APPLICATION OF ETHEPHON AND POTASSIUM NITRATE TO INDUCE OFF- SEASON FLOWERING AND FRUIT PRODUCTION IN MANGOES

By

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DECLARATION

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

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DEDICATION

This work is dedicated to the Almighty God the giver of life and knowledge, to my parents who out of wisdom and foresight sacrificed their resources to set me off in pursuit of a sound education and to my brothers and sisters for their unwavering support.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZs Agro-Ecological Zones

ANOVA Analysis of Variance

AOAC Association of Official Analytical Chemists

EAC East Africa Community

FAO Food Agricultural Organization

GDP Gross Domestic Product

HCDA Horticultural Crops Development Authority

HPLC High Performance Liquid Chromatograph

JICA Japan International Cooperation Agency

KARI Kenya Agricultural Research Institute

KER Kenya economic report

LSD Least Significance Difference

ml Milliliter

MT Metric Tons

NHP National Horticulture Policy

ppm Parts per million

PCARRD Philippine Council for Agriculture, Forestry and Natural Resources Research and Development

TSS Total soluble solids

TTA Total Titratable Acidity

NaOH Sodium hydroxide

KOH Potassium hydroxide

TCA Trichloroacetic acid

ABSTRACT

Mango (*Mangifera indica* L.) is one of the most important orchard fruit trees in the tropics. In Kenya, mango is the third most important fruit crop cultivated mainly by smallholder farmers for domestic and export markets. Mango production in Kenya is seasonal, with high and low seasons. Oversupply of mango fruits during the high season is one of the factors that contribute to the high postharvest losses (≥50%) reported in the supply chain. Manipulation of mango trees through application of flower inducing chemicals is one strategy that can be used to address mango seasonality and ultimately address the high postharvest losses resulting from oversupply. The objective of the present study was to determine the effect of the off-season flower induction technologies (ethephon and potassium nitrate) on reproductive growth parameters and yield components of 'Apple' and 'Ngowe' mango trees under two different agro-ecological zones (AEZs) of Kenya namely, Embu County (a high potential AEZ) and Makueni County (a low potential AEZ). The study also sought to establish the effect of the off-season flower induction technologies on quality attributes of the mango fruits. Potassium nitrate was applied at two concentrations (2 and 4%), while ethephon was applied at three concentrations (300, 600 and 1000ppm) in the first experiment and at two concentrations (600 and 1000ppm) in the second experiment then compared to control (water). 300ppm ethephon was left out because it showed no much significance differences in most of the parameters tested in the first experiment. The treatments were applied to mango trees which failed to flower/set fruit in the 2013 and 2014 seasons. The test trees comprised of randomly selected 6 – 8 years old 'Apple' and 'Ngowe' trees of uniform in vigor and size. The spraying of the treatments was done on mature flushes one week after the leaves had attained a dark green color. One hundred (100) terminal shoots were marked randomly on each tree prior to spraying. After inflorescence development, 20 panicles per tree were marked randomly on each tree to establish fruit set. The experiments were laid out in a complete randomized design with three replicates and three trees per treatment where the three trees represented a replicate. Each replicate comprised of 18 and 15 trees in the first and second experiment respectively. Effect of the treatments was established from reproductive growth parameters including days to flowering and fruit set, number of panicles per tree and average fruit set per 20 panicles. Other responses of the trees to the treatments such as fruit fall and hormonal effect (internal ethylene in young fruits) were also evaluated. Tree ripe fruits (50 fruits) were sampled from treated and untreated trees, and the effect of the treatments on various fruit quality attributes: major sugars, vitamin C, beta carotene, total soluble solids,

and total titratable acidity determined. The results from the effect of the treatments on reproductive growth parameters, yield and yield components of mango trees showed that Potassium nitrate (4%) increased percentage flowering (% of tagged shoots) in both 'Ngowe' and 'Apple' in both AEZs. Response to ethephon increased with concentration with the 1000ppm giving the best response. Time to flowering was significantly shortened by both KNO_3 and ethephon treatments with 'Ngowe' being more responsive than 'Apple'. Significant treatment effect ($p \leq 0.05$) was observed on fruit set with 4% KNO_3 and 1000ppm ethephon resulting in the highest fruit set in both AEZs and varieties. Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on total number of fruits per tree. There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Although KNO_3 and ethephon affected some of quality attributes evaluated, most of the observed differences were not consistent. The differences could partly be attributed to the inherent varietal differences in 'Apple' and 'Ngowe' and the differences in agro-ecological conditions in Embu and Makueni. However, significant treatment effect was observed in some of the quality parameters. In beta-carotene, significant ($p \leq 0.05$) treatment effect was observed in trees treated with 2% KNO_3, 600 ppm and 1,000 ppm ethephon where beta-carotene levels averaged 1.5, 1.6 and 1.7 mg/100 ml respectively compared to 1.4 mg/100ml in the untreated control. Regardless of variety or location, slightly higher vitamin C levels (average 93 mg/100 ml) were reported in KNO_3 treated trees compared to those treated with ethephon (86.8 to 90.2 mg/100 ml. The trend in total soluble solids and sugars was inconsistent with the AEZ and variety showing the greatest effect. The findings show that potassium nitrate and ethephon can be used to induce flowering and fruiting in mango fruits without negatively affecting the fruits' quality attributes. These technologies can therefore be applied to induce off-season fruit production in 'Apple' and 'Ngowe' fruit as a strategy to address seasonality and reduce postharvest losses currently reported during the peak season due to oversupply.

Key words: Seasonality, Ngowe, Apple mango, Postharvest losses, Fruit quality

CHAPTER ONE

INTRODUCTION

1.1 Background information

Kenya's economy is dependent on agriculture, which contributes to rural employment, food production, foreign exchange earnings and rural incomes (KER, 2013). The agricultural sector directly accounts for about 26 percent of Kenya's Gross Domestic Product (GDP) and 27 percent indirectly through linkages with manufacturing, distribution and other service related sectors. The sector accounts for 65 per cent of Kenya's total exports, 18 percent and 60 percent of the formal and total employment, respectively. The agriculture sector still remains a key driver of economic growth in Kenya for the last four decades and is the main source of livelihood for almost 80 percent of Kenya's population living in rural areas (FAO, 2013).

Horticultural industry in Kenya is among the leading foreign exchange earners, contributes to food security and is a source of livelihood to the majority of rural people who practice its one form or another (HCDA, 2009). This sub-sector is the fastest growing industry within the agricultural sector, recording an average growth of 15% to 20% per annum and contributes 36 percent of agriculture's share of GDP. The industry continues to contribute to the Kenyan economy through generation of income, creation of employment opportunities for rural people and foreign exchange earnings, in addition to providing raw materials to the agro processing industry. The sub sector employs approximately 4.5 million people countrywide directly in production, processing, and marketing, while another 3.5 million people benefit indirectly through trade and other activities (NHP, 2012).

The total domestic value in the horticulture sector in 2013 amounted to Ksh177 billion occupying an area of 605,000 Ha with a total production quantity of 132 million MT. As compared to 2012, the total value and area increased by 17% and19% respectively while productivity had a variation of only 2%. The value of horticultural exports as of 2013 was Kshs. 94.7 Billion with flowers constituting 48.7% of the total value. The overall exports in terms of value and quantity increased by 7% and 20% respectively as compared to 2012 (HCDA, 2013).

In 2013, fruit contributed Kshs. 48 billion accounting for 32% of the domestic value of horticultural produce. The area under fruit was 160,000 Ha with a production of 2.3 million MT. The area and value of fruits increased by 7% and 17% respectively compared to the previous year. The increase in area and quantity was positive for most fruits due to rehabilitation of

irrigation schemes which has extended irrigation to fruit crops. The major fruit grown in order of importance are; Banana (37.6%), Mangoes (19.6%), pineapples (12.1%), Avocado (9.8%), pawpaw (5.4%), oranges (4.6%), water melon (4.2%) and Passion fruit (3.7%), (HCDA, 2013).

Besides the export market, a significant proportion of all fresh fruit and vegetable produce is consumed locally. The domestic market accounts for over 90% of the total growth in Kenya's horticultural production (JICA, 2013). 70% of all rural households sell fresh produce of mangoes. The gross value of smallholders' sales of horticultural crops is almost as large as that of maize. Most fresh produce enter the national market from relatively few farmers.

Mango production has been on the increase due to increased demand of fruits for fresh market and for processing. Acreage increased by 7.3% from 43,776 ha in 2012 to 46,968 ha in 2013. Production and value showed an upward trend of 11.69% and 20.7% increase from 2012 to 2013 respectively. In 2013, Kenya produced approximately 581,290 metric tons of mangoes. This amount accounts for half the total production in the East African Community (EAC) making Kenya a regional market leader (HCDA, 2013). Mangoes earned Kenya $70 million in 2010 in the domestic market, up 25% per year from $23 million in 2005 and $10.1 million in exports earnings, 25% higher than in 2009. In the domestic market, consumption of mangoes grew at an annualized rate of 24% between 2006 and 2009. Mangoes are becoming an increasingly important fruit in the Kenyan diet. The average person consumes an estimated 12.7 kilograms per year. Moreover, the rapid urbanization of Kenya's growing middle class, which has been growing at 4% per year since the 1980s, has increased household demand for mangoes. Assuming the annualized growth rate of 24% remains constant, local consumption demand could potentially rise to 2.9 million metric tons by 2016.

Although horticultural crops have been relatively successful for smallholder farmers, the sector is still faced with challenges (JICA, 2013). There are challenges at various stages of the supply chain. The key constraints faced by farmers in mango production at the farm-level are the lack of clean planting material, inadequate technology such as limited access to improved ways of managing pests and diseases, the length of the production cycle and inadequate post-harvest handling facilities. There is a generalized shortage of grafted seedlings and as a result, farmers opt for inferior, low yielding seedlings which translate to low productivity (FAO, 2003). Most farmers do not have knowledge on improved production technology and there is little or no use of fertilizers and pesticides. Insect pests particularly fruit fly and mango seed weevil coupled

with diseases like anthracnose and powdery mildew are the major challenges to increased production of quality mangoes (HCDA, 2012). Low productivity is also attributed to poor crop management practices that result into low yields and poor quality of mango fruits. High postharvest loss is also a major challenge facing smallholder mango farmers. The losses are mainly attributed to poor postharvest handling practices and lack of appropriate postharvest technologies.

Mango is a tropical perennial fruit crop that can flower and fruit all year round. However in Kenya, mango fruiting is seasonal. In most mango producing regions of Kenya, the trees give fruits only once in a year. However, in some regions (mainly at the Coast), the trees give fruits twice a year with the main season being September to January and a lighter crop in June. In the regions where the trees fruit once a year, some mango farmers have diversified to other crops, including passion fruits, melons and seedling production, to smooth their income pattern throughout the year (JICA, 2013).

As a result of seasonality, during the high season, there is often an oversupply which leads to low prices and high postharvest losses. Most of the resource-poor farmers lack appropriate post-harvest handling techniques, leading to significant losses, which affect returns to the farmer and traders. Furthermore, these farmers do not have good storage facilities available at the farm level, and this forces them to sell their mango fruits immediately after harvest. No collective bargaining takes place on the price and each farmer interacts individually with the trader and other buyers, often receiving prices well below reigning market prices.

1.2 Problem statement

The fruiting season of the improved commercial mango varieties such as ‘Apple’ and ‘Ngowe’ starts in November and ends in March with a peak in December and January. During the peak season, prices for mango fruits at farm gate are very low because of the glut in the market. Mango is a highly perishable fruit with a shelf life of 7 to 10 days depending on the stage of maturity at harvest. Therefore, once the fruits attain maturity or ripen, they have to be harvested or left to spoil on the tree. The majority of the farmers lack cold storage facilities or postharvest technologies to extend the shelf life and the marketing period of the highly perishable fruits and therefore they are forced to sell at the prevailing prices making huge losses (HCDA, 2011).

Apart from lost profits for the farmers, seasonality in mango production is a problem for the fruit processing industries. These industries receive fewer mango fruits therefore operate below capacity during the low season (April to December). This not only denies the proprietors of these

factories continuous income, but also creates seasonal unemployment for the workers. On the other hand, consumers are denied the benefit of continuous supply of mango at reasonable prices because during the low season, the prices of mango fruits are high.

In some countries such as India and Philippines, flower induction technologies have been used to induce off-season flowering in mango trees thereby leading to year-round fruit production. For example 'Carabao' mango is a highly seasonal fruit, producing mostly in April and May in Philippines. However, with the use of potassium nitrate (KNO_3) as flower inducer, the mango variety has been able to flower and produce fruits throughout the year (PCARRD, 2005). Ethephon has been successful in India for increasing flowering of 'Langra and 'Deshehari' mango varieties during 'off' years (Chacko et al., 1972, 1974; Chanda and Pal, 1986) and for inducing earlier production in juvenile plants (Chacko et al., 1974). In a 10-year-old 'Haden' mango variety, 500-1,000ppm ethephon applied one month before the normal flowering date increased flowering by 40 - 55 % (Nunez-Elisea et al., 1980). Some of the chemicals such as potassium nitrate, ethephon and paclobutrazol have been tested in Kenya in the mango producing regions but have shown contradicting results. Efficacy of these chemicals is dependent on several factors including mango variety, dosing, time of application and stage of development among others (Galan and Fernandez, 1987). In some cases, poor timing or wrong dosage in the use of flower inducers has achieved the opposite effect, often inhibiting flowering or reducing the flowering percentage in the subsequent season.

1.3. Justification

Seasonality in mango production is a major factor contributing to the high postharvest losses ($\geq$ 50%) reported in the mango value chain. Effective strategies to address seasonality can contribute significantly to postharvest loss reduction. Although the flower induction technologies have been used in Kenya before, varied results have been reported due to many factors including differences in varieties, agro-ecological zones, dosing range and time of application.

For these chemicals to be successfully promoted among the small holder farmers for the desired benefits of off-season flower induction and to ensure year-round production there is need for studies to establish the effective dosing range in the major commercial varieties of mango. There is also the need to establish AEZ(s) wherein flower inducers can be successfully used. Potassium nitrate and ethephon (and other forms of ethylene) have been used in some fruits to induce off-

season flowering and promote uniform flowering. However, their effect on fruit quality attributes is seldomly reported.

1.4 Objectives

The overall objective of this study was to evaluate the efficacy of flower induction technologies to induce off-season flowering in mango fruits as a strategy to reduce the high postharvest losses resulting due to seasonality in mango production.

Specific objectives

1. To determine the effect of the off-season flower induction technologies (ethephon and potassium nitrate) on reproductive growth parameters and yield components of ‘Apple’ and ‘Ngowe’ mango trees under two different agro-ecological zones
2. To establish the effect of the off-season flower induction technologies (ethephon and potassium nitrate) on quality attributes of ‘Apple’ and ‘Ngowe’ mango fruits.

1.5 Hypotheses

1. Off-season flower induction technologies (ethephon and potassium nitrate) have no effect on reproductive growth parameters and yield components of ‘Apple’ and ‘Ngowe’ mango trees.

2. Off-season flower induction technologies (ethephon and potassium nitrate) have no effect on quality attributes of ‘Apple’ and ‘Ngowe’ mango fruits.

CHAPTER TWO: LITERATURE REVIEW

2.1 Description of mango

2.1.1 The tree

The mango tree is a deep-rooted, evergreen plant which can develop into a huge tree, especially on deep soils. The height and shape varies considerably among seedlings and cultivars. Under optimum climatic conditions, the trees are erect and fast growing and the canopy can either be broad and rounded or more upright (Salim et al., 2002). Seedling trees can reach more than 20 m in height while grafted ones are usually half that size. The tree is long-lived with some specimens known to be over 150 years old and still producing fruit. The mature leaves are simple, entire, leathery, dark green and glossy; they are usually pale green or red while young. They are short-pointed, oblong and lanceolate in shape and relatively long and narrow, often measuring more than 30 cm in length and up to 13 cm in width (Salim et al., 2002). New leaves are formed in periodic flushes about two to three times a year.

2.1.2 Flowers

Mango flowers are borne on terminal pyramidal panicles and are pubescent. The greenish-white or pinkish flowers are usually placed terminally on current or previous year's growth in large panicles of up to 2000 or more minute flowers. Male flowers usually outnumber the bisexual or perfect flowers. The inflorescence is rigid and erect up to 30 cm long and is widely branched. The flowers are either monoecious or polygamous both of which are borne within a single inflorescence. The ratio of monoecious to polygamous flowers is strongly influenced by environmental and cultural factors (Litz, 2009).

2.1.3 Fruit

Mango fruits of various cultivars differ greatly in shape, size, appearance and internal characteristics. The fruit is a fleshy drupe, varying in size from 2.5 to 30 cm long, and weigh from approximately 200 g to over 2000 g. Fruit shape varies including elongate, oblong and ovate or intermediate forms involving two of these shapes (Yahia *et al*., 2006 and Ornelas-Paz *et al*., 2008).The leathery skin is waxy and smooth and when ripe entirely pale green or yellow marked with red, depending on the cultivar (Salim et al., 2002).

The mango fruit is climacteric and increased ethylene production occurs during ripening. The mesocarp is resinous and highly variable with respect to shape, size, colour, presence of fibre and flavour. The flavour ranges from turpentine to sweet. The exocarp is thick and glandular. There is a characteristic beak that develops laterally on the proximal end of the fruit.

The fruit quality is based on the scarcity of fibre, sweetness and minimal turpentine taste. The flesh of the improved cultivars is peach-like and juicy, of a melting texture and more or less free from fibre. The single, compressed ovoid seed is encased in the white fibrous inner layer of the fruit. The seed is enclosed in a stony endocarp, varying in size/shape with two fleshy cotyledons. Each seed contains either one embryo (the so-called mono-embryonic cultivars) or more than one embryo (the so-called polyembryonic cultivars), producing several seedlings without fertilization. Most of the seedlings will be nucellar seedlings which have originated vegetatively, they are mostly true-to-type and genetically identical with the mother tree. Most Indian cultivars are mono-embryonic, while generally cultivars from Indonesia, Thailand and the Philippines are polyembryonic (Salim et al., 2002).

2.1.4 Mango varieties

2.1.4.1 Apple

This cultivar originated from the Kenya coastline, most probably around the Malindi area. It is a chance seedling and its parentage is unknown. The fruits are medium to large, nearly round in shape and have a rich yellow/orange to red colour when ripe. Average length measures 9.7 cm by 11 cm in width, and the weight is 280-580 g (mean: 397 g). Normally, if not diseased, the skin is smooth and thin, and the juicy yellow flesh is of excellent flavour and of melting texture virtually free from fibre. This is not a polyembryonic cultivar and trees propagated by seed are very heterogeneous in fruit shape, colour and quality (Griesbach, 2003).

The trees are large/vigorous and of pyriform growth habit. Depending on location, harvesting seasons are from December to the beginning of March. Apple mangoes have a number of advantages. For instance, they have got excellent fruit quality and possess small/medium seed size. Additionally, they are free from fibers. However, the apple mango trees have some disadvantages such as their susceptibility to anthracnose and powdery mildew. Also, they have alternate bearing and their range of altitude adaptation is limited (ICRAF, 2003).

2.1.4.2 Ngowe

The original Ngowe tree is believed to have been brought from Zanzibar and planted in Lamu approximately 106 years ago. This typical coastal cultivar, also known as ‘Lamu mango’, can now be found all along the coastline and has also adapted well to medium altitude locations (ICRAF, 2003). Ngowe is the most easily recognized of the local mango fruits. It is large, oblong and slender with a very prominent hook-like beak at the apex. From pale green, the fruit

develops to a most attractive yellow to orange colour when ripe. The deep yellow flesh is of excellent quality, virtually free from fibre, melting, and carries no turpentine taste. The average fruit length measures 14 cm with a width of 9.5 cm, and a weight range of 425-600 g (mean: 523 g). The seeds are polyembryonic which means progeny develops more or less true-to-type (Griesbach, 2003).

The trees are comparatively small and round in shape. Depending on location, harvesting may start in November and continue until March. Yields are medium and alternate bearing may occur. Ngowe mangoes portray some desirable characteristics such as; their good to excellent fruit quality, moderate tree size, good shipper and also seed propagation is possible (polyembryonic). However, just like the apple mangoes, ngowe mangoes depict susceptibility to powdery mildew and tendency of alternate bearing (Griesbach, 2003).

2.1.4.3 Tommy Atkins

This cultivar originated from a seed planted in the 1920s at Fort Lauderdale in Florida. It was released in 1948. Tommy Atkins has become an important commercial variety. The fruits are medium to large, oval to oblong, orange/yellow with a heavy red blush, numerous white lenticels and a broadly rounded base. They measure an average length of 12.6 cm, are 9.9 cm wide and have an average weight of 522 g. The smooth skin is tough and thick. The flesh is firm and medium juicy with a moderate amount of fibre, yellow to deep yellow in colour, mild and sweet with a strong pleasant aroma. The eating quality is fairly good; the seed is mono-embryonic and covered in a thick, woody stone (6.6% of total fruit weight). The tree is large with a rounded canopy and it produces consistently heavy and good crops. It is an early to mid-season cultivar and is highly resistant to diseases (Griesbach, 2003).

2.1.4.4 Kent

This open pollinated seedling of the cultivar Brooks originated in Miami, Florida, and was released in 1944. Kent is often mistaken for the quite similar looking cultivar Keitt although Kent matures earlier; often in March. The large fruit is greenish-yellow with a red or crimson blush on the shoulder. The average length measures 12.4 cm with a width of 9.7 cm and an average weight of 545 g. The fruit-shape is regular ovate with a rounded base and often with two slight beaks. The skin is thick and tough and small yellow lenticels are numerous; the flesh is juicy, melting, deep yellow, and fibreless and of a rich flavour (Griesbach, 2003). The seed,

embedded in a thick, woody stone (8.5% of fruit weight) is mono-embryonic. The tree is large and vigorous, with a dense upright canopy, and it produces good yields in the late mid-season.

2.1.4.5 Van Dyke

This cultivar originated from Homestead (Florida) and belongs to a selected group of seedlings distinguished by a greater resistance to anthracnose, very attractive colour, and good shelf life and shipping qualities. These seedlings appeared in the 1950s and 1960s. The ovate, small- to medium-sized fruit (average weight 280 g) is very attractive showing a bright yellow ground colour with a heavy crimson blush and prominent beak. The average fruit dimensions are: 10.5 cm length by 7.9 cm width. The skin is thick, though easily separating and covered with numerous white/yellow lenticels. The flesh is quite firm, melting and juicy with little fibre, orange-yellow, rich, spicy and sweet with a strong pleasant aroma. It is of good to excellent quality. The seed is mono-embryonic and covered by a medium-sized woody stone (7.1% of fruit weight). The trees are medium-sized with a large open canopy and are regular producers but yield only moderately (Griesbach, 2003).

2.1.5 Economic importance and nutritive value of mangoes

The word fruit is derived from the Latin word *fructus* which means enjoyment. Of all fruits enjoyed throughout the world, few are as popular or universally acceptable as the mango. It is claimed to be the most important fruit of the tropics because of its attractive appearance and the very pleasant taste of selected cultivars. In fact it has been identified as the only tropical fruit which outranks the banana. With nearly US$ 500 million worth of mangoes exported each year and 40 times that amount consumed in the countries of production, its role in income generation and household food security is evident (ICRAF, 2003).

The mango fruit is one of the most delicious fruits, although it has undesirable features including coarse fibrous strands through the flesh and the pungent and turpentine flavors of some cultivars. There is a great diversity of mango fruit types which permits considerable manipulation for various purposes and markets: juice, chutney, pickles, jam or jelly, fresh fruit, canned and or dried fruit among others. Given the multiple products, it is therefore a potential source of foreign exchange for a developing country; it is also a source of employment for a considerable seasonal labor force (ICRAF, 2003).

The mango compares favorably in food value with both temperate and tropical fruits. Indeed the fruit contains almost all the known vitamins and many essential minerals. Studies have shown that one mango fruit can provide a large proportion of the daily human requirements of essential minerals, and vitamins. The calorific value of mango is mostly derived from the sugars (ICRAF, 2003). It is as high as that of grapes and even higher than that of apple, pears or peaches. The protein content is generally a little higher than that of other fruits except the avocado. Mangoes are also a fairly good source of thiamine and niacin and contain some calcium and iron.

Table 2. 1: Calories and nutrients per 100g edible portion of common fruits

Fruit	Calories (g)	Protein (mg)	Calcium (mg)	Iron (mg)	Vitamin A (IU)	Thiamin (mg)	Vitamin C (mg)
Orange	53	0.8	22	0.5	_	0.05	40
Banana	116	1	7	0.5	100	0.05	10
Mango	63	0.5	10	0.5	600	0.03	30

Source: Piatt (1962).

Table 2. 2: Minimum daily vitamin and mineral requirements for healthy people:

Niacin (mg)	Calcium (mg)	Iron (mg)	Vitamin A (IU)	Thiamin (mg)	Vitamin C (mg)
19	1000	18	2500	1.5	60

Source: Mervyn (2000).

2.2 Mango production

2.2.1 Global Production statistics

Mango is grown in more than 111 countries but it is greatly valued in India where 40% of total fruits grown are mangoes. In India, mango enjoys supreme percentage in fruit production and has nearly 1000 varieties grown in an area of 1.60 million hectare, which accounts for 58% of total area under fruit crops (Anon., 2008). In the year 2006 to 2007, India exported 79,060.88 MT of mangoes (APEDA, 2007). India is the largest producer of mango in the world with the production of approximately 14 million tones, contributing more than 57% share of the world production (FAO, 2009).

Asia accounts for approximately 77% of global mango production. Americas and Africa account for approximately 13% and 9% respectively (FAOSTAT, 2007). Between 1996 and 2005, production grew at an average annual rate of 2.6%. In 2005, world production of mango was estimated to have reached 28.51 million tonnes, an increase from the 27.82 million tonnes recorded in the previous year. From 2003 to 2005, India was ranked the largest producer, accounting for 38.58% of global production. During that period in, the Indian mango crop averaged 10.79 million tonnes, followed by China and Thailand at 3.61 million t (6.2%). Other leading mango-producing countries and their respective shares of world production during the 2003-2005 periods include Mexico (5.50%), Indonesia (5.29%), Pakistan (4.48%), Brazil (4.30%), Thailand (3.61%), the Philippines (3.53%), Nigeria (2.61%) and Egypt (1.28%), (FAOSTAT, 2007).

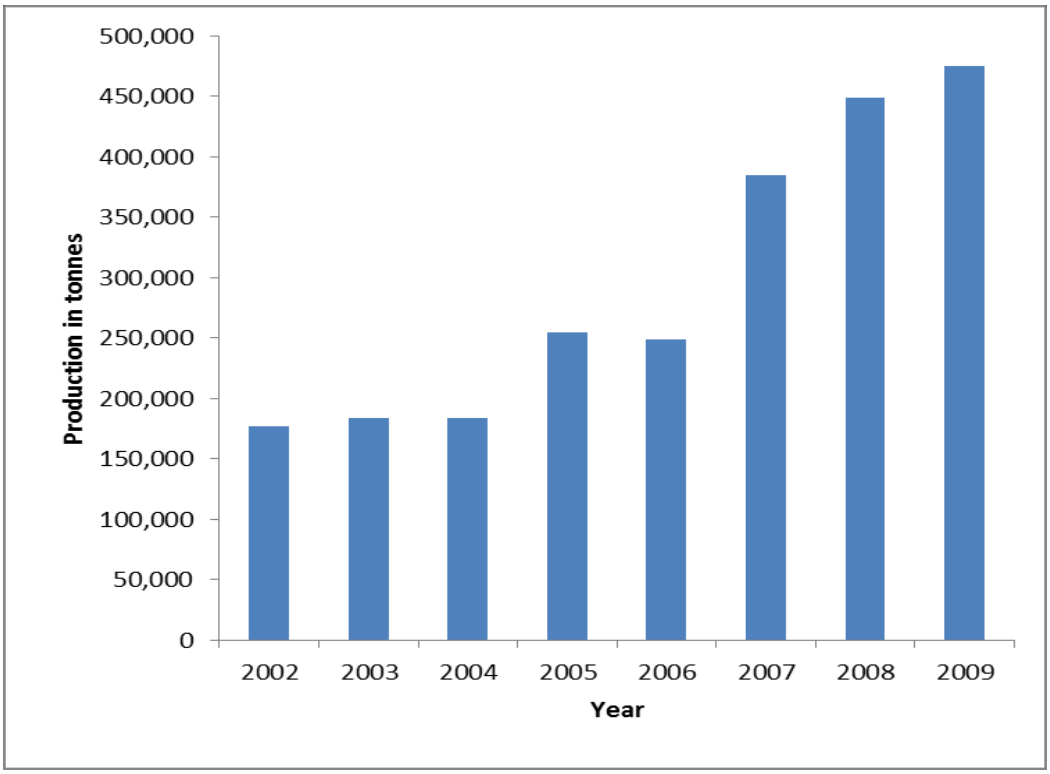
Despite the fact that currently only 3.3% of the world production of mango is traded globally, this represents a noticeable increase over the quantities traded since the late 1980s. In terms of distribution, Mexico, Brazil, Peru, Ecuador and Haiti supply the majority of North America's imports. India and Pakistan are the predominant suppliers to the West Asian market. South-East Asian countries get most of their supplies from the Philippines and Thailand. European Union buyers source mango mainly from South America and Asia (FAO, 2009).

Global exports of mango reached 912,853t in 2005, a slight decrease of 0.73% compared with the previous year. The exports were valued at US$543,100,000 (FAOSTAT, 2007). Recently India overtook Mexico as the number one exporter of mango. In the year 2000 to 2005 period, Mexico and India dominated the export trade with shares of 22.64% and 20.25%, respectively followed by Brazil (13.18%) and Pakistan (6.94%). Other major exporters include the Netherlands (major re-exporter; imports from other countries then export), Peru, Ecuador, the Philippines, Thailand and China. World imports of mango increased from 397,623 t in 1996 to 826,584 t in 2005. The USA has been ranked as major importer of mango.

2.2.2 Mango production in Kenya

Mango production has been on the increase due to increased demand of fruits for fresh market, processing, and health concerns (HCDA, 2012). There has been an upward trend in both production (Graph 2.1) and expansion of area. In 2012, area under mango production increased to 57,021 Ha and quantity produced to 2.8 million MT. This increase in area and quantity majorly occurred in North Rift and Eastern region in an effort to developing a cash crop in the

marginalized areas. As a result, the value increased to 13billion from 11.9 billion in 2011. This steady increase can be attributed to marketing systems with various government and private sector initiatives across the value chain, increased consumption of mango fruits, juices and salads. The leading counties in mangoes production in Kenya are Makueni (21%), Machakos (21%), Kilifi (15%) and Kwale (13%) (HCDA, 2012). Currently, mango production is based on improved varieties including Tommy Atkins, Kent, Van Dyke, Kensignton, Sensation, Haden, Apple, Ngowe, Boribo, Batawi, Pears, Sabro, Dodo and Sabine. Approximately 98% of mangoes produced in Kenya are consumed locally or processed while the remaining 2% is meant for export markets (HCDA, 2011).



Graph 2.1: Mango production trends from 2002 to 2009 in Kenya

Source; FAOSTAT, 2010

2.3 Agro-ecological requirements

Mango is best adapted to a warm tropical monsoon climate with a pronounced dry season (>3 months) followed by rains. However, information from other countries indicates that crops cultivated for a long time over an extended area show a high degree of diversity due to varied environmental influences. In Kenya, mangos are produced across a wide range of agro-ecological zones extending from the Coastal lowlands to the highlands in the Central region of

Kenya. The agro-ecological zones found in the widely spread mango producing regions range from sub-humid to semi-arid.

In mango production, the intensity and distribution of rainfall is very important. Rainfall of 500-1000 mm at the right time of the year is sufficient for successful cultivation. However, the mango cannot do well in areas which experience frequent rains or very high humidity during the flowering period. Such conditions are not conducive to good fruit set and they increase the incidence of serious diseases like powdery mildew and anthracnose (ICRAF, 2003).

Temperatures ranging from 20 to 26^{o}c are ideal for optimum growth and productivity of quality mangoes. Temperatures exceeding 40°C may, especially in hot/dry areas, lead to sunburn of fruits and stunting of tree growth. The two important considerations for mango cultivation are a dry period at the time of flowering in Kenya mainly during the months of August to October and sufficient heat during the time of fruit ripening. (ICRAF, 2003).

Mango is successfully grown on a wide range of soils. The trees do well in sandy soils at the coastline as well as on loam, black cotton and even murram soils at other elevations. The essential prerequisites for good development of the mango trees are deep soils (at least 3 m), good drainage and preferably a pH value of between 5.5 and 7.5.

Mango trees of selected cultivars like Sabre and Peach have been observed at elevations of up to about 1900 m. However, for more successful crops, areas below 1200 m should be considered.

2.4 Effect of agro-ecological conditions on mango fruit growth and development

Water stress mainly affects the mango fruit size. The effect of water stress on the mature mango size varies with the quantity of water shortage and the period when the stress occurs (Simmons et al., 1995). Early water stress influences the fruit cell number hence reducing the fruit size. Fruit drop has been noted to increase on water-stressed mango trees (Schaffer et al., 1994). Higher levels of abscisic acid (ABA) are synthesized in response to water stress resulting in fruit abscission in the early stages of mango development (Hartung et al. 2002). Late water stress strongly affects soluble sugar concentration of mango fruits on a fresh mass basis (Léchaudel et al., 2005b).

Temperature influences processes involved in fruit growth at the sink level (fruit demand and growth rate). The contribution of temperature to fruit demand can be associated with the daily variation in degree-days used to compute fruit demand in the model of mango growth in dry

mass (Léchaudel et al., 2005a). Temperature affects mango fruit growth rate. It has been suggested in other species, including Satsuma mandarin (Marsh et al., 1999) and apples (Austin et al., 1999), that temperature may affect the rate of cell division.

Light also affects mango production and quality. For instance, mango trees grown in areas with poor light penetration to the tree causes lower carbon assimilation in shaded leaves. Fruit growth in dry mass depends on the partitioning of carbohydrates between the fruit-bearing branch, fruit growth and storage in leaves and stems. If the carbon supply decreases, fruit growth in terms of dry mass is reduced as well. It has been shown that fruit size and dry matter content decrease in 'Kensington' fruit from upper to lower positions in the canopy (Hofman et al., 1995). Soluble solids content and total sugars, have also been reported to be lower in mango fruits on the lower portion of the canopy (Mendoza and Wills, 1984). Light effect can also influence anthocyanin production resulting in red pigmentation of the mango skin which affects the visual qualities of the fruit. On the other hand, mangoes inside the canopy retain a greener skin colour due to the decrease of fruit exposure to sunlight (Simmons et al., 1998a).

2.4.1 Mango flowering physiology

Flowers are borne on inflorescences (panicles) which are usually terminal, but panicles may also arise from auxiliary buds (Davenport, 2000, 2008). Flowers are either male or hermaphroditic and may be 300 to 3,000 on each panicle, depending on the cultivar. The percentage of hermaphroditic flowers varies with cultivar (Chanda and Pal, 1986). Flowering period in mango is mainly related to weather patterns and to some degree to the cultivar differences under the same climatic conditions (Whiley, 1985).

Studies in Florida revealed that low temperature is the major environmental factor with the greatest influence on flower induction (Nunez-Elisa and Davenport, 1992). The authors also concluded that water stress was not responsible for flower induction, but could enhance the response to cool temperatures. Reliable flowering is necessary to consistent mango production in the tropics. Generally, flowering in Kenya lasts from about late July to early November, depending mostly on weather conditions (Table 2.4). At the coast, flowering can occur as early as February and March (Table 2.3). Pollinators are usually flies, rarely bees or nectivorous bats. Pollen cannot be shed in high humidity or rain as this might prevents pollination and fruit setting. Mangos are self-fertile, thus a single tree will produce fruits without cross-pollination (ICRAF, 2003).

2.4.2 Growth pattern and flushing episodes in relation to mango flowering

Induction of generative (floral), vegetative or mixed shoots from axillaries or apical buds of mature flushes appears to be governed by several factors reviewed in details as follows. Growth of mango is not continuous but it occurs as intermittent, short lasting flushes of shoots from apical or lateral buds. Flushing refers to the emergence of new shoots on the terminals of old shoots. Generally a healthy mango shoot completes four to five flushing episodes per year depending upon cultivars and growing condition (Davenport and Nunez-Elisea, 1997), while blooming occurs on a few of them during the following year (Issarakraisila et al., 1991). Terminal inflorescences or panicles are initiated in dormant apical buds on stems that developed vegetative from lateral buds following the previous flowering seasons (Litz, 1997). Studying the different vegetative growth cycles may help the mango growers to know the most important vegetative growth cycle for regulation of vegetative growth, flowering, fruiting stage so as to increase yield. In this case the growers can use methods of inducing trees to produce their vegetative growth cycles in the time which help to maximize income.

According to the Davenport and Nunez-Elisea (1997), conceptual flowering model of mango, individual stems borne on branches of mango trees are in rest or a quiescent mode most of the time. Stems are different from shoots, which are growing structures that evoke from buds of stems. Vegetative shoots bear only leaves, whereas generative shoots produce inflorescences and mixed shoots produce both leaves and inflorescences within the same nodes.

Initiation of shoot growth in buds of resting stems is the first event that must occur in order to produce flowering (Davenport and Nunez-Elisea, 1997; Davenport, 2000, 2008). Reece et al. (1946, 1949) recognized that the fate of mango buds is not determined until their growth is initiated. The vegetative or reproductive fate of resting apical or lateral mango buds is not predetermined at the time of shoot initiation (Mustard and Lynch, 1946; Nunez-Elisea and Davenport, 1992). New shoots arise mostly as laterals from axillary buds around the stump of the twigs which fruited the previous year. Such growth either remains unextended or makes further extension growth in subsequent months, largely depending on the variety. Terminal growth is always in the form of an extension of shoots already produced. Growth occurs in different flushes which vary from variety to variety and under different environmental conditions. In Kenya, production of Ngowe mangoes is most prominent in the Coast region, along the Tana River (Table 2.3).

Table 2.3: Mango Production Calendar in the coastal region of Kenya

Month	Feb.-Mar.	Mar.-Apr.	Jun.-Aug.	Aug.-Oct.	Oct.-Dec.	Nov.-Feb.
	Flushing and flowering	Fruiting and fruit development	Harvesting and marketing	Flushing and flowering	Fruiting and fruit development	Harvesting and marketing

Source: FAO, 2003

Table 2.4: Mango Production Calendar for upper Eastern region in Kenya

Month	Apr.-May	May-Jun.	Sep.-Oct.	Oct.-Nov.	Nov.-Dec.	Dec.-Mar.
	Flushing and flowering	Fruiting and fruit development	Harvesting and marketing	Flushing and flowering	Fruiting and fruit development	Harvesting and marketing

Source: FAO, 2003

2.5. Biennial bearing in mango production in Kenya

Biennial bearing in mango means that the mango tree carries optimum load of crop in one year, but in the following year it fails to flower or and produce unsatisfactory crop. Seasonality on the other hand is a case where some seasons produce an oversupply of mangoes while other seasons result in a deficit of mangoes and as a result, many farmers sell their produce immediately after harvest, thus creating price fluctuations in the market (Davenport, 2008).

Biennial or irregular bearing occurs often with the mango and it is common for some cultivars to bear heavily in one year and sparsely the next. It results to mango trees having an irregular crop load from year to year. In the "on" year too much fruit is set, leading to small fruit size. Excess weight in the main branches can be too much for their mechanical resistance, causing them to break. Another major consequence is that flower induction will be lower, and the subsequent year will be "off" year (too little fruit) (Usha et al., 2014). One of the reasons for this phenomenon is that trees over-bear in one year, thus inhibiting adequate flower bud formation the following year. Under these circumstances, it is difficult to get accurate local long-term yield records. This tendency of on and off remains so and goes continuously unless the habit is altered

by external factors such as diseases or pests, bad weather at flowering or by growers deliberate attempts by proper tree management (Davenport, 2000, 2008).

The management of biennial bearing becomes important as the profitability of mango trees depend on the production of reasonable crop every year. Therefore getting an understanding of the factors that result to biennial bearing in mango trees is critical. The biennial bearing may be caused by one or combination of more factors. This disorder can be reduced by pruning, and thinning of flowers and young fruits.

2.5.1 Factors that contribute to biennial bearing in mangoes

2.5.1.1. Variety

Varieties with a long growth cycle show natural biennial tendency. Mangos show clearly demarcated and very distinct growth patterns during an annual growth cycle. New growth flushes emerge after harvesting and these flushes mature and remain dormant for some period before the trees flower. Again from flowering to fruit harvesting there is a period called fruit development. After harvesting, the vegetative flushes emerge and this growth cycle continues (Usha and Shiva, 2014).

Time spans for the periods from harvesting to flushing, from flushing to flowering and from flowering to harvesting vary according to variety. Time taken from flowering to harvesting may vary from 3.5 to 5 months for a range of mango varieties, and based on these the varieties may be classified as early, mid-season and late varieties. Usually for a single variety time taken from flowering to fruit maturity is fairly constant and may slightly vary with climatic conditions experienced during fruit development (Usha and Shiva, 2014).

Thus, for late varieties it takes more than 12 months to complete a growth cycle. Then after giving a heavy crop in one year, late varieties have less time period before next flowering to produce the flush and to accumulate reserves for the next crop. Then that crop in the second year may be poor or sometimes trees may not flower at all if the shoots are not physiologically conditioned for flowering by the time next flowering season starts (Usha and Shiva, 2014). However, by the third year, again the tree will have accumulated more reserves to support a heavy crop. In this way, biennial production pattern continue in such varieties.

It is therefore very difficult to completely overcome this problem if it is originating as a result of varietal character. Nevertheless, this problem may be minimized to a certain extent by controlled application of nitrogen and water at least 2 weeks before harvesting fruits to induce an early growth flush. This technique is used to reduce the time period taken for a growth cycle as much as close to 12 months (Davenport, 2008).

2.5.1.2. Climatic Conditions

Even if a regular variety is grown under rainfed conditions, irregular bearing may be observed, not necessarily biennial bearing, in line with the variations in climatic conditions. The primary climatic factor affecting the irregular bearing is rainfall. If rains delay after harvesting, there will be a longer time period between harvesting and the following growth flush. Then the time period available for trees to have the rest before flowering and accumulate food reserves is shorter than that happen under a normal season. Under such conditions, poor crops will be produced in the following season (Usha and Shiva, 2014).

If mango trees under rain fed conditions face this kind of irregular bearing, then the only option available to control it is to provide irrigation facilities. In so doing the productivity of the orchards may be significantly improved.

2.5.1.3. Problems in Planting Site

If mango trees are established in very fertile, deep rich soils or in places with high water tables, or in locations with lot of shade, irregular bearing may be a problem. Under such conditions, it is difficult to control the vegetative growth of trees. Especially in places where growth checks cannot be achieved between flushing and flowering as a result of too much nitrogen or too much water, irregular crops may be produced. Under this kind of situation also the crop load depend on rainfall. However, heavy crops may be possible only when drought periods occur. Drought affects the availability of nitrogen and water to trees and results to growth control for successful flowering and fruiting under the drought conditions (Usha and Shiva, 2014).

To control irregular bearing under circumstances of very fertile, deep rich soils or in places with high water tables, chemical growth retardants may be quite helpful. Also, change of varieties is another possibility (Usha and Shiva, 2014).

2.5.1.4. Poor Tree Management

If the variety, growing environment and planting site is alright, still the biennial or irregular bearing problem might exist due to lack of a proper tree management. If the trees are subjected to a management system based on tree phenological cycle, this irregular bearing may be controlled effectively (Davenport, 2003). Some of important management tools available for control of irregular bearing are nitrogen and irrigation (James et al., 1992). Special care should be taken to apply nitrogen and water at right time. Another key factor when managing mango flowering is proper management of vegetative growth in tree canopies to allow all the stems in a canopy to be in the same physiological stage of maturity when KNO_3 applications are made (Davenport, 2000). Synchronized growth is best accomplished by proper tip-pruning all terminal stems on trees (Davenport, 2003, 2006).

Proper tip-pruning not only produces a specifically timed uniform flush of vegetative growth throughout the canopy, but it removes factors that inhibit growth and flower formation in stems derived from the previous season's flowering and fruiting panicles (Davenport, 2000, 2009). Tip-pruning mature trees quickly results in a synchronous flush of lateral vegetative shoots if water is adequate (Davenport, 2003). If the lateral stems produced by this pruning event subsequently remain in rest for 4 or 5 months (depending on cultivar) in warm temperatures, then flowering will usually occur when shoots are initiated to grow by foliar application of potassium or ammonium nitrate (Davenport, 2006).

In addition, crop protection also affects irregular bearing. If flowers are not protected from pests like mango hoppers or from diseases like anthracnose, the crop will be very poor in that season. However, the following season crop may be little higher due to the buildup of more tree reserves essential from flowering to harvesting to control this (Usha and, 2014).

2.5.1.5 Plant hormones

In addition, the behavior could be due to plant hormones, particularly gibberellins produced in excess in the "on" years in the embryos of the young fruit. It could also be caused by depletion of carbohydrate reserves in the tree (Davenport, 2003).

2.6. Seasonality of mango production in Kenya

In Kenya, mango supply peaks between October and February (Tables 2.3 and 2.4). It is well known that yields of 25 t/ha and more for Kent, Sabine, Tommy Atkins and Keitt is not

uncommon. Cultivar trials carried out under rainfed conditions at government prison farms in Kenya indicate that even higher yields could be achieved. Unlike in the Makueni and Murang'a counties, in the main production area, the Coast Province, two supply seasons can be differentiated (Tables 2.3). The first and main season runs from November to February and the second from June to August. In areas of higher altitude such as Murang'a and Mwea (Central Province), the harvest season is 4 to 6 weeks later than at the coast, with a peak in February and March. The mango picking season in Kenya competes with that of other mango producing countries (Mexico, Brazil, India, Pakistan, Israel, and South Africa) and extends over a period of between 5 and 6 months. Out of the worldwide export tonnage of 580,000 per year, Kenya exports only about 3000 t (FAO, 2001).

Seasonality has serious implications for mango processing. Seasonal production of the mangoes is only enough to supply factories for seven months of the year (FAO, 2003). According to the Horticultural Crops Development Authority (HCDA), mangoes in Kenya are available from November to April (and sometimes to July) HCDA, (2011). Because of less competition, better prices are fetched in Europe and the Middle East between November and December.

2.6.1. Factors that contribute to mango seasonality

The problem of floral initiation in plants is not as simple as the one being controlled by the synthesis and accumulation of a substance up to a certain concentration but is a complex one involving a photo-mechanism controlling various growth and developmental processes (Sen, 1951). Singh (1961) showed that the newly merged leaves in the shoots of regular bearing cultivars such as 'Neelum' was capable of synthesizing flower inducing hormone.

Chacko (1968) found a high level of auxin-like substance in the shoots of 'Dashehari', which were expected to flower. In many of the cold-requiring biennials and long-day annual plants, Gibberellins are known to be involved in the production of floral stimulus. A study of Chacko (1968) showed that the amount of gibberellin-like substance was higher in the shoot extracts of 'Dashehari' 'off' season trees as compared with those of 'on' season trees. Minimum flowering and yields thereof were obtained in the off-season trees and one of the reasons was associated with high content of endogenous gibberellins noted in the 'off' season trees that inhibited floral formation.

2.7 Regulating mango flowering

Tropical climates are conducive to year-round vegetative growth of perennial tropical fruit crops, but flowering and fruit set are usually seasonal. Flowering from one season to the next is unreliable, because the environmental signals for flower initiation are often inconsistent, subtle, or poorly defined. An alternative to dependence upon environmental signals for flower initiation is the development of management strategies that can substitute for these signals (Dutcher, 1972). In Hawaii, one method to extend the availability of fruit within or slightly beyond the ripening period of May-June to September is by growing different cultivars. There are usually some seedling and off-season fruits available at other times. Recently, technologies have been developed to induce flowering of mangoes during off-seasons (Hamilton et al. 1992).

2.8 Flower induction technologies

The use of off-season flower induction technologies has been commercially accepted. This is because of the benefits of these technologies which include an altered earlier harvest, to take advantage of the good market price. Also, these technologies help to fill the gap of under-supply and reduce effect of disease on the crop since flowering is induced during the dry spell. The readiness of a tree to flower is an important factor for a successful operation. To use chemical treatments effectively to control mango fruit production, application should be assessed in relationship to the plant's growth phenology (Macias-Gonzales *et a1.*, 1992).

Many techniques have been used in other countries to improve productivity and to alter the cropping season. Foliar sprays of KNO_3, NH_4NO_3, or ethephon have been used to stimulate off-season flowering of mango, especially in tropical regions, for many years (Bondad and Linsangan, 1979). These techniques are discussed below;

2.8.1 Smudging

Smudging of the mango trees was embraced in certain parts of the Philippines as a way of inducing flowering in order to obtain earlier and increased flowering of 'Carabao' and 'Pico' mango (Dutcher 1972; Madamba 1978). Smudging entails burning moist organic material such as grass or leaves slowly under the tree canopies and the resulting smoke induces flowering. It is an old technique reported from the Philippines for enforcing off-season flowering, but this has largely given way to chemical induction. In the Philippines, smudging has been used to obtain earlier and increased flowering of 'Carabao' and ‘Pico' mango (Dutcher, 1972; Gonzales, 1923; Madamba, 1978). Smudging is done continuously for several days and it’s stopped if flower buds do not appear within two weeks. The process may be repeated 1-2 months later, but results are uncertain.

2.8.2. Use of Ethephon and its mode of action

The ethylene-generating agent, ethephon, applied at 125- 200 parts per million, induced flowering of 'Carabao' mango in the Philippines within six weeks after treatment (Dutcher, 1972). Flower induction also occurred at concentrations between 500 and 1,000 parts per million. However, defoliation has been experienced at the higher concentrations (Bondad, 1976). Ethephon has also been successful in India for increasing flowering of 'Langra and 'Deshehari' during “off years” (Chacko *et al*. 1972, 1974; Chanda and Pal 1986) and for inducing earlier production in juvenile plants (Chacko *et al*. 1974). In 10-year-old 'Haden', 500-1,000 parts per million applied one month before the normal flowering date increased flowering by 40- 55 percent (Nunez-Elisea *et al*. 1980). These results were contrary to those obtained by Pal *et al*., (1979), who found ethephon ineffective after five consecutive years of treatment, and by Sen. *et al*., (1973) who reported an increase in flowering during "on" years but failed to stimulate flowering during "off' years.

Ethephon, invented in 1965, is a liquid that converts into ethylene and acts as a plant hormone after it is sprayed on plants (Henny, 2001). The phytohormone ethylene is well known to influence a number of physiological and developmental processes in plants including, but not limited to seed germination, seedling growth, and formation of the apical hook, senescence, fruit ripening, abscission and gravitropism (Abeles *et al.,* 1992). It can be speculated that the ethylene generated when ethephon is sprayed plays a critical role in flower induction. The ethylene-generating agent, Ethephon, has been used to successfully induce and increase flowering in various mango varieties in the Philippines and India (Chanda and Pal, 1986; Dutcher, 1972).

2.8.3. Use of potassium nitrate and mode of action

The first studies to demonstrate that potassium nitrate could induce flowering of mango trees were from the Philippines (Barba 1974, Bondad and Linsangan 1979; Bueno and Valmayor 1974). Flowering was evident within seven days after treatment and was effective on shoots that were between 4.5 and 8.5 months old when treated. Bondad and Linsangan (1979) reported that concentrations of potassium nitrate between 1% and 8 % stimulated flowering of seedling 'Carabao' and 'Pahutan' trees and 'Pico' trees within one week after sprays were applied.

The treatment was effective for stimulating flowering of trees that had remained vegetative well beyond normal bearing ages, for advancing the flowering and fruiting periods, and for breaking the biennial bearing habits of trees. Potassium nitrate is currently recommended in the

Philippines for inducing uniform flowering and for the production of off-season fruits in the 'Pico' and 'Carabao' cultivars (Madamba 1978). In India, workers have reported variable results with potassium nitrate (Pal *et. al.,* 1979). Areas that have reported success with potassium nitrate include Trinidad with 'Tommy Atkins' (James *et al.,* 1992), the Ivory Coast with 'Kent' and 'ZiU' (Goguey 1992) and Mexico with 'Manila' and 'Haden' (Nunez-Elisea 1985; 1986).

In Mexico, studies by Nunez-Elisea (1986) have shown that potassium nitrate is effective on 'Haden' shoots which are six months of age or older. In the case of 'Manila', effective response of potassium was on shoots as young as 3-4 months of age. In that study, it was noted that leaves should be dark green with a mature, "woody" texture and well developed terminal buds. Upon treatment with a 4 % potassium nitrate solution, slight leaf wilting can be observed within two days, and at 10 days buds begin to swell. A second application is made at 15-20 days after the first application if the response is poor. Application should be made prior to emergence of the flowers, because flowers are usually damaged by the potassium nitrate sprays. Harvesting occurs at about five months after treatment. Advancing the flowering season in Mexico has enabled growers to get fruits into the market at an earlier date, extend the harvest season, and harvest crops during the drier periods.

Off-season flowering was also stimulated when application was made to seedling trees in May after the flowering season was completed. Nearly 16 percent of the terminals treated with 4 percent potassium nitrate flowered by six weeks after treatment (Nunez-Elisea, 1985). Results also showed that terminals that flowered were associated with specific trees; some trees in the test exhibited no response, while others produced vegetative terminals after treatment. These results suggest that potassium nitrate did not induce flowering, but probably stimulated growth of terminal buds. Flowering was determined by the condition of the terminal bud or the environmental conditions at the time potassium nitrate application was made. Their results with seedling trees also showed that genotypic differences among trees exist with regard to flowering responses to potassium nitrate. Some trees were highly responsive to the treatment and flowered, while others produced vegetative shoots instead of panicles (Nunez-Elisea (1985).

In studies conducted in Hawaii, potassium nitrate application to mature 'Haden' trees in Pahala and Waimanalo also showed that flowering was stimulated in October and November. Stimulation of flowering during these periods could enable producers to obtain fruits five months later (April), which would be about two months earlier than the usual seasonal production in

Hawaii. Preliminary tests with other varieties showed that 'Fairchild' was not as responsive as 'Haden' to applications made in November, while no response was observed with 'Keitt' (Hamilton et al. 1992).

The mode of action for potassium nitrate during flower induction is not fully understood. Therefore, an explanation for the variable results between cultivars and application periods remains unclear. The influence of endogenous Gibberellic acid (GA) levels (possible flowering inhibitors) and the interaction between shoot age and environmental conditions on the response to potassium nitrate are not known. To obtain reliable seasonal and off- seasonal flowering in Hawaii, its critical to identify varieties that are responsive to potassium nitrate and determining the influence of application times. It is also necessary to determine the type of shoots that will respond to potassium nitrate, and the development of management strategies that force development of responsive shoots at any period during the year.

2.8.4. Ammonium nitrate

Studies done in Mexico showed that mango flowering could also be stimulated with ammonium nitrate sprays (Macias-Gonzales *et a1.,* 1992; Nunez-Elisea 1988, Nunez-Elisea and Caldeira, 1992). Concentrations of 2% ammonium nitrate was sufficient to promote early flowering in 'Haden', 'Tommy Atkins', 'Kent', 'Diplomatico' and 'Manila'. The similar results between ammonium and potassium nitrate indicate that the nitrate ion is the active portion of the molecule. Experiments in Hawaii by the authors showed that 2 and 4 % potassium nitrate applied to mature seedling trees early in the flowering season in February, 1986 stimulated flowering. A single application stimulated flowering within three weeks after treatment, and maximum response was observed at about four weeks.

CHAPTER THREE

EFFECT OF OFF-SEASON FLOWER INDUCTION TECHNOLOGIES (ETHEPHON AND POTASSIUM NITRATE) ON REPRODUCTIVE GROWTH PARAMETERS AND YIELD COMPONENTS OF 'APPLE' AND 'NGOWE' MANGO TREES

Abstract

Mango (*Mangifera indica*) fruit production in Kenya is seasonal with peak and low seasons which is the one of the contributing factors to postharvest losses. Off-season flower induction is a strategy that can be used to address mango seasonality. Manipulation of mango trees to produce an off-season crop can be achieved through application of flower induction chemicals. In the present study, the two flower induction chemicals, potassium nitrate (KNO_3) and ethephon were evaluated on two mango varieties: 'Apple' and 'Ngowe'. The study was conducted at Embu County (a high potential AEZ III) and Makueni County (a low potential AEZ V). Potassium nitrate was applied at two concentrations (2 and 4%), while ethephon was applied at three concentrations (300, 600 and 1000ppm) in the first experiment and at two concentrations (600 and 1000ppm) in the second experiment. The treatments were applied to mango trees which failed to flower/set fruit in the 2013 and 2014 seasons. The test trees comprised of randomly selected 6 to 8 years old 'Apple' and 'Ngowe' trees of uniform vigor and size. The spraying of the treatments was done on mature flushes one week after the leaves had attained a dark green color. 100 terminal shoots were marked randomly on each tree prior to spraying. After inflorescence development, 20 panicles per tree were tagged randomly on each tree to establish fruit set. The experiment was laid out in a randomized complete design with three replicates and three trees per treatment where the three test trees represented a replicate. Effect of the treatments was established from reproductive growth parameters including days to flowering and fruit set, number of panicles per tree and average fruit set per 20 panicles. Other responses of the trees to the treatments such as fruit fall and hormonal effect (internal ethylene in young fruits) were also evaluated. Potassium nitrate (4%) increased percentage flowering (% of tagged shoots) in both 'Ngowe' and 'Apple' in both AEZs (III and V). In Embu, 4% KNO_3 resulted in 48% flowering in 'Ngowe' compared to 27% in 'Apple'. Similarly, in Makueni, the response was greater in 'Ngowe' (99.7%) compared to 'Apple' (94%). Response to ethephon increased with concentration with the 1000ppm giving the best response; 21% and 95% flowering (% of tagged shoots) for Embu and Makueni, respectively, in 'Apple'. In both AEZs and varieties, flowering was $\leq$ 31% in untreated controls. Time to flowering was significantly shortened by both KNO_3 and ethephon treatments with 'Ngowe' being more responsive than 'Apple'. Significant

treatment effect ($p \leq 0.05$) was observed on fruit set with 4% KNO_3 and 1000ppm ethephon resulting in the highest fruit set in both AEZs and varieties. From the results, it can be concluded that potassium nitrate and ethephon can be beneficial for flowering and fruiting parameters if applied at the right dose on well-selected variety grown in the right AEZ.

3.1 Introduction

Mango flowering is a key reproductive event that sets the stage for fruit production. Initiation is the first event that takes place for mangoes to flower (Davenport and Nunez-Elisea, 1997, Davenport, 2000, 2003, 2009). Initiation involves cell division and elongation of the cells in vegetative shoots, lateral meristems or both in the nodes of the resting buds. It is followed by cell divisions in the apical meristem to form more nodes (Davenport, 2007, 2009). Shoot initiation can be stimulated by environmental factors such as pruning, irrigation, application of nitrogen substances and/or fertilizers and exposure to ethylene (Davenport, 2009). Coincident with shoot initiation, flower induction occurs based on the conditions present at the time of initiation. Floral induction and subsequent initiation are linked events in herbaceous plants (Boss *et al*., 2004). In contrast, shoot initiation in mango must occur before induction can determine the type of shoot to be evoked in those buds (Davenport, 2007, 2009).

Mango flowering can be manipulated in order to obtain out-of-season fruits and improve mango productivity. Reliable flowering is necessary to obtain consistent mango production in the tropics (Davenport and Ramirez, 2010). Cool temperatures in the subtropics stimulate mango flowering and age of the last vegetative flush. This phenomenon has an important bearing on the ability of mango trees to flower in marginally cool or warm temperatures of the tropics (Davenport, 2000, 2003*)*. Consequently, mango flowering can be enhanced during its normal season or manipulated to occur at other times of the year in the tropics. This manipulation can be achieved using cultural practices and application of certain chemicals. For example, potassium nitrate (KNO_3) can stimulate out-of-season flowering in mangoes in tropical latitudes (Davenport, 1993; Protacio, 2000), although this treatment has not always been dependable. In Mexico, off-season flowering was stimulated when application of potassium nitrate was made to seedling trees in May after the flowering season was completed. In the latter case, nearly 16% of the terminals treated with 4% potassium nitrate flowered by six weeks after treatment (Nunez-Elisea, 1986). The use of KNO_3 to induce flowering has revolutionized the mango industry in the Philippines making the crop one of the country's top export earners (Barba, 2008). 'Carabao'

mango is a highly seasonal fruit, producing mostly in April and May in Philippines. However, with the use of KNO_3 as flower inducer, it is now possible to induce mango trees to flower and produce all throughout the year (PCARRD, 2005). Nonetheless, trees could respond to chemical concentration in the same variety. For instance, ethephon applied at 125- 200 parts per million, induced flowering of 'Carabao' mango within six weeks after treatment (Dutcher, 1972).

Also, trees could respond to chemical inducers with flushes, or have no response at all, instead of flowers (Davenport, 2000, 2003*)*. Many factors affect the success of any flower inducer in mango trees. They include the age of the tree, age of shoots and months of flower induction, including appearance of shoots or leaves, bearing history, vigor of the shoot, concentration of the flower inducer, and weather conditions or soil moisture retention (PCARRD, 2005). Many studies have been done on off-season flower induction in different mango cultivars treated with various concentrations of the flower inducers. In these studies, mixed results have been reported. For instance, in 10-year-old 'Haden', 500-1,000 parts per million of ethephon applied one month before the normal flowering date increased flowering by 40- 55 percent (Nunez-Elisea *et al*. 1980). These results were contrary to those obtained by Pal *et al*., (1979), who found ethephon ineffective after five consecutive years of treatment. Similarly Sen *et al*., (1973) reported an increase in flowering during "on" years following ethephon application but failure to stimulate flowering during "off' years.

In Kenya, little has been done to establish the efficacy of flower inducers on off-season flower induction in major commercial varieties of mango. As such, seasonality of mangoes continues to present a great challenge to mango growers and other key players in the mango value chain. The objective of this study was therefore, to determine the effect of off-season flower induction technologies (ethephon and potassium nitrate) on reproductive growth parameters and yield components of ‘Apple’ and ‘Ngowe’ mango trees grown under two different agro-ecological zones in Kenya.

3.2 Materials and Methods

3.2.1 Study sites

The study was carried out in two of the major mango producing counties of Kenya, Embu and Makueni focusing on two of the popular mango varieties, ‘Ngowe’ and ‘Apple’.

Embu county falls in agro ecological zone III and it is a semi-humid region. The mean annual temperature ranges between 12°C – 27°C. The rainfall pattern is generally bimodal with two

distinct rainy seasons. The average annual rainfall ranges between 700 mm and 1300 mm. The first rains start about mid to end of March with peaks in April/May and the second rains start in October with their peaks in October/November (Jaetzold and Schmidt, 1983). Most of the soils are volcanic with good drainage. The soils are characterized by high nutrient availability and very high moisture storage capacity. Embu orchard soils are rich in nitrogen (0.12%), organic carbon (1%) and high in potassium (1.48ppm).

Makueni County is a semi-arid area that occurs in agro-ecological zone V. The rainfall received during the year ranges between 150 mm to 650 mm or less. Average temperatures vary between 21^0C to 35^0C resulting in low or no yields in rain fed agriculture. The soils in Makueni County are a combination of sandy and loamy soils with good drainage and low nutrient availability. Makueni orchard soils are low of nitrogen content (0.07%), organic carbon (0.52%) and potassium content (1.40ppm).

3.2.2 Experimental design and treatments

A randomized complete design with three replicates and three trees per treatment per plot were used. This translated to fifteen trees per plot for the five treatments. The three test trees for each treatment represented a replicate. The treatments applied were two rates of potassium nitrate (2% and 4%) and two rates of ethephon (600ppm and 1000ppm). The control trees were sprayed with water alone.

To obtain the spray volume per tree, the required quantities of active ingredients (KNO_3 or Ethephon) were dissolved in 5 litres of water. In the case of KNO_3, the 2% was obtained by dissolving 2g KNO_3 in 100ml of water. For the Ethephon, the following formula was used; $C_1V_1=C_2V_2$ Where; C1 was the active ingredient concentration as was indicated on the 1 litre ethephon container i.e. 480000 ppm, V1 was the unknown quantity of ethephon in milliliters which was to be dissolved in the 5litres-5000 ml, C2 was the 1000 ppm rate and V2 the 5000 ml i.e. the spray volume $tree^{-1}$. The same concept was used to derive the quantities of ethephon for the rates 300ppm and 600ppm that was dissolved in the 5 litres. Igepal (active ingredient; Polyoxyethylated alkylphenol), a surfactant was added to the chemicals at 0.5cc/litre to enhance the period of contact of the chemicals on the mango trees foliage.

3.2.3 Experimental set up

The first experiment was set up on 22nd and 23rd of October 2013. Potassium nitrate was applied at two concentrations (2% and 4%), while ethephon was applied at three concentrations (300ppm, 600ppm and 1000ppm) and compared to a control (water). The treatments were applied to mango trees which failed to flower/set fruits in the 2013 season. The first experiment was purposely meant to indicate the general trend in the performance of the various concentrations of the flower inducers under the trial. There was no information documented in the literature for Kenya on the use of Potassium nitrate and ethephon as flower inducers. There was no much data obtained from the first experiment as a result of prolonged drought which was experienced in Kenya at the end 2013 apart from prediction of better chemical rates as discovered from parameters observed. Data was collected on the number of days to flowering (Table 3.1) and the percentage flowering (Table 3.3) in the first experiment. There was a lot of fruit abortions from both the untreated and treated trees which later dried due to the severe drought, but rejuvenated with the onset of rains. The focus was now on the multisite study in the two contrasting AEZs (Embu and Makueni Counties) in the second season which helped to compare and bring out the effect of the two technologies on the two varieties ("Apple" and "Ngowe"). The second phase experiment was set up on 13th and 15th of March 2014. The test trees in both experiments comprised of trees (average age 6 – 8 years) old 'Apple' and 'Ngowe' trees. The trees were uniform in vigor and size. They were randomly selected to study the effects of KNO_3 and Ethephon on flowering. One hundred (100) terminal shoots were marked randomly on each tree prior to spraying so as to enable recording the percentage of flowering shoots. After inflorescence development, 20 panicles per tree were marked randomly on each tree for recording fruit set. The spraying of the treatments was done once on mature flushes after one week from when leaves had attained a dark green color (plate 3.1)

Plate 3.1: 'Ngowe' tree (Makueni)

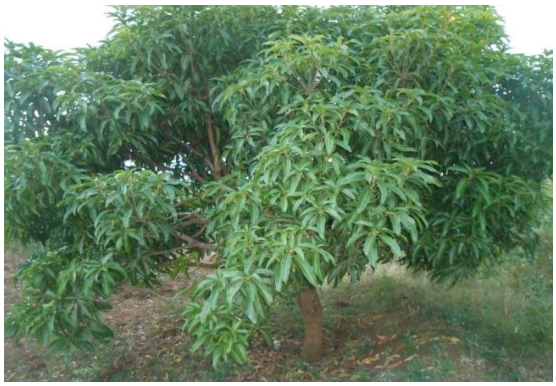


Plate 3.2: 'Apple' tree (Makueni)

3.2.4 Data collection

Data were collected on % flowering, days to flowering, number of panicles, fruit set, internal ethylene production, fruit drop, fruit number and fruit density.

Percentage flowering was done by using the hundred tagged shoots and the % of the shoots that flowered recorded. Days to flowering was recorded as the number of days between the spray and the stage where inflorescences from the tagged shoots per tree were at bud break. The total number of panicles per tree was counted 90 days after the spray. The fruit set was evaluated at the pea size stage (when the immature fruits were at the size of a pea). The number of fruitlets was counted on 20 panicles which were marked randomly on the test trees. The base of each test tree was cleared a week from initial fruit set and then, fruit drop monitored. The total number of fruit drop was counted on every day for 4 times. The cumulative fruit drop values were compiled and analyzed after every two weeks and expressed as a percentage of the initial fruit set.

Lab analysis of internal ethylene in the young fruits commenced after one month from fruit set. Ten young fruits were peeled and each placed in plastic jars of 700 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 (Model GC-9A, Shimadzu Corp., Kyoto, Japan for ethylene production rate). Ethylene production rate was calculated using the formula $k \times 1/r \times h \times (v-w)/t/w$ and expressed as nl/g/hr.

Where: k = Calibration value (nm equivalent to 1cm peak height on gas chromatograph)

r = Volume of gas injected for sample (ml)

h = Weight of sample (g)

t = Incubation time (hr.)

Any harvesting done from the three test trees for each treatment and the control was recorded from the onset of harvesting up to the end of the harvesting season. The total number of fruits in each harvest per tree for each treatment was then determined. Fifty fruits at tree-ripe stage were randomly sampled from each of the three test trees per treatment and used to determine the average fruit weight.

At maturity, 9 fruits were sampled from each treatment. The mass of each of the fruits was determined and displacement method was used to determine the volume of each. The density of the fruits from various treatments was calculated and expressed as g/cm^3.

3.2.5 Data analysis

Parameters measured and analyzed were days to flowering, cumulative flowering, percentage flowering, number of panicles, fruit set, internal ethylene production from immature fruits, fruit drop, total number of fruits per tree, total weight of fruits per tree and density of fruits from the treatments and control. Analysis of Variance (ANOVA) was done using GENSTAT (15^{th} Edition). Treatment means were separated using the Least Significant Difference (LSD) at the 5% level of significance.

3.3 Results

3.3.1 Effect of Potassium nitrate (KNO_3) and Ethephon on the days to flowering

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on days to flowering (Table 3.2). There was no significant interaction ($p \leq 0.05$) amongst treatments, location and the varieties. Time to flowering was significantly shortened by both KNO_3 and Ethephon (600 and 1,000ppm) treatments with 'Ngowe' being more responsive than 'Apple'.

In 'Apple' mango from Embu, flowering started 39 and 36 days earlier than the control in 4% KNO_3 and 1000ppm ethephon treated trees respectively. In Makueni, 4% KNO_3 and 1000ppm resulted in earlier flowering by 63 and 58 days respectively in the same variety. Trees treated with 2% KNO_3 and 600ppm ethephon took 77 and 59 days respectively to flower in the same variety and location. The longest time to flowering was registered in control Makueni 'Apple' and control Embu 'Apple' trees which took 129 and 125 days to flower respectively.

In 'Ngowe', flowering of the trees was also hastened, but the response was less dramatic in Embu. 4% KNO_3 and 1000 ppm Ethephon treated trees recorded 83 and 88 days respectively compared to 125 days for the control. 1000ppm ethephon-treated 'Ngowe' trees took 37 days fewer to flowering in the same location. This was relatively lower than the 26 days in 'Apple' variety for the same treatment. The days to flowering were reduced by 54 days compared to the control in 'Ngowe' trees treated with 4% KNO_3 treatments in Makueni.

On average, among all the treatments in the two locations, the control trees took the highest number of days to flowering followed by 2% KNO_3 treatments (116.6 and 87.3 days

respectively) (Table 3.2). The effect of the treatments was significantly affected by the season with the first season registering a lower percentage flowering (Table 3.1).

Table 3.1: Effect of Potassium nitrate (KNO_3) and Ethephon on days to flowering of Apple and Ngowe mango trees in Embu and Makueni Counties in season 1

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	**APPLE**	**NGOWE**	**APPLE**	**NGOWE**	**MEANS**
2% KNO_3	70.0jk	33.0bcd	65.0i	34.0cd	50.5
4% KNO_3	68.0ij	30.0ab	40.0fg	29.0a	41.5
Ethephon 300ppm	76.0l	42.0gh	72.0k	35.0de	56.3
Ethephon 600ppm	69.0jk	35.0de	45.0h	36.0de	46.3
Ethephon 1000ppm	65.0i	31.0abc	44.0h	31.0abc	42.8
Control	83.0m	40.0fg	80.0m	38.0ef	60.2
$LSD_{0.05}$ (Treat)	4.1	4.0	3.2	3.0	
$LSD_{0.05}$ (Loc. x Var. xTreat)	3.2				
CV (%)	3.9				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.2: Effect of Potassium nitrate (KNO_3) and Ethephon on days to flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties for season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	101.0h	97.3gh	77.0d	74.0d	87.3
4% KNO_3	90.0f	83.0e	50.0a	45.0a	67.0
Ethephon 600ppm	103.0h	100.0h	59.0c	57.0c	79.8
Ethephon 1000ppm	93.0fg	88.0ef	55.0bc	51.0b	71.8
Control	129.0j	125.0j	113.0i	99.3h	116.6
$LSD_{0.05}$ (Treat)	7.5	3.8	6.5	3.9	
$LSD_{0.05}$ (Loc. x Var. x Treat)	5.2				
CV (%)	3.7				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= Location, Var= Variety and Treat = Treatment.

3.3.2 Effect of Potassium nitrate and Ethephon on cumulative flowering

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on cumulative flowering. All treated trees produced a significant ($p \leq 0.05$) higher number of flowers than the control trees as time progressed. Except for 4% KNO_3 and 1000 ppm ethephon treatments, the number of flowers in the first two weeks did not differ significantly between the other treatments and the control.

In 'Ngowe' mango trees from Embu, 4% KNO_3 and 1000 ppm ethephon treatments significantly ($p \leq 0.05$) increased flowering cumulatively from the first 7 days (Figure 3.1). 4% KNO_3 produced the highest flowering increment to make an increase of about 283 flowers with respect to the control in the same location. In Makueni, flowering was significantly ($p \leq 0.05$) increased within the first week from the initial flowering in the same variety (Figure 3.1). At the end of the first week, 4% KNO_3 and 1000ppm Ethephon treatments had 42 and 18 flowers more as compared to the control trees respectively.

In ‘Apple’ mango from Embu, flowering amongst the treated trees and the control trees did not differ significantly ($p \leq 0.05$) within the first 14 days of flowering (Figure 3.2). However, with time, significant differences were recorded on the total number of flowers produced amongst the treatments and the control trees. 4% KNO_3 had the highest total number of flowers (255) which was about twice as many as that of 2% KNO_3 and differed significantly ($p \leq 0.05$) with the control trees. In Makueni, the highest cumulative number of flowers in the same variety was observed in the 4% KNO_3 treatment which had 342 flowers more compared to the control trees. This was relatively higher compared to 226 more flowers produced by 1000ppm ethephon treated trees with respect to the control (figure 3.2).

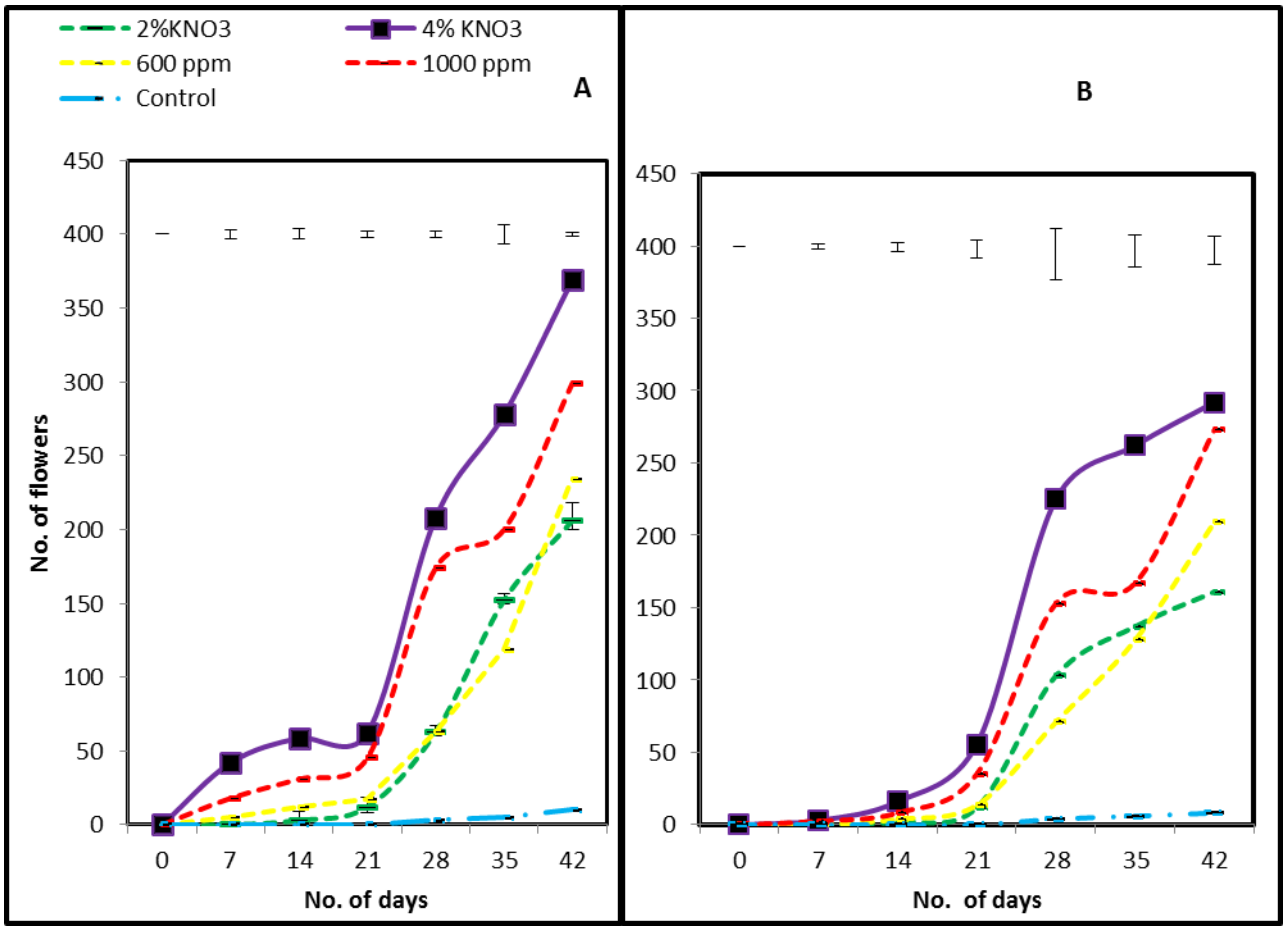


Figure 3.1: Effect of ethephon and Potassium nitrate on the average number of flowers (cumulative) for ‘Ngowe’ variety in Makueni (A) and Embu (B) Counties respectively. Top bars indicate least significant difference (LSD) between means at p=0.05

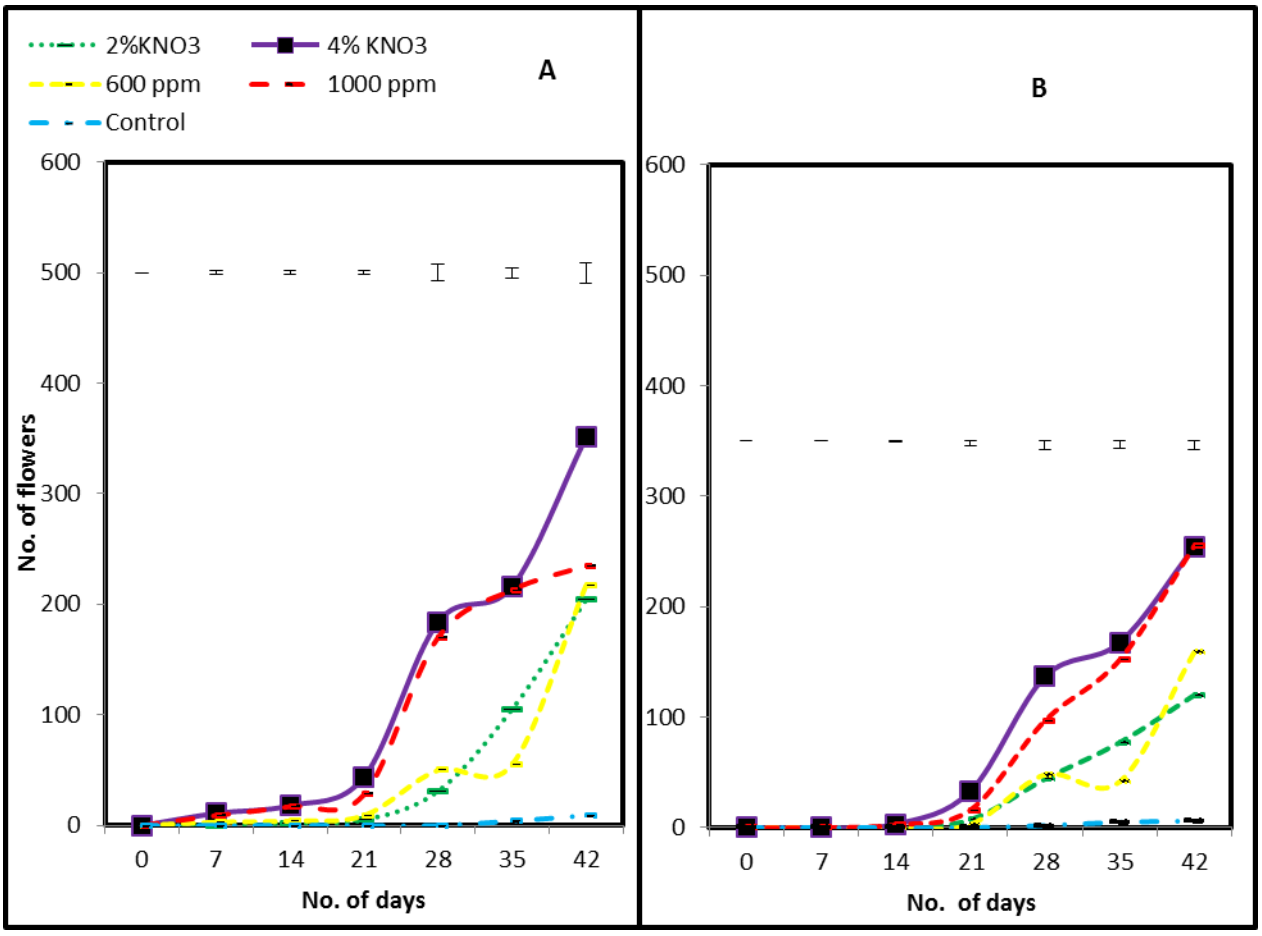


Figure 3.1: Effect of ethephon and Potassium nitrate on the average number of flowers (cumulative) for 'Apple' variety in Makueni (A) and Embu (B) Counties respectively. Top bars indicate least significant difference (LSD) between means at p=0.05

3.3.3 Effect of Potassium nitrate and Ethephon on percentage flowering

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on percentage flowering (Table 3.4). There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Among all the treatments in the two locations, test trees treated with 4% KNO_3 recorded the highest percentage flowering. It was followed by 1000ppm treated trees in the two locations. They had 67.2 and 63.3% flowering on average respectively.

Irrespective of the study location, the highest percentage flowering was observed in 4% KNO_3 treated trees in both varieties followed by 1000 ppm Ethephon (Table 3.4).

In 'Apple' mango from Embu, there was no significant difference in flower induction between 2% KNO_3 and 600ppm ethephon treated trees. However, both differed significantly in relation to the control. The percentage flowering induced by 4% KNO_3 treatment in Embu was 27%. This was a 22% increase respectively with respect to control. The lowest percentage flowering (5%) was recorded in the control 'Apple' trees in the same location. In Makueni, the percentage flowering induced by 4% KNO_3 in the same variety was 94%. Flowering in the control trees was 25 % in the same location.

In 'Ngowe' from Embu, the percentage flowering induced by 4% KNO_3 treatment was 48%. In Makueni, the percentage flowering induced by 4% KNO_3 in the same variety was 100%. Flowering in the control trees was 31% in the same location. Response of the test trees to ethephon increased with concentration with 1000ppm giving the best response; 37% and 100% flowering (% of tagged shoots) for Embu and Makueni respectively in 'Ngowe' treated trees (plate 3.5 A). This was a 29% and a 69% increase respectively compared to the control (Table 3.4).

The effect of the treatments was significantly affected by the season with first season registering a lower percentage flowering (Table 3.3).

Table 3.3: Effect of Potassium nitrate (KNO3) and Ethephon on percentage flowering of Apple Ngowe and mango trees in Embu and Makueni Counties in season 1

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	**APPLE**	**NGOWE**	**APPLE**	**NGOWE**	**MEANS**
2% KNO_3	0.0a	7.0de	0.0a	7.0de	3.5
4% KNO_3	4.0bc	46.0j	60.0k	27.0i	34.3
Ethephon 300ppm	0.0a	3.0bc	0.0a	4.0bc	1.8
Ethephon 600ppm	0.0a	16.0g	2.0ab	9.0ef	6.8
Ethephon 1000ppm	2.0ab	22.0h	5.0cd	28.0i	14.3
Control	0.0a	3.0bc	0.0a	2.0ab	1.3
$LSD_{0.05}$ (Treat)	1.6	4.4	1.4	3.4	
$LSD_{0.05}$ (Loc. x Var. x Treat)	2.7				
CV (%)	15.7				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.4: Effect of Potassium nitrate (KNO_3) and Ethephon on percentage flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	10.0b	19.0c	38.0g	43.0h	27.5
4% KNO_3	27.0ef	48.0i	94.0k	99.7lm	67.2
Ethephon 600ppm	11.0b	18.0c	52.0i	72.0j	38.3
Ethephon 1000ppm	21.0cd	37.0g	95.0kl	100.0m	63.3
Control	5.0a	8.0ab	25.0de	31.0f	17.3
$LSD_{0.05}$ (Treat)	4.4	4.1	7.7	6.4	
$LSD_{0.05}$ (Loc. x Var. x Treat)	4.8				
CV (%)	6.8				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.4 Effect of potassium nitrate (KNO_3) and Ethephon on number of panicles

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on panicle development (Table 3.5). There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. In both varieties and locations, the effect of the two treatments (KNO_3 and Ethephon) increased as the concentration increased, with the highest concentrations (4% and 1000 ppm respectively) resulting in the highest response.

In 'Apple' mango from Embu, 4% KNO_3 and 1000 ppm Ethephon resulted in the highest number of panicles, 136 and 98 respectively compared to 8 panicles in the control. In the same variety from Makueni, the same treatments resulted in more panicles compared to Embu, 351 and 340 for 4% KNO_3 and 1000 ppm ethephon respectively compared to 41 panicles in the control (Table 3.5).

In 'Ngowe', a higher number of panicles were observed compared to 'Apple'. In Embu, 4% KNO_3 and 1000ppm ethephon resulted in 225 and 153 panicles respectively compared to 21 panicles in the control. As observed in 'Apple', the response to the treatments was greater in Makueni whereby 4% KNO_3 and 1000ppm ethephon resulted in 370 versus 344 panicles

respectively compared to 45 panicles in the control (Table 3.5).The effect of the treatments was significantly affected by the season with second season recording a higher number of panicles.

Table 3.5: Effect of Potassium nitrate (KNO_3) and Ethephon on number of panicles of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	44.7c	102.7e	204.6h	206.5h	139.6
4% KNO_3	136.0f	225.3i	351.0l	369.7m	270.5
Ethephon 600ppm	48.5c	72.3d	217.4i	235.6j	155.6
Ethephon 1000ppm	98.0e	153.0g	339.7k	344.0kl	233.7
Control	8.0a	21.0b	40.7c	45.3c	28.8
$LSD_{0.05}$ (Treat)	6.6	6.9	10.7	9.6	
$LSD_{0.05}$ (Loc. x Var. x Treat)	8.0				
CV (%)	3.0				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.5 Effect of potassium nitrate and Ethephon on fruit set

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on fruit set (Table 3.6). There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. 4% KNO_3 and 1000 pm ethephon resulted in the highest fruit set in both AEZs and varieties. All the treatments significantly ($p \leq 0.05$) increased the initial fruit set at pea size stage compared to the control. Moreover, fruit set amongst the treatments differed significantly.

In 'Apple' from Embu, control had the lowest number of fruits (31) at the pea size stage. In the same location, 2% and 4% KNO_3 had 56 and 216 fruit set respectively compared to 31 for the control in the same variety. The number of fruits counted on 'Apple' trees treated with 600 and 1000ppm ethephon were 83 and 152 fruits respectively. In Makueni, fruit set in 'Apple' trees treated with 1000ppm ethephon did not vary significantly ($p \leq 0.05$) with the 'Apple' trees in which 2% Potassium nitrate was applied. They had 141 and 139 fruits respectively. 4% KNO_3 treatment resulted in the highest fruit set (237) in the same variety and location (Table 3.6) (plate 3.4).

In 'Ngowe' mango, trees treated with 4% KNO_3 in Embu had fruit set of about 280 which represented an increase of 227 with respect to the control. This was relatively higher than 250 recorded for the 1000 ppm ethephon treatment which represented an increase of 197 compared to the control. 2% KNO_3 and 600ppm ethephon treated 'Ngowe' trees had 110 and 130 fruits at the pea size stage in the same location. In the same variety in Makueni, fruit set in 4% KNO_3 treated trees was more than twice that of 600ppm-Ethephon treated trees (plate 3.3).. 2% KNO_3 and 1000ppm ethephon treatments resulted to 169 and 181fruits at the pea size stage in Makueni (Table 3.6).

Overall, the highest fruit set at the pea size stage was seen in 'Ngowe' trees that were treated with Potassium nitrate at 4%. 288 immature fruits were recorded compared to 55 fruitlets for the control.

Table 3.6: Effect of Potassium nitrate (KNO_3) and Ethephon on fruit set of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	56.7c	110.3e	139.5g	169.0i	118.9
4% KNO_3	216.0k	280.8m	237.0l	288.0n	255.5
Ethephon 600ppm	83.3d	130.0f	113.0e	134.6fg	115.2
Ethephon 1000ppm	152.6h	250.0m	141.6g	181.0j	181.3
Control	31.0a	53.0c	39.0b	55.0g	44.5
$LSD_{0.05}$ (Treat)	7.1	4.1	7.6	4.0	
$LSD_{0.05}$ (Loc. x Var. x Treat)	7.2				
CV (%)	3.1				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.6 Effect of Ethephon on the internal levels of ethylene in immature fruits

There was no significant interaction ($p \leq 0.05$) amongst the treatment, production location and the varieties. Internal ethylene content in immature fruits did not differ significantly ($p \leq 0.05$) within the first month from fruit set both amongst the treatments and the control. On average, 3.5nl/g/hr.

of ethylene was evolved by fruits from treated trees across the two locations compared to 2.9nl/g/hr. for the control (Table 3.7).

In ‘Apple’ from Embu, ethylene level for fruits from treated and non-treated trees was 3.4nl/g/hr. and 2.6nl/g/hr. respectively. In the same variety in Makueni, the values were 3.7nl/g/hr. and 3.3nl/g/hr. The highest content of ethylene was recorded from immature ‘Apple’ fruits in Makueni. This was 3.7nl/g/hr. Fruits from control ‘Apple’ trees in Embu had the lowest content of ethylene. The ethylene level recorded was 2.6nl/g/hr. All these were statistically not significantly different.

In ‘Ngowe’, the content of ethylene in treated trees was 3.5nl/g/hr. and 3.3nl/g/hr. for Embu and Makueni respectively in comparison with 3nl/g/hr. and 2.8nl/g/hr. (Table 3.7). They were not statistically different.

However after 44 days from fruit set, internal ethylene levels in immature fruits differed significantly between the two production areas. Varieties in Makueni revealed relatively higher values as compared to those in Embu. In ‘Apple’ from Embu, fruits from treated trees had 1.3nl/g/hr. less than treated ‘Apple’ from Makueni (Table 3.8). In ‘Ngowe’ ethylene content for fruits from treated trees varied significantly ($p \leq 0.05$) between the two locations. The content was 3.1nl/g/hr. and 4.9nl/g/hr. for Embu and Makueni respectively. In addition, significant differences also occurred between varieties. ‘Ngowe’ in Makueni produced 1.6nl/g/hr. more than ‘Apple’ in Embu.

Irrespective of the study site and the variety, no significant difference was observed in the production of ethylene by immature fruits at day 58 from fruit set. In ‘Apple’ from Embu, fruits from treated trees evolved 0.4nl/g/hr. ethylene more than control. In Makueni, the same variety had 4.5nl/g/hr. and 4.4nl/g/hr. ethylene for fruits from 1000ppm ethephon treated trees and the control. In Makueni, fruits from treated ‘Ngowe’ trees had the highest content of ethylene. The content was 4.9nl/g/hr. compared to 4.1nl/g/hr. for immature fruits from control trees (Table 3.8).Overall, internal ethylene content from immature fruits was found to be higher in Makueni than in Embu.

Table 3.7: Effect of Ethephon on internal ethylene (nl/g/hr.) in 'Apple' and 'Ngowe' immature fruits sampled 30 days from fruit set from Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
Ethephon 1000ppm	3.4a	3.5a	3.7a	3.3a	3.5
Control	2.6a	3.0a	3.3a	2.8a	2.9
$LSD_{0.05}$ (Treat)	3.1	1.9	2.2	0.1	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.9				
CV (%)	16.9				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.8: Effect of Ethephon on internal ethylene (nl/g/hr.) in 'Apple' and 'Ngowe' immature fruits sampled 44 days from fruit set from Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
Ethephon 1000ppm	3.2a	3.1a	4.5b	4.9b	3.9
Control	3.3a	3.1a	4.2b	4.3b	3.7
$LSD_{0.05}$ (Treat)	0.3	0.3	0.7	1.5	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.6				
CV (%)	8.5				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.9: Effect of Ethephon on internal ethylene (nl/g/hr.) in 'Apple' and 'Ngowe' immature fruits sampled 58 days from fruit set from Embu and Makueni Counties in season 2

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
Ethephon 1000ppm	4.4a	4.4a	4.5a	4.9a	4.6
Control	4.0a	4.1a	4.4a	4.1a	4.2
$LSD_{0.05}$ (Treat)	1.2	0.3	1.5	0.8	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.7				
CV (%)	8.8				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.7 Effect of potassium nitrate and Ethephon on percentage fruit drop

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on percentage fruit drop. There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties even as time progressed from the fruit set (Table 3.10).

In 'Apple' mango, except for the trees that were treated with 1000ppm ethephon, fruit drop in all the other treatments did not differ significantly ($p \leq 0.05$) in Embu. Percentage fruit drop after the second week was 9 more in 1000ppm ethephon treated 'Apple' trees with respect to the control (Table 3.10). The highest fruit retention was observed in the 'Apple' trees treated with 4% KNO_3 in Embu. In the same variety in Makueni, trees treated with 2% and 4% KNO_3 had about 21 and 18% fruit drop respectively as compared to 20% fruit drop for the control after the second week from fruit set.

In 'Ngowe' mango from Embu, within the first two weeks, trees that were treated with 1000 and 600 ppm ethephon had about 33.5 and 19.6% fruit drop respectively compared to the 25% for the control. The same treatments registered 53.9 and 38% fruit drop in the same variety in Makueni (Table 3.10).

Fruit drop in 'Ngowe' variety was observed to be relatively higher in Makueni than in Embu after the next two weeks (4^{th} week) from the fruit set (Table 3.11). The highest fruit drop

occurred in the 'Ngowe' trees that were treated with 1000ppm ethephon resulting to 33% fruit drop after the second two weeks from fruit set. This was relatively higher than 22% fruit drop for the control. In Embu, there was no significant ($p \leq 0.05$) difference in fruit drop between 'Ngowe' trees that were treated with Potassium nitrate. They varied significantly ($p \leq 0.05$) with the control. 2% and 4% KNO_3 recorded 10 and 9% fruit drop respectively in comparison with 17% for the control (Table 3.11).

In 'Apple' mango trees from Embu, Potassium nitrate treatments did not result to significant ($p \leq 0.05$) difference in fruit drop irrespective of the variety as at day 42 from fruit set. Trees treated with 2% and 4% KNO_3 had 5.8 and 4% fruit drop respectively compared to 6.8% for the control. 'Apple' trees treated with 600 and 1000ppm ethephon in the same location had experienced 13.3 and 10% fruit drop respectively by that time. In Makueni, there was no significant ($p \leq 0.05$) difference that resulted in fruit fall between the Potassium nitrate treatments applied to 'Apple' trees in Makueni. 2% and 4% KNO_3 had 8 and 9% fruit drop respectively. Moreover, these values did not differ significantly ($p \leq 0.05$) compared to 11% fruit drop for the control (Table 3.12).

In 'Ngowe', 2% and 4% KNO_3 had 7.4 and 6% fruit drop respectively compared to 14% for the control in Embu. 600 and 1000ppm ethephon resulted to 15.8 and 16.4% fruit drop respectively for the same variety. In Makueni, at day 42 from fruit set, the highest fruit drop had occurred in 'Ngowe' trees treated with 1000ppm ethephon (Table 3.12). An average of 29% fruit drop was established compared to 16% fruit drop from the control trees.

Percentage fruit drop was lower in potassium nitrate treated trees compared to Ethephon treated irrespective of the study site as at day 56 from fruit set (Table 3.13). In 'Apple' mango trees from Embu, there was significant ($p \leq 0.05$) difference in percentage fruit fall from potassium nitrate treated trees. Trees treated with 2% and 4% KNO_3 resulted to an average of about 2% fruit drop each. This was relatively lower than 4% fruit drop for the control. In the same location, 'Apple' trees treated with 600 and 1000ppm ethephon had 1 and 4.4% higher fruit drop compared to the control. 'Apple' trees treated with 4% KNO_3 had the least fruit fall (5%) in Makueni which differed significantly ($p \leq 0.05$) with 8% for the control (Table 3.13).

In 'Ngowe', trees treated with 1000ppm ethephon had the highest fruit drop of 11.3% in Embu. Makueni had the highest fruit drop. The highest fruit drop was recorded in 'Ngowe' trees treated with 1000ppm ethephon in this location. Fruit drop was 23% on average. This varied

significantly ($p \leq 0.05$) with 13% for the control. Fruit fall in 'Ngowe' trees treated with 600ppm ethephon was 14.5% in Makueni. 'Ngowe' trees treated with 2% and 4% KNO_3 had an average of 9 and 7.4% fruit drop respectively in the same location. On the whole, fruit drop was observed to decline with time from fruit set.

Table 3.10: Effect of Potassium nitrate (KNO3) and Ethephon on percentage fruit drop after 14 days from fruit set for 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	11.7a	14.5abc	21.7d	30.8efg	19.7
4% KNO_3	10.5a	13.0ab	18.7bcd	25.2de	16.9
Ethephon 600ppm	14.0abc	19.6bcd	24.3de	38.0h	24.0
Ethephon 1000ppm	20.5cd	33.5fgh	36.7gh	53.9i	36.2
Control	11.7a	25.4de	20.5cd	29.4ef	21.8
$LSD_{0.05}$ (Treat)	4.8	5.9	7.9	9.0	
$LSD_{0.05}$ (Loc. x Var. x Treat)	6.2				
CV (%)	15.7				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.11: Effect of Potassium nitrate (KNO_3) and Ethephon on percentage fruit drop after 28 days from fruit set for 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	8.0ab	10.0abc	9.2abc	15.0def	10.6
4% KNO_3	7.4a	9.2abc	10.5abcd	16.5ef	10.9
Ethephon 600ppm	14.0cde	15.0def	16.0ef	25.7h	17.7
Ethephon 1000ppm	16.5ef	20.0fg	19.4fg	33.5i	22.4
Control	9.0abc	17.0ef	13.0bcde	22.0gh	15.3
$LSD_{0.05}$ (Treat)	2.7	3.7	2.9	9.1	
$LSD_{0.05}$ (Loc. x Var. x Treat)	4.4				
CV (%)	17.3				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.12: Effect of Potassium nitrate (KNO_3) and Ethephon on percentage fruit drop after 42 days from fruit set for 'Apple' and 'Ngowe' mango trees in Embu and Makueni

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	5.8ab	7.4abcd	8.0abcd	13.5efghi	8.7
4% KNO_3	4.0a	6.0ab	9.3bcde	11.0cdef	7.6
Ethephon 600ppm	13.3efgh	15.8hij	15.5ghij	18.0j	19.0
Ethephon 1000ppm	10.0bcdef	16.4hij	17.8ij	29.0k	18.3
Control	6.8abc	14.0fghij	11.5defg	16.0hij	12.1
$LSD_{0.05}$ (Treat)	2.7	3.3	4.3	5.3	
$LSD_{0.05}$ (Loc. x Var. x Treat)	3.8				
CV (%)	18.4				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Table 3.13: Effect of Potassium nitrate (KNO_3) and Ethephon on percentage fruit drop after 56 days from fruit set for 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	2.0a	6.5cde	6.5cde	9.0efg	6.0
4% KNO_3	2.3ab	5.0bcd	5.0bcd	7.4de	4.9
Ethephon 600ppm	5.0bcd	7.5de	7.0de	14.5i	8.5
Ethephon 1000ppm	8.4ef	11.3gh	10.6fgh	23.0j	13.3
Control	4.0abc	7.4de	8.0ef	13.4hi	8.2
$LSD_{0.05}$ (Treat)	2.4	2.8	1.5	5.3	
$LSD_{0.05}$ (Loc. x Var. x Treat)	2.8				
CV (%)	20.8				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.8 Effect of potassium nitrate and Ethephon on total number of fruits per tree

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on total number of fruits per tree (Table 3.14). There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties.

In 'Apple' mango from Embu, trees treated with 1000ppm ethephon gave 79 fruits at harvest in comparison with 149 fruits recorded from the control trees. In the same location and variety, 2% KNO_3 and 4% KNO_3 had 110 and 140 fruits respectively compared to 149 for the control. In Makueni, 'Apple' trees treated with 4% KNO_3 recorded the highest number of fruits. This was 292 with respect to 150 fruits for the control. 2% KNO_3 treatment was second with about 235 fruits on average in the same variety and location.

In 'Ngowe' variety from Embu, 2% KNO_3 and 4% KNO_3 resulted to a total of 185 and 217 fruits respectively compared to 131 for the control. 600 and 1000ppm ethephon treated 'Ngowe' trees had 41 and 19 fruits more with respect to the control unlike in 'Apple' variety in the same location. In Makueni, application of 2% KNO_3 and ethephon at 600ppm did not result to any

significant ($p \leq 0.05$) difference in total number of fruits per tree between the two treatments in 'Ngowe' trees. They had 77 and 84 fruits respectively in Makueni. Even if control 'Ngowe' trees had a lower fruit set at the pea size stage with respect to the 'Ngowe' trees treated with 1000ppm ethephon in the same region, they recorded a relatively higher number of fruits at harvest. This was about 121 as compared to 112 fruits for 1000ppm ethephon treatment.

Ability of the treated trees to retain fruits seemed to be higher in the trees treated with Potassium nitrate irrespective of the study location. Overall, test trees treated with potassium nitrate had higher total number of fruits per tree with respect to ethephon treatments (Table 3.14).

Table 3.14: Effect of Potassium nitrate (KNO_3) and Ethephon on total number of 'Apple' and 'Ngowe' fruits per tree in Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	110.3b	185.7i	235.7k	77.7a	152.4
4% KNO_3	140.7e	217.3j	292.0l	107.3b	189.3
Ethephon 600ppm	111.3b	172.3h	185.0i	84.3a	138.2
Ethephon 1000ppm	79.0a	150.3f	157.7g	112.7b	124.9
Control	149.3f	131.3d	150.3f	121.7c	138.2
$LSD_{0.05}$ (Treat)	2.0	3.8	11.8	4.0	
$LSD_{0.05}$ (Loc. x Var. x Treat)	7.3				
CV (%)	3.0				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.4.9 Effect of potassium nitrate and Ethephon on total weight of fruits per tree

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on total weight of fruits per tree (Table 3.15). There was significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. The lowest weight was observed in control Makueni 'Apple' trees which had about 21 kilograms on average.

In 'Apple' from Embu, 1000ppm ethephon resulted to a total fruit weight of 33kg per tree compared to 61.9kg for the control. Fruits from trees treated with 2% KNO_3 and 4% KNO_3 had a

total weight of 44.3 and 60.5kg respectively. In Makueni, total weight of 'Apple' fruits from trees treated with 2% KNO_3 and 600ppm ethephon did not vary significantly ($p \leq 0.05$). Each treatment registered about 31kg on average. However, their weight differed significantly ($p \leq 0.05$) with that of the control which recorded 21 kilograms. Total weight of 'Apple' fruits per tree from 1000ppm treated trees was 5.5kg more compared to control in Makueni. Application of 4% KNO_3 to 'Ngowe' trees resulted to fruits with the highest total fruit weight per tree in the same location.

In 'Ngowe', total fruit weight per tree for fruits from trees treated with 1000ppm ethephon did not differ significantly ($p \leq 0.05$) with that of control trees' fruits in Embu. A total weight of 58.4 and 59.67 kilograms were recorded respectively. 'Ngowe' fruits from trees treated with 2% KNO_3 and 4% KNO_3 had a total weight of 87.3 and 95kg respectively compared to 59.7kg for the control in the same location. 'Ngowe' fruits from 2% KNO_3 and 600ppm ethephon treatments had 73.3 and 63.4kg compared to 51.5kg for the control fruits in the same location.

Irrespective of the treatment and the study location, 'Ngowe' trees had the highest total fruit weight per tree. The highest total fruit weight was obtained from 'Ngowe' trees in Embu which were treated with 4% KNO_3. This was followed by the weight of fruits from trees treated with 600ppm ethephon in the same variety and location. They attained a total fruit weight of 95.03 and 87.70 kilograms per tree respectively. This differed significantly ($p \leq 0.05$) with 59.67 kilograms for the control. Overall, in both locations and varieties 4% KNO_3 treatment registered the highest total fruit weight per tree of 68.8kg (Table 3.15).

Table 3.15: Effect of Potassium nitrate (KNO_3) and Ethephon on total fruit weight (kg) per tree for 'Apple' and 'Ngowe' trees in Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	44.3de	87.3k	31.3bc	73.3i	59.1
4% KNO_3	60.5gh	95.0l	39.2d	80.5j	68.8
Ethephon 600ppm	44.9e	87.7k	31.5bc	63.4h	56.9
Ethephon 1000ppm	33.0c	58.4gh	26.6b	55.8fg	43.5
Control	61.9h	59.7gh	21.1a	51.5f	48.6
LSD $_{0.05}$ (Treat)	5.7	6.7	2.9	7.1	
LSD $_{0.05}$ (Loc. x Var. x Treat)	5.1				
CV (%)	5.6				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

3.3.9 Effect of potassium nitrate and Ethephon on the density of fruits

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on the density of fruits (Table 3.16). There were no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. The mass of each of the three sampled fruit was determined and the displacement method was used to determine the volume of each fruit. The density of each fruit was calculated and expressed as g/cm^3.

In 'Apple' from Embu, a part from control fruits, the density of fruits from all other treatments did not differ significantly ($p \leq 0.05$) irrespective of the treatment. The highest density was recorded in 'Apple' fruits harvested from trees treated with 4% KNO_3 in Makueni. This was 1.7 g/cm^3. It did not differ significantly ($p \leq 0.05$) with 1.5 g/cm^3 for the control. Fruits from 'Apple' trees treated with 600 and 1000ppm ethephon in the same location registered 1.6g/cm^3 each compared to 1.5g/cm^3 for the control.

In 'Ngowe', similar to the 'Apple' variety, the density of fruits from all treatments did not differ significantly ($p \leq 0.05$) regardless of the treatment. In Makueni in the same variety, fruits

harvested from trees treated with 2% and 4% KNO_3 had a density of 1 and 1.2 g/cm^3 respectively compared to 1.1g/cm^3 for the control.

In both locations and varieties, fruits harvested from trees treated with 4% KNO_3 recorded the highest density (1.4g/cm^3) on average (Table 3.16).

Table 3.16: Effect of Potassium nitrate (KNO_3) and Ethephon on the density (g/cm^3) of 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	1.6c	1.1ab	1.6c	1.0ab	1.3
4% KNO_3	1.5c	1.1ab	1.7c	1.2ab	1.4
Ethephon 600ppm	1.5c	1.0ab	1.6c	1.1ab	1.3
Ethephon 1000ppm	1.5c	1.1ab	1.6c	0.9a	1.3
Control	1.2b	1.0ab	1.5c	1.1ab	1.2
LSD $_{0.05}$ (Treat)	0.7	0.1	0.1	0.2	
LSD $_{0.05}$ (Loc. x Var. x Treat)	0.3				
CV (%)	11.9				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

Plate 3.3: 'Ngowe' mango tree treated with 4% KNO_3 in Makueni

Plate 3.4: 'Apple' mango tree treated with 4% KNO_3 in Makueni

Plate 3.4: 'Ngowe' mango trees in Embu (A: treated with 4% KNO_3, B: Control)

Plate 3.5: 'Ngowe' mango tree treated with ethephon 1000ppm in Makueni

Plate 3.6: 'Ngowe' mango tree (control) in Makueni

Plate 3.7: 'Apple' mango tree (control) in Makueni

Plate 3.8: 'Apple' mango trees in Embu (A: treated with ethephon 1000ppm, B: Control)

Plate 3.9: 'Apple' mango tree treated with ethephon 1000ppm in Makueni

3.4 Discussion

Understanding mango flowering is essential to efficiently utilize management systems that extend the flowering and crop production seasons (Kulkarni, 2004; Davenport, 2009). Flower induction in mango is the temporary commitment of buds to evoke a particular development pathway which can be vegetative shoot, generative shoot or mixed shoot when growth is initiated. Initiation of plant flowering refers to the onset of floral bud growth in actively growing vegetative shoots after the floral inductive event (Huala and Sussex, 1993; Kinet, 1993).

In the present study flower induction chemicals (potassium nitrate and ethephon) were used to manipulate flowering in trees that failed to flower during the fruiting season. The findings show that the treatments had a significant effect on reproductive growth parameters and subsequently on the yield components of the fruit trees. The effect of the chemicals was significantly affected by the mango variety and production location. There was significant interaction amongst the treatments, mango production location and the varieties.

The differences in responses observed could be attributed to many factors. One of the major differences in response was observed between the two AEZs – Makueni and Embu. The two AEZ differ significantly in temperature and rainfall. Embu is relatively cooler (mean temperature 19 ^{o}C) while Makueni is hotter (mean annual temperature ranging between 26^{o}C to 35^{o}C). The significant differences in temperature, coupled with differences in rainfall and soils could have significant effect on tree growth and physiology, subsequently affecting the trees' responses to treatments.

Significant KNO_3 treatment effect on time to flowering, percentage flowering, number of panicles and fruit set was observed in both mango varieties regardless of the production location. KNO_3 at 4% induced early flowering in treated trees compared to control trees. This effect could be in part attributed to additional N from KNO_3. Increased nitrogen fertilization through the soil has been found to increase fruit retention and yield in mango (Yeshitela *et al*. 2004). Kulkarni (2004) suggested that the floral stimulus is present in stems when buds are forced in response to KNO_3. He also opined that KNO_3 may sensitize buds to the floral stimulus. Davenport (2003), observed 100% vegetative shoots when 4% KNO_3 foliar was applied to two-month-old stems whereas, application of the same spray treatment to 4.5-month-old stems on trees in the orchards resulted in 100% reproductive shoots. The study shows that amongst other factors, the time of application of the flower inducing chemical has a significant effect on the kind of response

obtained. In the present study, the response was also affected by the concentration of the chemicals with 4% and 1,000 ppm of KNO_3 and ethephon respectively resulting in the greatest response compared to the lower concentrations. Similar results were reported by Sergent *et al.* (1996) who observed that trees treated with high KNO_3 dose (3.6 and 4.6%) induced early flowering and harvesting (30 to 45 days earlier) as compared to those treated with lower concentrations and untreated trees. Similarly, higher concentration of Ethephon (600 ppm and 1000 ppm) induced higher percentage flowering and fruit set. However trees treated with 1000ppm of Ethephon experienced relatively higher fruit fall compared to the control. The ethylene-generating agent, Ethephon, has been used to successfully induce and increase flowering in various mango varieties in the Philippines and India (Chanda and Pal, 1986; Dutcher, 1972). The phytohormone ethylene is well known to influence a number of physiological and developmental processes in plants including, but not limited to seed germination, seedling growth, and formation of the apical hook, senescence, fruit ripening, abscission and gravitropism (Abeles *et al.*, 1992). A clear trend in terms of the responses of the ethephon treated trees for most of the parameters measured was observed between the rates of ethephon applied. Responses of the ethephon treated trees increased with concentration. This observation concurs with the findings of Galan and Fernandez (1987) who reported clear different results for 400 and 800ppm ethephon rates applied to three mango cultivars (Zill, Haden and Sensation). In this study epinasty of mature leaves, senescence of some leaves, flowers and some fruit abscission was observed in ethephon treated trees. More effect was observed in test trees treated with 1000ppm ethephon in both locations. In a similar study, very high percentage abscission was reported in fruit trees treated with ethephon at 800 ppm or more and partial results in trees treated with 400 ppm (Stephenson and Gallagher, 1978). The effect of ethylene on abscission can be accredited to ethylene emitted with the decomposition of ethephon. The effect may logically be explained by the well-known action of ethylene in promoting senescence and death of flowers (Abeles, 1973). These observations indirectly link to symptoms of ethylene production and indicate the involvement of endogenous ethylene in flowering. Other related studies show that KNO_3-stimulated flowering of mango is mediated by increased levels of endogenous ethylene. Mosqueda-Vazquez and Avila-Resendiz (1985) reported that the efficacy of KNO_3 was negated by cobalt chloride ($CoCl_2$) and silver nitrate ($AgNO_3$) which inhibit the synthesis and action of ethylene, respectively, when sprayed 1-4 h after KNO_3. In that study, a gradual increase in endogenous leaf ethylene production was reported as the season of

floral initiation approached. Ethylene production by stems producing reproductive shoots was up to fivefold that of resting stems. Davenport and Nunez-Elisea (1990) reported elevated ethylene production in mango stems in response to ethephon sprays without an accompanying floral response.

There was a clear relation between flowering and fruit yield per tree in both phases of the study with trees sprayed with 4% KNO_3 registering higher fruit yield in both sites. Relatively lower fruit number in Ethylene sprayed trees could be related to the higher fruit drop experienced by the trees as compared to the trees sprayed with KNO_3 and the control.

3.5 Conclusion

The variable results obtained between the two off-season flower induction technologies and their different concentrations clearly reflect the effect of different off-season flower induction technologies and the dosing range on the responses of the mango cultivars to the flower inducers. Potassium Nitrate sprayed at the rate of 4% resulted in a better response than 2% rate in both study sites as established from the reproductive growth parameters measured including days to flowering and fruit set; number of panicles per tree, average fruit set per 20 panicles, number of fruits at harvest, the total tree weight and the size of fruits. Ethephon on the other hand resulted in better response at 600 and 1000ppm in both sites in some of the parameters. However, abscission of some leaves, flowers and immature fruits accompanied ethephon treatments especially 1000ppm.

Spraying the ‘Apple’ and ‘Ngowe’ mango trees with 4% KNO_3 was found to be beneficial for all the flowering and fruiting parameters in both study sites. Ethephon can be sprayed at the rate of 600ppm rather than 1000ppm to minimize the negative effect of fruit drop on the trees. Moreover in terms of the amount of Ethephon chemical used in application it is more cost effective to spray Ethephon at 600ppm rather than 1000ppm.

CHAPTER 4

EFFECT OF OFF-SEASON FLOWER INDUCTION TECHNOLOGIES (ETHEPHON AND POTASSIUM NITRATE) ON THE QUALITY ATTRIBUTES OF 'APPLE' AND 'NGOWE' MANGO FRUITS

Abstract

Mango, a tropical fruit of great economic importance, is generally harvested green and then commercialized after a period of storage. Unfortunately, the final quality of mango batches is highly heterogeneous, in fruit size as well as in gustatory quality and postharvest behavior. A large amount of knowledge has been gathered on the effects of the maturity stage at harvest and postharvest conditions on the final quality of mango. Considerably less attention has been paid to the influence of preharvest factors such as chemicals used and other environmental factors on mango growth, quality traits, and postharvest behavior. The objective of the current study was to establish the effect of the off-season flower induction technologies (ethephon and potassium nitrate) on quality parameters of 'Apple' and 'Ngowe' mango trees. The study was conducted in two agro-ecological zones (AEZs) of Kenya namely, Embu County (a high potential AEZ) and Makueni County (a low potential AEZ). Potassium nitrate and ethephon were each applied to 'Apple' and 'Ngowe' mango trees at two concentrations, 2 and 4% versus 600 and 1000 ppm respectively.) The treated trees were compared to untreated controls which were sprayed with water. A random sample of fruits were harvested at the tree-ripe stage and quality attributes including major sugars (sucrose, glucose and fructose), vitamin C, beta carotene, total soluble solids, and total titratable acid evaluated. Although KNO_3 and Ethephon affected some of quality attributes evaluated, much of the observed differences were not consistent and could somewhat be attributed to the inherent varieties differences in 'Apple' and 'Ngowe'. The differences in the agro-ecological zones (Embu and Makueni) and the cultural practices by farmers in the two locations could have also affected the quality attributes independent of the flower-induction chemicals. In beta-carotene, significant ($p \leq 0.05$) treatment effect was observed in trees treated with 2% KNO_3, 600 ppm and 1,000 ppm ethephon where beta-carotene levels averaged 1.5, 1.6 and 1.7 mg/100 ml compared to 1.4 mg/100ml in the untreated control. Regardless of variety or location, slightly higher vitamin C levels (average 93 mg/100 ml) were reported in KNO_3 treated trees compared to those treated with ethephon (86.8 to 90.2 mg/100 ml). Apple mango fruits generally had higher vitamin C levels compared to Ngowe fruits regardless of the treatments and AEZ. The trend in total soluble solids and sugars was inconsistent with the AEZ and variety showing the greatest differences. These findings show that off-season flower inducing chemicals

have minimum effect on nutritional quality attributes of 'Apple' and 'Ngowe' mango fruits and could therefore be adopted as a strategy for addressing seasonality in mango production without limiting significantly the quality of the fruits.

4.1. Introduction

Heterogeneity in quality of an agricultural produce or product is caused by many factors, including the cultural practices underlying its production (Luning and Marcelis, 2006; Ritter et al., 2008). Finding the source of this heterogeneity in the field is therefore fundamental for designing methodologies to obtain a more uniform produce or product quality at harvest.

From the point of view of fruit quality, it is essential to understand how preharvest factors influence source-sink relationships involved in fruit growth. Taste of fresh fruit is highly dependent on the balance between organic acids and soluble sugars, which are predominantly represented in mango by citric and malic acids (organic acids), and sucrose, fructose and glucose (soluble sugars), respectively (Medlicott and Thompson, 1985). The patterns of these compounds during mango development and maturation are well described, even if many studies deal with the evolution of fruit flesh composition during ripening according to harvest date. Preharvest cultural practices, which affect the environmental conditions of fruit development, profoundly influence postharvest performance and final quality (Crisosto et al., 1995; Hewett, 2006). Few studies related to the effects of environmental factors on mango quality before harvest have been carried out, and even less have focused on the interaction between pre-harvest and postharvest factors, whereas it is necessary to take these factors into account in order to propose technical solutions to improve final mango quality.

Pre-harvest treatment used to address various production challenges could have a significant effect on postharvest quality and longevity. Past studies in other fruits have shown mixed effects of pre-harvest sprays with flower induction chemicals. Yeshitela (2004) reported a non-significant difference for the qualitative parameters between potassium nitrate (4%) treated 'Tommy Atkins' mango and non-treated trees. The parameters tested include total soluble solids, total titratable acidity, reducing sugars and total sugars. This was contrary to results obtained by Hegazi et al. (2011) who reported that foliar application of potassium nitrate at 4% after final fruit set or pit hardening improved the vegetative growth, nutritional status especially in the second season and the productivity in both seasons. In a different study, sprays of KNO_3 at 4 % after pit hardening gave the best values of fruit quality (fruit minerals, flesh oil content, and flesh

dry weight) and flesh oil content of Picual olive fruit in both seasons of the study. Khayyat et al., (2012) showed that KNO_3 significantly influenced fruit quality of pomegranate when fruit are in the beginning stages of growth and development. Although there was not a significant difference among treatments on titrable acidity and pH contents of fruits, the highest total soluble solids and vitamin C were obtained in the 250mg/litre KNO_3 treatment when compared with the control.

Ethephon (and other forms of ethylene) has been used in some fruits to induce off-season flowering and promote uniform flowering. Its effect on fruit quality attributes is seldom reported. Past studies indicate that ethephon application could have a significant effect on the fruit quality. Fruits from ethephon-sprayed trees of sour cherry (cultivar 'Cigany') had significantly lower soluble solids concentration (SSC), anthocyanin content, antioxidant activity, and firmness than those from non-sprayed control. The ethephon spray did not affect total phenolic content, although its content tended to be higher in fruits from non-treated control (Khorshidi and Davarynejad, 2010). Watada et al., (1976) reported that ethylene affects the vitamin C content but not the B-carotene content of tomatoes. In pineapple, application of chemicals such as ethephon, acetylene and calcium carbide for flower induction has helped growers increase production, attain uniform fruiting and maturity (Addo-Quaye *et al*., 1995; Soper *et al*., 1997; Chang, 2000). In some pineapple cultivars such as 'Smooth Cayenne', fruit maturity has been synchronized by applying ethephon (Smith, 1991). Ethephon application in pineapple has been reported to affect other fruit quality attributes. Moisture content of chemically induced pineapple was reported to be lower (84.3%) than the non-induced fruits (86.8%). Similarly, total sugars, sucrose and reducing sugars were all higher in induced fruits than the non-induced fruits (Bediako et al. 2007).

These studies reveal that treatment of fruit trees with chemicals such as ethephon and KNO_3 aimed at influencing flowering in fruits can potentially affect fruit quality and other postharvest characteristics. Therefore the objective of the current study was to establish the effect of the off-season flower induction technologies (ethephon and KNO_3) on quality attributes of 'Apple' and 'Ngowe' mango trees grown under two contrasting agro-ecological zones in Kenya; a high potential AEZ (Embu) and a low potential AEZ (Makueni).

4.2. Materials and Methods

4.2.1 Fruit sampling

'Apple' and 'Ngowe' mango fruits were harvested from the test trees in Embu County (AEZ with some high potential areas) and Makueni County (a low potential AEZ). The fruits were harvested at tree ripe maturity stage judged by flesh color. Thirty to fifty fruits were harvested from each treatment. The fruits were carefully harvested, packed in plastic crates and then transported to a postharvest laboratory in Jomo Kenyatta University of Agriculture and Technology where they were immediately washed using cold water treated with 1% acetic acid for sanitization. Thereafter, the fruits were left to air-dry and then selected for uniformity and freedom from blemishes. Eight fruits were then selected from each of the three replicates per treatment (a total of twenty four fruits per treatment). The treatments included Potassium nitrate applied at two rates (2 and 4%), Ethephon at 600 and 1000ppm, and the control (plain water). The fruit quality attributes evaluated included total soluble solids, total titratable acidity, ascorbic acid, β-carotene and soluble sugars.

4.2.2. Analysis of biochemical quality attributes

4.2.2.1. Total soluble solids (°brix) content

Total soluble solids (TSS) content was determined using an Atago hand refractometer (Model 500, Atago, Tokyo, Japan) and expressed as ^{o}Brix. Juice was separately extracted from 3 fruits (from each of the three batches per treatment) and the TSS level determined using the refractometer. The TSS level was expressed as °brix.

4.2.2.2. Total titratable acidity

Total titratable acidity (TTA) was determined by titration of fruit juice sample with 0.1N NaOH using phenolphthalein as an indicator. Five milliliters of the juice extracted was diluted with 25ml of distilled water. 10ml of the diluted juice was used for titration with 0.1N Sodium Hydroxide using phenolphthalein as an indicator. The TTA was expressed as % citric acid using the formula:

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

Four tree-ripe fruits from each of the three batches per treatment (different variety and production site – AEZ) were randomly sampled, diced and packed in zip-lock bags and frozen at -20^{0}C.Various quality attributes were then determined. The quality attributes determined

included beta-carotene, vitamin C (ascorbic acid), and soluble sugars (fructose, glucose and sucrose).

4.2.2.3. Determination of β-carotene content

The β-carotene content was determined by a modified chromatographic procedure (Heionen, 1990). A sample of 5g (pulp) was crushed in a pestle with a mortar. A spatula of hydroflorosupercel was added and then extracted using 50ml acetone until the residue became white. Partitioning was done using 25ml of petroleum ether in a separating funnel. Saponification was done by adding an equal amount of extract in to 3ml of 10% KOH in methanol, and a few drops of 0.1% butylatedhydrotoluene in petroleum ether. Sodium sulphate (anhydrous) was added to remove water and further concentration done using a rotary evaporator. The ß-carotene content was determined using HPLC (Model LC-10AS, Shimadzu Corp., Kyoto, Japan), having the following conditions;

Mobile phase: acetonitrile: methanol: dichloromethane (70: 10: 20),

Flow rate: 1.0 ml/min,

Column: ODS 150,

Injection volume: 10µL,

Oven temperature: 35 ^{o}C.

The β−carotene content was calculated as follows:

β−carotene (mg/100ml) = A × Volume (ml) ×104

A1% 1cm × sample weight (ml)

Where A= absorbance; volume = total volume of extract (25 ml); A1%1cm = absorption coefficient of β−carotene in PE (2592).

4.2.2.4. Determination of ascorbic acid content

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.

4.2.2.5. 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. 2 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 µl

Mobile phase: Acetonitrile: water (75:25).

The sugars present were identified and their individual concentration calculated using the standards.

4.2.3. Data analysis

Data was analyzed using Genstat (15^{th} Edition). Comparison of means was done by Analysis of Variance (ANOVA) and where there were significance differences, further separation done using Least Significance Difference (LSD) at $P \leq 0.05$. The ANOVA tables showing the levels of significance and interactions between the factors are presented in the appendices.

4.3. Results

4.3.1. Beta-carotene

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on β-carotene content in the fruits (Table 4.1). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. In both locations (Embu and Makueni) and varieties ('Apple' and 'Ngowe'), mango fruits harvested from trees treated with 1000ppm ethephon had the highest content of β-carotene on average (1.7mg/100ml). Fruits from harvested from mango trees treated with 4% KNO_3 recorded the lowest β-carotene content (≤1.4mg/100ml) in both locations and varieties.

In 'Apple' mango from Embu, fruits harvested from trees treated with 1000ppm ethephon had the highest content of β-carotene (1.7mg/100ml) which however did not differ significantly

($p \leq 0.05$) with the control in the same location. 'Apple' mango from trees treated with 4% KNO_3 had the lowest content of β-carotene in both locations (1.3mg/100ml). In Makueni, β-carotene content in fruits from 'Apple' trees treated with 600 and 1000ppm ethephon was significantly higher (1.7mg/100ml) compared to that of the control (1.4 mg/100 ml). In 'Ngowe' mango, fruits from trees treated with 2% KNO_3 and 1000ppm ethephon in Embu recorded similar content of β-carotene. They had 1.6mg/100ml each compared to 1.3mg/100ml for the control. Fruits harvested from trees treated with 600 and 1000ppm ethephon had 1.5mg/100ml and 1.6mg/100ml respectively in the same variety in Makueni (Table 4.1).

Table 4.1: Effect of Potassium nitrate (KNO3) and Ethephon on Beta carotene content (mg/100ml) in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	1.4abc	1.6abc	1.4abc	1.6abc	1.5
4% KNO_3	1.3ab	1.3ab	1.3ab	1.4abc	1.3
Ethephon 600ppm	1.6abc	1.5abc	1.7c	1.5abc	1.6
Ethephon 1000ppm	1.7c	1.6bc	1.7c	1.6abc	1.7
Control	1.5abc	1.3a	1.4abc	1.5abc	1.4
$LSD_{0.05}$ (Treat)	0.1	0.2	0.2	0.2	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.2				
CV (%)	7.1				

Values followed by the same letter(s) in a column or row do not differ significantly at 5% level of significance. Loc=location Var=variety and Treat=treatment

4.3.2. Ascorbic acid (vitamin C)

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on vitamin C content in the fruits (Table 4.2). There was a significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Overall, the highest content of vitamin C (93mg/100ml) was recorded in fruits harvested from trees treated with 4% KNO_3 in both locations (Embu and Makueni) and varieties. Fruits from trees treated with 1000ppm ethephon had the lowest content of vitamin C on average (86.8mg/100ml).

In ‘Apple’ mango from Embu, fruits harvested from trees treated with 2% KNO_3 and 4% KNO_3 had 100.7 mg/100ml and 99.2mg/100ml vitamin C respectively. Vitamin C in fruits from ethephon treated trees and the control did not differ significantly ($p \leq 0.05$) in the same variety. In Makueni, vitamin C content in fruits harvested from treated ‘Apple’ trees were largely not significantly ($p \leq 0.05$) different. They however differed significantly ($p \leq 0.05$) with the control in the same location where the control was more superior in terms of vitamin C. The content of vitamin C in the fruits from the control trees was 106.9 mg/100ml, which was relatively higher than 100.7 mg/100ml, 100.2 mg/100ml and 100.4 mg/100ml for 2% KNO_3, 4% KNO_3 and 600ppm treatments respectively (Table 4.2).

In ‘Ngowe’, the lowest vitamin C content was recorded by fruits harvested from untreated ‘trees in Embu (67.9mg/100ml). It did not differ significantly ($p \leq 0.05$) with 68.3 mg/100ml for fruits from trees treated with 1000ppm ethephon (Table 4.2). In the same variety, fruits from trees treated with 2% and 4% KNO_3 in Makueni had 85.9 mg/100ml, and 86.9 mg/100ml respectively. Vitamin C in fruits from trees treated with 1000ppm ethephon recorded 83.2 mg/100ml compared to 90.2mg/100ml for the control in Makueni.

Overall, ‘Apple’ fruits had higher levels of ascorbic acid content compared to ‘Ngowe’ fruits irrespective of the treatments and the study sites (Table 4.2).

Table 4.2: Effect of Potassium nitrate (KNO_3) and Ethephon on vitamin C content (mg/100ml) in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	100.7ef	82.4bc	102.7fg	85.9cd	92.9
4% KNO_3	99.2ef	85.8cd	100.2ef	86.9cd	93.0
Ethephon 600ppm	96.8e	78.3b	100.4ef	84.6c	90.0
Ethephon 1000ppm	96.3e	68.3a	99.5ef	83.2bc	86.8
Control	95.9e	67.9a	106.9g	90.2d	90.2
$LSD_{0.05}$ (Treat)	2.0	1.9	4.7	4.6	
$LSD_{0.05}$ (Loc. x Var. x Treat)	3.1				
CV (%)	2.1				

Values followed by the same letter(s) in a column or row do not differ significantly at 5% level of significance. Loc=location Var=variety and Treat=treatment

4.3.3. Total Soluble Solids (TSS = °brix)

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on TSS content in the fruits (Table 4.3). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. There was no consistent trend with respect to treatments and varieties. For example in Embu, although 'Apple' fruits from potassium nitrate treated trees had higher content of °brix compared to those from ethephon treated trees, it was the reverse in 'Ngowe' variety ('Ngowe' fruits from potassium nitrate treated trees had lower content of °brix compared to 'Ngowe' fruits from ethephon treated trees).

In 'Apple' from Embu, application of Potassium nitrate to the trees did not result to any significant ($p \leq 0.05$) difference in the TSS content. Brix levels of 14.4° and 14.9° were recorded for 2% KNO_3 and 4% KNO_3 respectively. The brix level for the fruits from control 'Apple' trees in the same location was relatively higher than fruits from the trees applied with 4% KNO_3 (Table 4.3).

In ‘Ngowe’ mango, fruits from untreated trees had the highest TSS content (15.8°) in Embu. In Makueni in the same variety (Ngowe), the trees treated with 1000ppm ethephon had the lowest level of total soluble solids (10.4°) which was significantly different ($p \leq 0.05$) from that of the control (16.8°). Overall, fruits harvested from Makueni had higher °brix content than fruits harvested from Embu. Moreover, fruits harvested from non-treated trees recorded higher levels of °brix content than fruits harvested from treated trees on average (Table 4.3).

Table 4.3: Effect of Potassium nitrate (KNO_3) and Ethephon on total soluble solids content (°brix) in ‘Apple’ and ‘Ngowe’ mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	‘APPLE’	‘NGOWE’	‘APPLE’	‘NGOWE’	MEANS
2% KNO_3	14.4defg	12.6bcd	15.2fgh	12.5bcd	13.7
4% KNO_3	14.9efgh	10.8ab	16.7hi	14.0defg	14.1
Ethephon 600ppm	13.6cdef	12.2abcd	14.0defg	12.9cde	13.2
Ethephon 1000ppm	12.6bcd	11.7abc	13.0bcde	10.4a	12.0
Control	16.4hi	15.8gh	17.9i	16.8hi	16.7
$LSD_{0.05}$ (Treat)	1.7	2.0	1.6	1.4	
$LSD_{0.05}$ (Loc. x Var. x Treat)	1.4				
CV (%)	6.1				

Values followed by the same letter(s) in a column or row do not differ significantly at 5% level of significance. Loc=location Var=variety and Treat=treatment

4.3.4. Total Titratable Acidity (TTA)

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on TTA content in the fruits (Table 4.4). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. On average, in both locations (Embu and Makueni) and varieties (‘Apple’ and ‘Ngowe’), fruits harvested from untreated trees had the highest content of TTA (average 0.4% citric acid equivalent). Regardless of the production location and variety, fruits from trees treated with 1000ppm ethephon recorded the lowest TTA (0.2%) on average (Table 4.4).

In ‘Apple’ mango from Embu, fruits harvested from the untreated and 4% KNO_3 treated trees had the highest TTA content (0.4%). This was relatively higher than 0.2% for fruits from trees treated with 1000ppm ethephon in the same variety and location. In Makueni, there was no significant ($p \leq 0.05$) difference in total titratable acidity content in fruits harvested from trees treated with Potassium nitrate and untreated trees in the same variety. TTA content recorded was 0.3% for each.

In ‘Ngowe’ mango from Embu, fruits harvested from untreated ‘Ngowe’ trees had the highest TTA (0.4%) compared to TTA content in fruits harvested from treated trees in the same location irrespective of the treatment. In Makueni, the total titratable acidity content in fruits harvested from treated and untreated trees was ≤ 0.3% in the same variety (Table 4.4).

Table 4.4: Effect of Potassium nitrate (KNO3) and Ethephon on total titratable acidity content (percentage) in ‘Apple’ and ‘Ngowe’ mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	‘APPLE’	‘NGOWE’	‘APPLE’	‘NGOWE’	MEANS
2% KNO_3	0.3bcd	0.3abc	0.3abc	0.2ab	0.3
4% KNO_3	0.4de	0.3abcd	0.3bcd	0.2ab	0.3
Ethephon 600ppm	0.3bcd	0.3abcd	0.3abc	0.2ab	0.3
Ethephon 1000ppm	0.2ab	0.2ab	0.2ab	0.2a	0.2
Control	0.4e	0.4de	0.3cde	0.3bcd	0.4
$LSD_{0.05}$ (Treat)	0.1	0.1	0.1	0.1	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.1				
CV (%)	10.5				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

4.3.5. Major sugars

4.3.5.1. Fructose

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on fructose content in the fruits (Table 4.5). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. In both locations (Embu and Makueni) and varieties ('Apple' and 'Ngowe'), fruits harvested from trees treated with 1000ppm ethephon had the highest content of fructose (7.5mg/100ml) on average. Fruits from untreated trees recorded the lowest fructose (5.7mg/100ml) on average (Table 4.5).

In 'Apple' mango from Embu, fructose content was relatively lower in the fruits compared to that in the same variety fruits from Makueni. The lowest content of fructose (5.2mg/100ml) was recorded in fruits harvested from untreated 'Apple' trees in the same production location. Fruits harvested from the 'Apple' trees treated with 2% and 4% KNO_3 had 5.5mg/100ml and 5.4mg/100ml respectively. These values did not vary significantly ($p \leq 0.05$) with 5.2mg/100ml for the control (Table 4.5). In the same variety in Makueni, fruits harvested from the trees treated with 1000ppm ethephon had the highest fructose content amongst all the treatments. This was 8.4mg/100ml.

In 'Ngowe' mango from Embu, fruits harvested from the trees treated with 1000ppm ethephon had the highest fructose content (7.1mg/100ml). In Makueni, fruits harvested from the trees treated with 2% and 4% KNO_3 had 6.5mg/100ml and 6.6mg/100ml compared to 5.9mg/100ml for the control in the same variety,

Irrespective of the production location and variety, fruits harvested from ethephon treated trees had relatively higher content of fructose compared to fructose content in fruits harvested from the test trees treated with KNO_3 (Table 4.5).

Table 4.5: Effect of Potassium nitrate (KNO_3) and Ethephon on fructose content (mg/100ml) in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	5.5abc	5.7abc	6.7fg	6.5f	6.1
4% KNO_3	5.4ab	5.5abc	6.8fg	6.6ef	6.1
Ethephon 600ppm	5.8abcd	6.0cd	7.6i	7.3hi	6.7
Ethephon 1000ppm	6.1cde	7.1gh	8.4j	8.3j	7.5
Control	5.2a	5.3ab	6.3def	5.9bcd	5.7
$LSD_{0.05}$ (Treat)	0.3	0.3	0.6	0.5	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.4				
CV (%)	3.7				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

4.3.5.2. Sucrose

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on sucrose content in the fruits (Table 4.6). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Sucrose levels were relatively lower in cultivated Embu fruits compared to those grown in Makueni. Additionally, fruits harvested from test trees treated with ethephon had higher sucrose levels than those from potassium nitrate treated trees in both locations (Embu and Makueni). In both locations and varieties, fruits from trees treated with 1000ppm ethephon registered the highest content of sucrose (6.0mg/100ml) on average. Fruits harvested from the untreated trees had the lowest sucrose content on average. This was 4.9 mg/100ml (Table 4.6).

In 'Apple' mango, the lowest content of sucrose was recorded in fruits harvested from untreated trees in Embu. This was 4.6mg/100ml. Sucrose content in fruits harvested from trees treated with 600ppm ethephon in both locations varied significantly ($p \leq 0.05$) in the same variety. This was 5mg/100ml and 5.8mg/100ml respectively. Also, they differed significantly ($p \leq 0.05$) with 4.6mg/100ml and 4.9mg/100ml for their respective control. The highest content of sucrose was

recorded in 'Apple' fruits harvested from trees treated with 1000ppm ethephon in Makueni. This was 6.4mg/100ml (Table 4.6).

In 'Ngowe' mango from Embu, sucrose content in the fruits harvested from the trees treated with 1000ppm ethephon was the only one that differed significantly ($p \leq 0.05$) with that of the fruits from the untreated trees. They had 6.0mg/100ml under ethephon treatment and 5.2mg/100ml in the untreated trees respectively. In Makueni, fruits harvested from trees treated with 4% KNO_3 recorded sucrose content of 4.8mg/100ml. Sucrose content in 'Ngowe' fruits harvested from control trees was 0.2mg/100ml higher than the sucrose content in the fruits harvested from trees treated with 4% KNO_3 in the same variety in Makueni (Table 4.6).

Table 4.6: Effect of Potassium nitrate (KNO_3) and Ethephon on sucrose content (mg/100ml) in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	5.1abc	5.5bcde	5.2abc	5.0ab	5.2
4% KNO_3	4.9ab	4.9ab	5.1abc	4.8ab	4.9
Ethephon 600ppm	5.0abc	5.2abc	5.8defg	5.6cdef	5.4
Ethephon 1000ppm	5.4bcd	6.0efg	6.4g	6.2fg	6.0
Control	4.6a	5.2abc	4.9ab	5.0ab	4.9
$LSD_{0.05}$ (Treat)	0.4	0.5	0.5	0.3	
$LSD_{0.05}$ (Loc. x Var. x Treat)	0.4				
CV (%)	4.0				

Values followed by the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

4.3.5.3. Glucose

Potassium nitrate and ethephon treatment had a significant ($p \leq 0.05$) effect on glucose content in the fruits (Table 4.7). There was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Irrespective of the study location and variety, glucose content in fruits from trees treated with 4% KNO_3 did not differ significantly ($p \leq 0.05$) with respect to the glucose content in the fruits harvested from the untreated trees. A total mean of 2.8mg/100ml was recorded for the treatment in both locations and varieties.

Similarly, apart from 'Apple' fruits in Makueni, fruits harvested from trees treated with 2% KNO_3 did not vary significantly ($p \leq 0.05$) in glucose content with respect to that in fruits harvested from control regardless of the location and the variety (Table 4.7). Overall, in both locations and varieties, fruits harvested from trees treated with 1000ppm ethephon had the highest content of glucose. This was 4.2mg/100ml.

In 'Apple' mango from Embu, fruits harvested from trees treated with 1000ppm ethephon had the highest glucose content, but statistically similar to the rest (Table 4.7). This was 3.9mg/100ml. In Makueni, glucose content in fruits harvested from trees treated with 600 and 1000ppm ethephon did not differ significantly ($p \leq 0.05$). 4.1mg/100ml and 4.5mg/100ml respectively were recorded.

In 'Ngowe', fruits harvested from untreated trees in Embu had the lowest glucose content. This was 2.3mg/100ml, but only different from fruits treated with 1000ppm ethephon (4.2mg/100ml). This was followed by glucose content in fruits harvested from test trees treated with 4% KNO_3 (2.4mg/100ml). Glucose content in 'Ngowe' fruits harvested from trees applied with ethephon at 1000ppm in Makueni was 4.1mg/100ml as compared to 4.2 mg/100ml recorded in the same variety and treatment in Embu (Table 4.7).

Table 4.7: Effect of Potassium nitrate (KNO_3) and Ethephon on glucose content (mg/100ml) in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

	PRODUCTION LOCATION				
	EMBU		MAKUENI		
Variety/Treatment	'APPLE'	'NGOWE'	'APPLE'	'NGOWE'	MEANS
2% KNO_3	3.1abcd	2.8abcd	4.8e	3.2abcd	3.5
4% KNO_3	2.7abc	2.4ab	3.1abcd	3.0abcd	2.8
Ethephon 600ppm	3.7cde	3.2abcd	4.1de	3.7bcde	3.7
Ethephon 1000ppm	3.9cde	4.2de	4.5e	4.1de	4.2
Control	2.6abc	2.3a	3.1abcd	3.0abcd	2.8
LSD $_{0.05}$ (Treat)	0.4	1.4	1.2	0.4	
LSD $_{0.05}$ (Loc. x Var. x Treat)	0.8				
CV (%)	14.3				

Figures having the same letter(s) in a column or a row do not differ significantly at 5% level of significance. Loc= location, Var= variety and Treat= treatment

4.4 Discussion

Pre-harvest factors (environmental and cultural practices) can affect both fruit growth during its development by changing the accumulation of water and dry matter, including biochemical and mineral (Léchaudel et al., 2006).

In the current study, effect of flower inducers (Ethephon and Potassium nitrate) on the quality attributes of 'Apple' and 'Ngowe' mango fruit varieties produced under two agro ecological conditions of Kenya; Embu (a high potential AEZ) and Makueni (a low potential AEZ) were analyzed. Biochemical parameters evaluated in the present study included total soluble solids (TSS), total titratable acidity (TTA), vitamin C, Beta carotene, simple sugars and mineral nutrients. Although the flower inducing chemicals affected the levels of these parameters, the trend was not consistent (Table 4.3). The effect was dependent largely on the variety and production location thereby pointing to inherent varietal differences and/or differences in cultural practices and agro-ecological conditions.

Fruits harvested from untreated trees in both sites (Table 4.3) had higher TSS content than fruits from treated trees. Higher TSS content obtained in the fruits harvested from the control trees can be ascribed to trees getting enough time to produce new flushes and those flushes took time to mature without any interference. As compared to old flushes, new and matured leaves can efficiently manufacture more photosynthates and consequently attain higher reserve levels. The implication with sufficient reserve and fruit number not exceeding the tree's capacity is that all the developing fruit would receive an adequate supply of carbohydrates (Léchaudel et al., 2006). Fruits harvested from treated and untreated trees in Makueni had relatively higher TSS compared to the fruits from treatments and control in Embu. Higher TSS in Makueni fruits could be attributed to longer periods of exposure to sunlight which led to increased accumulation of dry matter content in Makueni fruits compared to Embu fruits. Previous studies have reported a positive relationship between light exposure and TSS levels in mango (Mendoza *et al.* 1972).

As earlier reported, there was higher retention of the fruits in the test trees treated with Potassium nitrate. This could partially explain the lower levels of some of the nutrients evaluated. For example relatively lower ascorbic acid content was reported in KNO_3 treated trees compared to the control. This effect could be in part attributed to additional N from KNO_3. Increased nitrogen fertilization through the soil has been found to increase fruit retention and yield in mango (Yeshitela *et al*. 2004). The consequence with fruit number surpassing the tree's capability is that

the developing fruits would receive inadequate supply of ascorbic acid content as each fruit strive to get a share from the reserve. As recorded in table 18 of chapter 3, the ability of the treated trees to retain fruits seemed to be higher in the trees treated with Potassium nitrate irrespective of the study location.

The effect of ethephon on fruit quality was inconsistent and varied with AEZ and variety in the various quality attributes evaluated. However, there was a significant effect of ethephon treatment on β-carotene. Fruits from ethephon-treated trees had higher β-carotene levels compared to the control and those treated with Potassium nitrate (irrespective of the cultivar and the study area). This observation could be attributed to the phytohormone ethylene which was evolved with the application of the ethylene-generating agent, ethephon. It can be deduced that ethephon might have had an impact on the internal levels of ethylene in the fruits as it was revealed from the results obtained in the lab analysis of the internal levels of ethylene in immature fruits (Table 3.8).

The content of major soluble sugars analyzed including fructose, glucose and sucrose varied with production, location and variety. However, there was no significant interaction ($p \leq 0.05$) amongst treatments, production location and the varieties. Variation in the content of major sugars in the fruits from the two study areas could be attributed to the differences in weather conditions in the two areas. Embu, a high potential zone of mango production is generally characterized by low temperatures and high rainfall while Makueni, a low potential zone is characterized by high temperatures and low rainfall. Generally, higher sugar levels were observed in mango fruits from Makueni irrespective of variety and treatments. Longer periods of full sunlight and high temperatures typical of semi-arid areas like Makueni, tend to favor photosynthetic activity and carbon accumulation (Lëchaudel *et al.,* 2005a). Previous studies in 'Apple's 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.,* 1999). Similar observations were also reported in banana (Ambuko *et al.,* 2006) and passion fruits (Baraza *et al.,* 2012).

Fruits from ethephon-treated trees recorded higher levels of sugars regardless of the study area and the variety. This can be credited to more immature fruit abscission that occurred in Ethephon-treated trees. Immature fruit abscission is a result of competition between fruitlets: the biggest and most developed ones survive whereas the smallest undergo shedding. The

mechanism clearly indicates an active role of the organ subtending the abscission zone, as proposed in other systems (Else *et al.,* 2004, Alferez *et al.,* 2005). Additionally, this confirms the report of Asare-Bedieko et al., (2007), which asserts that treatment of pineapples with chemicals for floral induction affect total sugars, sucrose and reducing sugars. The total sugars, sucrose and reducing sugars were all higher in induced fruits than the non-induced fruits. Moreover, it can be speculated that the decomposition of the ethylene-generating agent, Ethephon, when sprayed enhanced the levels of ethylene in the tissues of the treated trees hence, the higher numbers of fruit drop. Ethylene and auxins are the major hormones involved in fruit abscission and their interaction is believed to be of paramount importance during abscission activation (Taylor and Whitelaw, 2001). As compared to Potassium nitrate treated trees and control where most of the fruits were retained, relatively lower number of fruits that remained on ethephon treated trees took advantage of the manufactured photosynthates and subsequently attained higher sugar levels. The implication with fruit number not beyond a tree's ability is that all the developing fruits would receive an adequate supply of carbohydrates (Léchaudel et al., 2007).

4.5 Conclusion

It was found in this study that there was no significant difference found due to interaction amongst the production location, treatments and varieties for most quality attributes analyzed. The results obtained in the current study largely confirm reports from previous studies on the effect of flower inducers on the final quality of fruits. In beta-carotene, significant ($p \leq 0.05$) treatment effect was observed in trees treated with 2% KNO_3, 600 ppm and 1,000 ppm ethephon where beta-carotene levels averaged 1.5, 1.6 and 1.7 mg/100 ml compared to 1.4 mg/100ml in the untreated control.

CHAPTER 5

GENERAL DISCUSSION AND RECOMMENDATIONS

5.1 Discussion

The world's population is projected to hit the 9 billion mark by the year 2050. Feeding the 9 billion people will require a 70 percent increase in agricultural yield, based on the current production trend. In developing countries food insecurity and malnutrition is a day to day reality for most households that live below the poverty line. Ironically, each year, approximately one-third (1.3 billion tons) of food produced for human consumption are lost or wasted along the supply chains (FAO, 2014). In the case of horticultural commodities which are highly perishable, the losses are even greater accounting for 44% of the total global losses (equivalent to 572,000 metric tons). The actual loss figures vary significantly depending on the region, commodity, season, production system, amongst other factors.

In mango fruits, the losses are estimated to be 40 – 50% (KARI, 2004). The losses are mainly attributed to poor postharvest handling practices, lack of storage facilities and lack of knowledge or access to applicable postharvest technologies, amongst other causes. Additionally mango production in most tropical countries faces a unique challenge of seasonality in fruiting. For most of the mango producing regions in Kenya, the high season (oversupply) is between November and March while the low season is between April and October. It is during the high season that very high postharvest losses occur. Mango is a highly perishable fruit with a very short shelf life of $\leq$ 10 days depending on the harvest maturity. With lack of cold storage facilities or other postharvest technologies to extend the shelf life of these fruits, they have to be harvested and utilized as soon as they attain maturity. The oversupply during the high season leaves the farmers with only two alternatives; to accept the low prices offered by the buyers (mostly brokers) or leave the fruits to rot away on the trees. In some cases, the farmers opt to leave the fruits to rot on the trees because the prices offered are too low (as low as 3 US cents). For farmers who depend on mango production as the only cash crop, the losses mean poor livelihoods and food insecurity. The effect of seasonality goes beyond the direct effect on mango farmers. Mango processing into various value-added products has been fronted as a strategy to reduce postharvest losses in the mango value chain. As a result there are a number of mango processing plants (small and large) that have been set up in addition to the established fruit processing companies. Some of the companies involved in mango processing include Milly Fruit Processors Ltd, Fresh

Squeeze Ltd, Frank Fresh Juice Ltd, Del Monte Ltd and Victoria Juice Company Ltd. There are also a number of small-scale processors centered around farmer groups in the various mango producing regions. Despite the great potential and with increasing demand for processed mango products domestically and globally, processing takes less than 5% of the total volume of mango fruits produced in Kenya. While some of the large companies (listed above) import fruit pulp to remain in production during the low season, most of the small scale processing plants remain idle or closed.

In regard to the background, this study was conducted to address the problem of seasonality in mango production. The study sought to evaluate the efficacy of two flower induction chemicals, ethephon and potassium nitrate to induce off-season flowering and fruiting in two popular mango varieties, 'apple' and 'ngowe'. The chemicals were applied on 6 -7 year old trees and the effect on reproductive growth parameters, yield components and quality attributes evaluated. The study was conducted in two major mango producing regions in Kenya, Makueni and Embu. Previous studies on the two chemicals have shown that their efficacy is affected by many factors including species/variety, agro-ecological conditions and cultural practices amongst others. The concentration and time of application of the two chemicals have also been reported to affect their efficacy. Therefore, the study sought to establish the effect of some of these factors on the efficacy of the two chemicals. In the application of these chemicals, it is critical that the quality and integrity of the fruits is preserved. Therefore a subsequent study to establish the effect of the chemicals in mango fruit quality attributes was important.

The results revealed that potassium nitrate and ethephon treatments had a significant ($p \leq 0.05$) effect on flowering and fruiting parameters in both mango varieties ('Apple' and 'Ngowe') and locations (Embu and Makueni). The response to both chemicals was concentration-dependent with better responses recorded at higher concentrations; 4% for potassium nitrate and 1000 ppm for ethephon. The response was also dependent on the variety and production location.

Analysis of mango fruit quality attributes showed no significant treatment effect on most of the parameters evaluated. However KNO_3 had an effect on beta-carotene and vitamin C. These nutritional quality attributes were positively affected by the treatment. The treatment effect on other attributes including sugars and minerals did not reveal any significant trend.

These studies show that ethephon and KNO_3 can be explored at as a strategy to induce an off-season crop where flower initiation and flowering are dependent on an environmental signal which is often inconsistent. The chemicals can be used to substitute this natural phenomenon and realize a reasonable crop outside the peak season. An off-season crop would not only assure better income for the farmers during the low season but also address the problem of idle capacity for mango processing plants during the low season. In Kenya, during the high season (November to March) mango fruits are sold for as low as 3 US Cents per piece at the farm gate. On the other hand, during the high season (April to October) the fruits can cost as high as 25 US Cents at the farm gate and up to 80 US Cents in up-market retail outlets. This means that a farmer with an off-season crop and access to good market can make good profits.

Off-season flower induction and mango production can therefore have three-prolonged benefits for the mango value chain. The first and direct benefit is better incomes for farmers involved in off-season mango fruit production. The better prices during the off-season could be as high as 10 times compared to the price during the high season. For majority of the smallholder farmers who feel short-changed by the brokers, this could be a game changer. With better returns from their crop, the farmers could possibly get incentivized to improve their orchard management practices such as water and nutrient management, pest/disease management and other cultural practices. With better returns to investment/cost of production, the farmers could plough back some of the returns to improve production for even better returns. The second benefit of an off-season crop is the provision of materials for mango processing plants/factories which otherwise remain idle during the low season. Lack of processing during the low season means no income for the processors and lost jobs and livelihoods for the factory workers. The ultimate benefit of an off-season crop is the spread of production around the year with no low and high seasons. If the production is spread out throughout the year, then ultimately the high postharvest losses occasioned by oversupply during the high season could be reduced significantly.

5.2 Recommendations

- Application of potassium nitrate at 4% could be recommended for ‘Apple’ and ‘Ngowe’ mango varieties. Similarly, ethephon at a rate of 600 to 1000 ppm could be recommended in the two varieties.
- Although application of potassium nitrate and ethephon resulted in significant effect on flowering and reproductive parameters the effect was significantly affected by production location, variety and dosage. Therefore there is need for additional studies to ascertain the

observed trends and make recommendations for other production locations, varieties and dosing ranging. There is need to identify other varieties that are responsive to potassium nitrate and ethephon and establish the most responsive application time and stage.

- Further physiological studies on internal hormonal balances would help explain the observed effect of the potassium nitrate and ethephon. For example, changes in phytohormones such gibberellic acid which is known to inhibit flowering should be investigated. Additionally, the application of these chemicals should be assessed in relationship to the plant's growth phenology.
- Ultimately, there is need to develop management strategies that force development responsive shoots at any period of the year. This strategy will encompass not only the flower induction chemicals but also cultural practices that enhance the trees' response to the treatments.

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APPENDICES

APPENDIX 1: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on days to flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	169.733	84.867	8.68	
Rep.*Units* stratum					
Location	1	16236.150	16236.150	1660.32	≤.001
Variety	1	380.017	380.017	38.86	≤.001
Treatments	4	18344.900	4586.225	468.99	≤.001
Location.Variety	1	3.750	3.750	0.38	0.539
Location.Treatments	4	1204.767	301.192	30.80	≤.001
Variety.Treatments	4	74.900	18.725	1.91	0.128
Location.Variety.Treatments	4	71.167	17.792	1.82	0.145
Residual	38	371.600	9.779		
Total	59	36856.983			

APPENDIX 2: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on percentage flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	148.633	74.317	8.94	
Rep.*Units* stratum					
Location	1	29792.817	29792.817	3582.30	≤.001
Variety	1	1430.817	1430.817	172.04	≤.001
Treatments	4	23033.567	5758.392	692.39	≤.001
Location.Variety	1	30.817	30.817	3.71	0.062
Location.Treatments	4	5028.767	1257.192	151.17	≤.001
Variety.Treatments	4	187.767	46.942	5.64	0.001
Location.Variety.Treatments	4	381.767	95.442	11.48	≤.001
Residual	38	316.033	8.317		
Total	59	60350.983			

APPENDIX 3: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on number of panicles of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	112.09	56.04	2.41	
Rep.*Units* stratum					
Location	1	313174.85	313174.85	13493.45	≤.001
Variety	1	12338.14	12338.14	531.60	≤.001
Treatments	4	425997.15	106499.29	4588.63	≤.001
Location.Variety	1	5495.09	5495.09	236.76	≤.001
Location.Treatments	4	61438.01	15359.50	661.78	≤.001
Variety.Treatments	4	3290.23	822.56	35.44	≤.001
Location.Variety.Treatments	4	2606.36	651.59	28.07	≤.001
Residual	38	881.96	23.21		
Total	59	825333.88			

APPENDIX 4: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on fruit set of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	34.67	17.34	0.90	
Rep.*Units* stratum					
Location	1	2693.40	2693.40	140.40	≤.001
Variety	1	29304.60	29304.60	1527.56	≤.001
Treatments	4	302011.01	75502.75	3935.73	≤.001
Location.Variety	1	2419.35	2419.35	126.11	≤.001
Location.Treatments	4	18677.09	4669.27	243.40	≤.001
Variety.Treatments	4	4549.19	1137.30	59.28	≤.001
Location.Variety.Treatments	4	1181.60	295.40	15.40	≤.001
Residual	38	728.99	19.18		
Total	59	361599.89			

APPENDIX 5: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on internal ethylene evolution (nl/g/hr.) from 'Apple' and 'Ngowe' immature fruits sampled 44 days from fruit set from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.7395	0.3698	3.50	
REP.*Units* stratum					
LOCATION	1	9.9074	9.9074	93.71	≤.001
VARIETY	1	0.0037	0.0037	0.04	0.853
TREATMENT	1	0.2166	0.2166	2.05	0.174
LOCATION.VARIETY	1	0.2053	0.2053	1.94	0.185
LOCATION.TREATMENT	1	0.2904	0.2904	2.75	0.120
VARIETY.TREATMENT	1	0.0384	0.0384	0.36	0.556
LOCATION.VARIETY.TREATMENT	1	0.0216	0.0216	0.20	0.658
Residual	14	1.4801	0.1057		
Total	23	12.9030			

APPENDIX 6: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on percentage fruit drop after 14 days from fruit set in 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	61.30	30.65	2.21	
Rep.*Units* stratum					
Treatments	4	2640.51	660.13	47.58	≤.001
Location	1	2322.55	2322.55	167.39	≤.001
Variety	1	1290.85	1290.85	93.03	≤.001
Treatments.Location	4	234.42	58.61	4.22	0.006
Treatments.Variety	4	211.00	52.75	3.80	0.011
Location.Variety	1	46.29	46.29	3.34	0.076
Treatments.Location.Variety	4	73.77	18.44	1.33	0.277
Residual	38	527.25	13.88		
Total	59	7407.94			

APPENDIX 7: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on total number of fruits per tree of 'Apple' and 'Ngowe' in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2315.20	1157.60	59.11	
Rep.*Units* stratum					
Location	1	881.67	881.67	45.02	≤.001
Variety	1	9425.07	9425.07	481.30	≤.001
Treatments	4	29400.23	7350.06	375.34	≤.001
Location.Variety	1	92041.67	92041.67	4700.21	≤.001
Location.Treatments	4	2096.17	524.04	26.76	≤.001
Variety.Treatments	4	7781.77	1945.44	99.35	≤.001
Location.Variety.Treatments	4	29850.50	7462.63	381.09	≤.001
Residual	38	744.13	19.58		
Total	59	174536.40			

APPENDIX 8: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on total fruit weight (kg) per tree of 'Apple' and 'Ngowe' in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.041	2.521	0.26	
Rep.*Units* stratum					
Location	1	3717.788	3717.788	385.05	≤.001
Variety	1	15299.260	15299.260	1584.56	≤.001
Treatments	4	4600.024	1150.006	119.11	≤.001
Location.Variety	1	137.713	137.713	14.26	≤.001
Location.Treatments	4	671.774	167.944	17.39	≤.001
Variety.Treatments	4	1578.976	394.744	40.88	≤.001
Location.Variety.Treatments	4	798.712	199.678	20.68	≤.001
Residual	38	366.899	9.655		
Total	59	27176.188			

APPENDIX 9: Analysis of Variance (ANOVA) table for seasonal effect on performance of Potassium nitrate (KNO_3) and Ethephon on days to flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	1	39277.008	39277.008	4454.86	≤.001
Location	1	12669.075	12669.075	1436.95	≤.001
Variety	1	8789.408	8789.408	996.91	≤.001
Treatments	4	17542.800	4385.700	497.43	≤.001
Season.Location	1	4575.675	4575.675	518.98	≤.001
Season.Variety	1	4380.208	4380.208	496.81	≤.001
Location.Variety	1	421.875	421.875	47.85	≤.001
Season.Treatments	4	3508.700	877.175	99.49	≤.001
Location.Treatments	4	1422.633	355.658	40.34	≤.001
Variety.Treatments	4	689.300	172.325	19.55	≤.001
Season.Location.Variety	1	541.875	541.875	61.46	≤.001
Season.Location.Treatments	4	162.533	40.633	4.61	0.002
Season.Variety.Treatments	4	327.000	81.750	9.27	≤.001
Location.Variety.Treatments	4	373.333	93.333	10.59	≤.001
Season.Location.Variety.Treatments	4	111.833	27.958	3.17	0.018
Residual	80	705.333	8.817		
Total	119	95498.592			

APPENDIX 10: Analysis of Variance (ANOVA) table for seasonal effect on performance of Potassium nitrate (KNO_3) and Ethephon on percentage flowering of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	1	27968.533	27968.533	3840.07	≤.001
Location	1	17909.633	17909.633	2458.99	≤.001
Variety	1	2842.133	2842.133	390.22	≤.001
Treatments	4	27800.583	6950.146	954.25	≤.001
Season.Location	1	12160.533	12160.533	1669.64	≤.001
Season.Variety	1	0.033	0.033	0.00	0.946
Location.Variety	1	653.333	653.333	89.70	≤.001
Season.Treatments	4	3671.383	917.846	126.02	≤.001
Location.Treatments	4	4004.283	1001.071	137.45	≤.001
Variety.Treatments	4	542.283	135.571	18.61	≤.001
Season.Location.Variety	1	313.633	313.633	43.06	≤.001
Season.Location.Treatments	4	1860.883	465.221	63.87	≤.001
Season.Variety.Treatments	4	313.883	78.471	10.77	≤.001
Location.Variety.Treatments	4	2438.583	609.646	83.70	≤.001
Season.Location.Variety.Treatments	4	1300.783	325.196	44.65	≤.001
Residual	80	582.667	7.283		
Total 119 104363.167					

APPENDIX 11: Analysis of Variance (ANOVA) table for seasonal effect on performance of Potassium nitrate (KNO_3) and Ethephon on number of panicles of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	1	687174.41	687174.41	44047.99	≤.001
Location	1	188638.84	188638.84	12091.78	≤.001
Variety	1	5704.92	5704.92	365.69	≤.001
Treatments	4	258234.04	64558.51	4138.21	≤.001
Season.Location	1	127518.16	127518.16	8173.94	≤.001
Season.Variety	1	6651.36	6651.36	426.35	≤.001
Location.Variety	1	2952.19	2952.19	189.24	≤.001
Season.Treatments	4	172741.00	43185.25	2768.18	≤.001
Location.Treatments	4	41513.41	10378.35	665.25	≤.001
Variety.Treatments	4	939.39	234.85	15.05	≤.001
Season.Location.Variety	1	2550.25	2550.25	163.47	≤.001
Season.Location.Treatments	4	22734.69	5683.67	364.32	≤.001
Season.Variety.Treatments					

	4	4326.95	1081.74	69.34	≤.001
Location.Variety.Treatments					
	4	2764.01	691.00	44.29	≤.001
Season.Location.Variety.Treatments					
	4	1220.25	305.06	19.55	≤.001
Residual	80	1248.05	15.60		
Total	119	1526911.93			

APPENDIX 12: Analysis of Variance (ANOVA) table for seasonal effect on performance of Potassium nitrate (KNO_3) and Ethephon on fruit set of 'Apple' and 'Ngowe' mango trees in Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	1	231370.57	231370.57	11399.95	≤.001
Location	1	59007.67	59007.67	2907.39	≤.001
Variety	1	65286.68	65286.68	3216.77	≤.001
Treatments	4	342176.83	85544.21	4214.88	≤.001
Season.Location	1	28737.08	28737.08	1415.92	≤.001
Season.Variety	1	180.08	180.08	8.87	0.004
Location.Variety	1	4762.80	4762.80	234.67	≤.001
Season.Treatments	4	39835.18	9958.80	490.68	≤.001
Location.Treatments	4	18664.87	4666.22	229.91	≤.001
Variety.Treatments	4	15209.47	3802.37	187.35	≤.001
Season.Location.Variety	1	19202.70	19202.70	946.14	≤.001
Season.Location.Treatments					
	4	41201.62	10300.40	507.52	≤.001
Season.Variety.Treatments					
	4	1985.32	496.33	24.45	≤.001
Location.Variety.Treatments					
	4	4092.47	1023.12	50.41	≤.001
Season.Location.Variety.Treatments					
	4	12470.72	3117.68	153.61	≤.001
Residual	80	1623.66	20.30		
Total	119	885807.71			

APPENDIX 13: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on Beta carotene content in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.03090	0.01545	1.37	
Rep.*Units* stratum					
Location	1	0.00748	0.00748	0.66	0.421
Variety	1	0.00000	0.00000	0.00	0.990
Treatments	4	0.72702	0.18175	16.08	≤.001
Location.Variety	1	0.01040	0.01040	0.92	0.343
Location.Treatments	4	0.02094	0.00524	0.46	0.762
Variety.Treatments	4	0.15332	0.03833	3.39	0.018
Location.Variety.Treatments	4	0.02889	0.00722	0.64	0.638
Residual	38	0.42950	0.01130		
Total	59	1.40846			

APPENDIX 14: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on vitamin C content in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.172	6.086	1.73	
Rep.*Units* stratum					
Location	1	708.847	708.847	201.48	≤.001
Variety	1	5134.305	5134.305	1459.32	≤.001
Treatments	4	312.343	78.086	22.19	≤.001
Location.Variety	1	110.406	110.406	31.38	≤.001
Location.Treatments	4	466.113	116.528	33.12	≤.001
Variety.Treatments	4	172.649	43.162	12.27	≤.001
Location.Variety.Treatments	4	94.829	23.707	6.74	≤.001
Residual	38	133.695	3.518		
Total	59	7145.357			

APPENDIX 15: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on total soluble solids (°brix) content in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.9940	4.9970	6.91	
Rep.*Units* stratum					
Location	1	11.0768	11.0768	15.31	≤.001
Variety	1	54.6451	54.6451	75.51	≤.001
Treatments	4	149.8477	37.4619	51.77	≤.001
Location.Variety	1	0.2381	0.2381	0.33	0.570
Location.Treatments	4	14.1895	3.5474	4.90	0.003
Variety.Treatments	4	11.5788	2.8947	4.00	0.008
Location.Variety.Treatments	4	3.9339	0.9835	1.36	0.266
Residual	38	27.4984	0.7236		
Total	59	283.0023			

APPENDIX 16: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on total titratable acidity content in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0005833	0.0002917	0.33	
Rep.*Units* stratum					
Location	1	0.0244017	0.0244017	27.42	≤.001
Variety	1	0.0198017	0.0198017	22.25	≤.001
Treatments	4	0.0904233	0.0226058	25.40	≤.001
Location.Variety	1	0.0003750	0.0003750	0.42	0.520
Location.Treatments	4	0.0022567	0.0005642	0.63	0.641
Variety.Treatments	4	0.0027233	0.0006808	0.77	0.555
Location.Variety.Treatments	4	0.0005167	0.0001292	0.15	0.964
Residual	38	0.0338167	0.0008899		
Total	59	0.1748983			

APPENDIX 17: Analysis of Variance (ANOVA) table for effect of Potassium nitrate (KNO_3) and Ethephon on fructose content in 'Apple' and 'Ngowe' mango fruits from Embu and Makueni Counties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.16603	0.08301	1.47	
Rep.*Units* stratum					
Location	1	24.84554	24.84554	440.82	≤.001
Variety	1	0.03700	0.03700	0.66	0.423
Treatments	4	24.04996	6.01249	106.68	≤.001
Location.Variety	1	1.42604	1.42604	25.30	≤.001
Location.Treatments	4	1.93557	0.48389	8.59	≤.001
Variety.Treatments	4	0.73671	0.18418	3.27	0.021
Location.Variety.Treatments	4	0.32367	0.08092	1.44	0.241
Residual	38	2.14177	0.05636		
Total	59	55.66228			