005
Residual	36	(60)	76.084	2.113		
Total	53	(90)	1866.928			

Appendix 4: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on percentage cumulative weight loss of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		56.234	56.234	36.41	<.001
LOCATION	1		1.105	1.105	0.72	0.399
TIME	8	(3)	1982.324	247.791	160.45	<.001
STAGE.LOCATION	1	15.837	15.837	10.26	0.002	
STAGE.TIME	6	(5)	43.345	7.224	4.68	<.001
LOCATION.TIME	5	(6)	75.863	15.173	9.82	<.001
STAGE.LOCATION.TIME	4	(7)	24.801	6.200	4.01	0.004
Residual	108	(84)	166.788	1.544		
Total	134	(105)	1837.996			

Appendix 5: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on total soluble solids of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		80.8115	80.8115	370.44	<.001
LOCATION	1		59.2364	59.2364	271.54	<.001
TIME	5	(6)	460.2827	92.0565	421.99	<.001
STAGE.LOCATION1		14.4613	14.4613	66.29	<.001	
STAGE.TIME	4	(7)	75.7245	18.9311	86.78	<.001
LOCATION.TIME	3	(8)	13.6927	4.5642	20.92	<.001
STAGE.LOCATION.TIME	2	(9)	4.2091	2.1046	9.65	<.001
Residual	36	(60)	7.8533	0.2181		
Total	53	(90)	467.2504			

Appendix 6: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on total titratable acidity of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		0.0587920	0.0587920	59.14	<.001
LOCATION	1		0.0621956	0.0621956	62.57	<.001
TIME	5	(6)	2.2241556	0.4448311	447.48	<.001
STAGE.LOCATION1		0.0000036	0.0000036	0.00	0.953	
STAGE.TIME	4	(7)	0.1156175	0.0289044	29.08	<.001
LOCATION.TIME	3	(8)	0.1299882	0.0433294	43.59	<.001
STAGE.LOCATION.TIME	2	(9)	0.0520041	0.0260020	26.16	<.001
Residual	36	(60)	0.0357867	0.0009941		
Total	53	(90)	1.8608795			

Appendix 7:Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on ascorbic acid content of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		259.09	259.09	12.84	<.001
LOCATION	1		4904.70	4904.70	243.00	<.001
TIME	5	(6)	20128.12	4025.62	199.44	<.001
STAGE.LOCATION1		4.78	4.78	0.24	0.630	
STAGE.TIME	4	(7)	1393.82	348.45	17.26	<.001
LOCATION.TIME	3	(8)	3454.88	1151.63	57.06	<.001
STAGE.LOCATION.TIME	2	(9)	675.29	337.64	16.73	<.001
Residual	36	(60)	726.63	20.18		
Total	53	(90)	21609.25			

Appendix 8: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on beta-carotene content of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		23.77394	23.77394	1146.46	<.001
LOCATION	1		2.82861	2.82861	136.41	<.001
TIME	5	(6)	327.53320	65.50664	3158.97	<.001
STAGE.LOCATION1		15.22832	15.22832	734.36	<.001	
STAGE.TIME	4	(7)	21.28884	5.32221	256.66	<.001
LOCATION.TIME	3	(8)	13.37909	4.45970	215.06	<.001
STAGE.LOCATION.TIME	2	(9)	4.97299	2.48649	119.91	<.001
Residual	36	(60)	0.74652	0.02074		
Total	53	(90)	290.29860			

Appendix 9: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on fructose content of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		172.9636	172.9636	1288.44	<.001
LOCATION	1		60.9068	60.9068	453.71	<.001
TIME	5	(6)	455.0290	91.0058	677.92	<.001
STAGE.LOCATION1		2.2833	2.2833	17.01	<.001	
STAGE.TIME	4	(7)	23.7689	5.9422	44.26	<.001
LOCATION.TIME	3	(8)	36.6570	12.2190	91.02	<.001
STAGE.LOCATION.TIME	2	(9)	1.9344	0.9672	7.20	0.002
Residual	36	(60)	4.8327	0.1342		
Total	53	(90)	542.5411			

Appendix 10: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on sucrose content of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		128.08685	128.08685	2143.53	<.001
LOCATION	1		84.98718	84.98718	1422.26	<.001
TIME	5	(6)	212.22227	42.44445	710.31	<.001
STAGE.LOCATION 1	1.12163		1.12163	18.77	<.001	
STAGE.TIME	4	(7)	52.55087	13.13772	219.86	<.001
LOCATION.TIME	3	(8)	16.14067	5.38022	90.04	<.001
STAGE.LOCATION.TIME	2	(9)	7.03153	3.51576	58.84	<.001
Residual	36	(60)	2.15118	0.05976		
Total	53	(90)	349.83498			

Appendix 11: Analysis of variance (ANOVA) table for effect of preharvest agro-ecological conditions on calcium content of 'apple' mango harvested at S1 and S2 (2nd season)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
STAGE	1		0.4496	0.4496	2.36	0.133
LOCATION	1		2.0726	2.0726	10.87	0.002
TIME	5	(6)	124.1992	24.8398	130.24	<.001
STAGE.LOCATION	1		4.0690	4.0690	21.33	<.001
STAGE.TIME	4	(7)	9.3080	2.3270	12.20	<.001
LOCATION.TIME	3	(8)	64.1647	21.3882	112.14	<.001
STAGE.LOCATION.TIME	2	(9)	21.4874	10.7437	56.33	<.001
Residual	36	(60)	6.8662	0.1907		
Total	53	(90)	159.3139			

Appendix 12: Analysis of variance (ANOVA) table for effect of 1-MCP application on rate of respiration of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	10		25592.926	2559.293	1588.79	<.001
STAGE	1		3381.366	3381.366	2099.13	<.001
TREATMENT	1		305.601	305.601	189.71	<.001
LOCATION	1		1003.135	1003.135	622.74	<.001
TIME.STAGE	9		4271.350	474.594	294.63	<.001
TIME.TREATMENT	8	(2)	1273.229	159.154	98.80	<.001
STAGE.TREATMENT	1		249.484	249.484	154.88	<.001
STAGE.LOCATION	1		180.321	180.321	111.94	<.001
TREATMENT.LOCATION	1		3.016	3.016	1.87	0.173

TIME.STAGE.TREATMENT	7	(2)	778.812	111.259	69.07	<.001
TIME.STAGE.LOCATION	7	(2)	311.905	44.558	27.66	<.001
TIME.TREATMENT.LOCATION	6	(4)	291.824	48.637	30.19	<.001
STAGE.TREATMENT.LOCATION	1		338.684	338.684	210.25	<.001
TIME.STAGE.TREATMENT.LOCATION	4	(5)	534.426	133.607	82.94	<.001
Residual	134	(34)	215.853	1.611		
Total	200	(51)	39230.288			

Appendix 13: Analysis of variance (ANOVA) table for effect of 1-MCP application on peel hue angle of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	7	(3)	31327.869	4475.410	3519.46	<.001
STAGE	1		757.515	757.515	595.71	<.001
TREATMENT	1		2.982	2.982	2.35	0.129
LOCATION	1		34.901	34.901	27.45	<.001
TIME.STAGE	4	(5)	1862.024	465.506	366.07	<.001
TIME.TREATMENT	5	(5)	1129.613	225.923	177.67	<.001
STAGE.TREATMENT	1		90.290	90.290	71.00	<.001
STAGE.LOCATION	1		66.667	66.667	52.43	<.001
TREATMENT.LOCATION	1		98.971	98.971	77.83	<.001
TIME.STAGE.TREATMENT	4	(5)	427.730	106.933	84.09	<.001
TIME.STAGE.LOCATION	4	(5)	325.352	81.338	63.96	<.001
TIME.TREATMENT.LOCATION	3	(7)	1127.855	375.952	295.65	<.001
STAGE.TREATMENT.LOCATION	1		23.321	23.321	18.34	<.001
TIME.STAGE.TREATMENT.LOCATION	2	(7)	231.822	115.911	91.15	<.001
Residual	84	(84)	106.816	1.272		
Total	125	(126)	27067.102			

Appendix 14: Analysis of variance (ANOVA) table for effect of 1-MCP application on peel firmness of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	3781.048	630.175	276.80	<.001
STAGE	1		76.877	76.877	33.77	<.001
TREATMENT	1		11.656	11.656	5.12	0.026
LOCATION	1		1133.712	1133.712	497.97	<.001
TIME.STAGE	6	(3)	137.630	22.938	10.08	<.001
TIME.TREATMENT	5	(5)	91.867	18.373	8.07	<.001
STAGE.TREATMENT	1		43.296	43.296	19.02	<.001
STAGE.LOCATION	1		1.632	1.632	0.72	0.400
TREATMENT.LOCATION	1		1.406	1.406	0.62	0.434
TIME.STAGE.TREATMENT	4	(5)	54.353	13.588	5.97	<.001

TIME.STAGE.LOCATION	4	(5)	32.868	8.217	3.61	0.009
TIME.TREATMENT.LOCATION	3	(7)	95.794	31.931	14.03	<.001
STAGE.TREATMENT.LOCATION	1		0.074	0.074	0.03	0.857
TIME.STAGE.TREATMENT.LOCATION	2	(7)	15.256	7.628	3.35	0.040
Residual	86	(82)	195.793	2.277		
Total	128	(123)	4555.794			

Appendix 15: Analysis of variance (ANOVA) table for effect of 1-MCP application on total soluble solids of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	1370.8974	228.4829	1089.22	<.001
STAGE	1		19.6154	19.6154	93.51	<.001
TREATMENT	1		6.2335	6.2335	29.72	<.001
LOCATION	1		167.9462	167.9462	800.63	<.001
TIME.STAGE	6	(3)	158.8204	26.4701	126.19	<.001
TIME.TREATMENT	5	(5)	64.9068	12.9814	61.88	<.001
STAGE.TREATMENT	1		13.8882	13.8882	66.21	<.001
STAGE.LOCATION	1		1.4205	1.4205	6.77	0.011
TREATMENT.LOCATION	1		0.6775	0.6775	3.23	0.076
TIME.STAGE.TREATMENT	4	(5)	30.6886	7.6721	36.57	<.001
TIME.STAGE.LOCATION	4	(5)	8.8019	2.2005	10.49	<.001
TIME.TREATMENT.LOCATION	3	(7)	9.6711	3.2237	15.37	<.001
STAGE.TREATMENT.LOCATION	1		12.1752	12.1752	58.04	<.001
TIME.STAGE.TREATMENT.LOCATION	2	(7)	7.4332	3.7166	17.72	<.001
Residual	86	(82)	18.0400	0.2098		
Total	128	(123)	1272.4681			

Appendix 16: Analysis of variance (ANOVA) table for effect of 1-MCP application on total titratable acidity of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	5.0526826	0.8421138	855.54	<.001
STAGE	1		0.2904546	0.2904546	295.08	<.001
TREATMENT	1		0.1481879	0.1481879	150.55	<.001
LOCATION	1		0.0221070	0.0221070	22.46	<.001
TIME.STAGE	6	(3)	0.2102724	0.0350454	35.60	<.001
TIME.TREATMENT	5	(5)	0.2248417	0.0449683	45.69	<.001
STAGE.TREATMENT	1		0.0737094	0.0737094	74.88	<.001
STAGE.LOCATION	1		0.0016847	0.0016847	1.71	0.194
TREATMENT.LOCATION	1		0.0413813	0.0413813	42.04	<.001
TIME.STAGE.TREATMENT	4	(5)	0.0776557	0.0194139	19.72	<.001
TIME.STAGE.LOCATION	4	(5)	0.0887297	0.0221824	22.54	<.001

TIME.TREATMENT.LOCATION	3	(7)	0.0841215	0.0280405	28.49	<.001
STAGE.TREATMENT.LOCATION	1		0.0114487	0.0114487	11.63	<.001
TIME.STAGE.TREATMENT.LOCATION	2	(7)	0.0315198	0.0157599	16.01	<.001
Residual	86	(82)	0.0846507	0.0009843		
Total	128	(123)	4.4981936			

Appendix 17: Analysis of variance (ANOVA) table for effect of 1-MCP application on ascorbic acid content of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	49300.63	8216.77	338.42	<.001
STAGE	1		877.72	877.72	36.15	<.001
TREATMENT	1		532.40	532.40	21.93	<.001
LOCATION	1		7889.30	7889.30	324.93	<.001
TIME.STAGE	6	(3)	4655.35	775.89	31.96	<.001
TIME.TREATMENT	5	(5)	1610.76	322.15	13.27	<.001
STAGE.TREATMENT	1		380.06	380.06	15.65	<.001
STAGE.LOCATION	1		133.87	133.87	5.51	0.021
TREATMENT.LOCATION	1		129.85	129.85	5.35	0.023
TIME.STAGE.TREATMENT	4	(5)	398.58	99.65	4.10	0.004
TIME.STAGE.LOCATION	4	(5)	452.91	113.23	4.66	0.002
TIME.TREATMENT.LOCATION	3	(7)	2265.62	755.21	31.10	<.001
STAGE.TREATMENT.LOCATION	1		249.23	249.23	10.26	0.002
TIME.STAGE.TREATMENT.LOCATION	2	(7)	525.77	262.89	10.83	<.001
Residual	86	(82)	2088.06	24.28		
Total	128	(123)	51688.91			

Appendix 18: Analysis of variance (ANOVA) table for effect of 1-MCP application on beta-carotene content of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	648.23919	108.03987	3734.61	<.001
STAGE	1		15.23286	15.23286	526.55	<.001
TREATMENT	1		4.55672	4.55672	157.51	<.001
LOCATION	1		1.87831	1.87831	64.93	<.001
TIME.STAGE	6	(3)	62.11273	10.35212	357.84	<.001
TIME.TREATMENT	5	(5)	45.33448	9.06690	313.41	<.001
STAGE.TREATMENT	1		0.17732	0.17732	6.13	0.015
STAGE.LOCATION	1		32.36928	32.36928	1118.91	<.001
TREATMENT.LOCATION	1		34.75333	34.75333	1201.32	<.001
TIME.STAGE.TREATMENT	4	(5)	3.23735	0.80934	27.98	<.001
TIME.STAGE.LOCATION	4	(5)	14.30376	3.57594	123.61	<.001
TIME.TREATMENT.LOCATION	3	(7)	17.41104	5.80368	200.62	<.001

STAGE.TREATMENT.LOCATION	1		0.34562	0.34562	11.95	<.001
TIME.STAGE.TREATMENT.LOCATION	2	(7)	2.95872	1.47936	51.14	<.001
Residual	86	(82)	2.48793	0.02893		
Total	128	(123)	685.02406			

Appendix 19: Analysis of variance (ANOVA) table for effect of 1-MCP application on fructose content of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	923.9946	153.9991	1212.82	<.001
STAGE	1		267.1203	267.1203	2103.71	<.001
TREATMENT	1		12.5527	12.5527	98.86	<.001
LOCATION	1		266.8635	266.8635	2101.68	<.001
TIME.STAGE	6	(3)	20.7901	3.4650	27.29	<.001
TIME.TREATMENT	5	(5)	28.6449	5.7290	45.12	<.001
STAGE.TREATMENT	1		2.3385	2.3385	18.42	<.001
STAGE.LOCATION	1		50.4532	50.4532	397.34	<.001
TREATMENT.LOCATION	1		5.0096	5.0096	39.45	<.001
TIME.STAGE.TREATMENT	4	(5)	18.9555	4.7389	37.32	<.001
TIME.STAGE.LOCATION	4	(5)	32.3588	8.0897	63.71	<.001
TIME.TREATMENT.LOCATION	3	(7)	9.3338	3.1113	24.50	<.001
STAGE.TREATMENT.LOCATION	1		7.8164	7.8164	61.56	<.001
TIME.STAGE.TREATMENT.LOCATION	2	(7)	5.6525	2.8262	22.26	<.001
Residual	84	(84)	10.6660	0.1270		
Total	125	(126)	1395.7127			

Appendix 20: Analysis of variance (ANOVA) table for effect of 1-MCP application on sucrose content of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	541.66740	90.27790	1512.39	<.001
STAGE	1		430.83516	430.83516	7217.63	<.001
TREATMENT	1		8.11886	8.11886	136.01	<.001
LOCATION	1		70.09211	70.09211	1174.23	<.001
TIME.STAGE	6	(3)	91.08322	15.18054	254.31	<.001
TIME.TREATMENT	5	(5)	29.83671	5.96734	99.97	<.001
STAGE.TREATMENT	1		26.45411	26.45411	443.18	<.001
STAGE.LOCATION	1		7.91677	7.91677	132.63	<.001
TREATMENT.LOCATION	1		27.54664	27.54664	461.48	<.001
TIME.STAGE.TREATMENT	4	(5)	10.08073	2.52018	42.22	<.001
TIME.STAGE.LOCATION	4	(5)	13.75453	3.43863	57.61	<.001
TIME.TREATMENT.LOCATION	3	(7)	11.56512	3.85504	64.58	<.001
STAGE.TREATMENT.LOCATION	1		0.08845	0.08845	1.48	0.227

TIME.STAGE.TREATMENT.LOCATION	2(7)	1.33049	0.66525	11.14	<.001
Residual	84 (84)	5.01413	0.05969		
Total	125 (126)	976.90693			

Appendix 21: Analysis of variance (ANOVA) table for effect of 1-MCP application on calcium content of fruits harvested at S1 and S2 from Makueni and Embu in season 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
TIME	6	(4)	222.7973	37.1329	175.29	<.001
STAGE	1		24.4154	24.4154	115.26	<.001
TREATMENT	1		3.5067	3.5067	16.55	<.001
LOCATION	1		11.1352	11.1352	52.57	<.001
TIME.STAGE	5	(4)	28.0998	5.6200	26.53	<.001
TIME.TREATMENT	5	(5)	11.4709	2.2942	10.83	<.001
STAGE.TREATMENT	1		47.4699	47.4699	224.09	<.001
STAGE.LOCATION	1		3.2412	3.2412	15.30	<.001
TREATMENT.LOCATION	1		30.9314	30.9314	146.02	<.001
TIME.STAGE.TREATMENT	4	(5)	7.4995	1.8749	8.85	<.001
TIME.STAGE.LOCATION	4	(5)	22.7427	5.6857	26.84	<.001
TIME.TREATMENT.LOCATION	3	(7)	57.8177	19.2726	90.98	<.001
STAGE.TREATMENT.LOCATION	1		1.1792	1.1792	5.57	0.021
TIME.STAGE.TREATMENT.LOCATION	2 (7)		26.6708	13.3354	62.95	<.001
Residual	84	(84)	17.7940	0.2118		
Total	125	(126)	401.9487			