EFFECT OF CALCIUM NUTRITION ON YIELD, JELLY SEED AND POSTHARVEST QUALITY OF MANGO FRUITS

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DECLARATION

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

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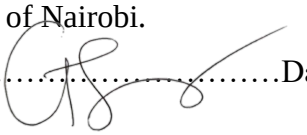
Signature  ……Date…14/07/2022……

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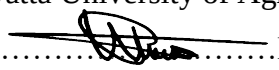
Signature  ……Date…15 July 2022……

DEDICATION

To my lovely wife, Evelyn Akinyi for her support during this study. She has been the force behind this work. “Thank you for believing in me”.

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GENERAL ABSTRACT

Mango (*Mangifera indica* L.) is an important fruit in Kenya for domestic and export markets. However, farmers attain low yields and suffer significant post-harvest losses. Physiological disorders, among them jelly seed, contribute to about 30-40% of post-harvest losses by reducing the marketability of fruits. Optimum yields, fruit quality at harvest and postharvest longevity of mango fruits require proper nutrient management. Some of the physiological disorders that contribute to postharvest losses in mango are attributed to poor calcium nutrition. A study was conducted at Karurumo in Embu County, Eastern Kenya during seasons 2017/2018 and 2018/2019 using Van Dyke cultivar with the following objectives: (1) To determine the effect of varied calcium sources, rates and timing of application on yield of mango fruits; (2) To determine the effect of varied calcium sources, rates and timing of application on jelly seed incidence, post-harvest quality and shelf life of mango fruits; (3) To determine the effect of pre and post-harvest applications of calcium chloride on the quality and shelf life of physiologically mature mango fruits. A randomised complete block design with a split-split plot arrangement replicated three times was used to achieve objectives 1 and 2. Calcium was supplied as calcium nitrate, easygro® and calcium chloride at concentrations of 1.0%, 1.5%, 2.0% or 0% (control) at three different times (fruit set, 30 days after fruit set and 30 days to physiological maturity). For objective 1, fruits were harvested at physiological maturity and fruit length, breadth, number of fruits, fruit weight, total weight, fruit retention percentage and fruit tissue calcium concentration were determined. For objective 2, a sample of physiologically mature fruits was taken and ripened in ambient conditions for determination of jelly seed occurrence, fruit weight and calcium distribution in the exocarp, mesocarp, endocarp and cotyledon. Additionally, samples of mature fruits were taken from each treatment for determination of total titratable acidity, total soluble solids, peel colour and peel firmness at harvest and after 12 days of storage under ambient conditions (25±2C, 75-80% RH), using standard protocols. Additionally, untrained panelists were used to score the ripened fruits for selected sensory quality attributes. Objective 3 was achieved by laying out a factorial experiment in a randomized complete block design with a split plot arrangement, replicated three times. Calcium chloride at 0.5%, 1.0%, 1.5% or 0% (control) was sprayed on fruits at maturity or 15 days later. Another set of mature fruits was immersed in calcium chloride (0.5%, 1.0% or 1.5% or 0%) for 10 (ten) minutes. The

fruits were then stored in ambient conditions and evaluated for selected shelf life indicators and sensory quality characteristics at an interval of two days for an eight days storage period. Peel firmness, total titratable acidity, total soluble solids, flesh colour, beta carotene, and percentage change in fruit weight, carbon dioxide and ethylene evolution rates were assessed. Results indicated that calcium sprayed fruits had higher length, weight, breadth, fruit number, total weight of fruits/tree, retention percentage and calcium content than unsprayed fruits. Calcium chloride (2.0%) sprayed at fruit set was the most effective in enhancing the mean fruit weight (346.3 g and 316.4 g), and the mean total weight of fruits/tree (63,723g and 39,138g) in both seasons respectively. There was a direct correlation between calcium concentration and fruit length (r=0.56 and r=0.81), fruit weight (r=0.34 and r=0.73), fruit breadth (r=0.79 and r=0.88), number of fruits (r=0.86 and r=0.59), fruit retention percentage (r=0.52 and r=0.62) and total weight of fruits (r=0.75 and r=0.68) in both seasons respectively. Application of calcium at fruit set increased calcium content in fruits more than application at later stages of fruit development. Application of calcium chloride, 2.0%, at fruit set stage reported the lowest average jelly seed score in season 1 (1.2) and season 2 (1.2). A significant negative correlation between fruit weight (r = -0.55, r = -0.52), calcium content in the exocarp (r = -0.56, r = -0.49), mesocarp (r = -0.52, r = -0.76), endocarp (r= -0.76, r = -0.66) and jelly seed incidence occurrence was demonstrated in both seasons respectively. Fruits sprayed with calcium chloride (2.0%) at fruit set maintained higher peel firmness (4.83 N, 4.77 N), titratable acidity (1.29%, 1.27%), peel hue angle (67.9, 67.2) and total soluble solids (10.47 ^{o} Brix, 9.10 ^{o} Brix) than all other treatments in both seasons respectively. Calcium chloride application improved peel colour appearance while calcium nitrate and easygro® led to a deteriorated peel colour appearance. Further, high rates of all sources of calcium led to a deterioration in taste of fruits. Immersion of fruits in calcium chloride (1.5 %) at maturity registered a higher peel firmness (10.6 N, 10.3 N), retained flesh colour (37.45, 36.78), highest TSS (14, 13.8), TTA (0.72%, 0.70%) and higher color appearance scores than the rest of the treatments in both seasons respectively. Fruits sprayed with calcium chloride (1.5%) at maturity registered the lowest amount of carbon dioxide (30.7 ml/kg/hr) and ethylene (1.5 ml/kg/hr). Post-harvest immersion had negative effects on the pulp flavor and increased shriveling of fruits. Spraying of calcium chloride (2.0%) at fruit set gave the highest yield, suppressed jelly seed occurrence, maintained fruit shelf life and improved organoleptic

attributes. Calcium applied at fruit set gave better results in the studied parameters than those sprayed later implying that calcium should be applied at early stages of fruit development. Additionally, fruits immersed in calcium chloride (1.5%) enhanced fruit shelf life. However, for good flavor and taste, rate of 1.0% are recommended when fruits are treated by immersion in calcium chloride. This study further demonstrated that calcium is available to the fruit particularly when applied by immersion rather than spraying.

CHAPTER ONE: INTRODUCTION

1.1 Background information

The Kenyan economy is heavily dependent on agriculture which contributes close to a quarter of the Gross Domestic Product (GDP) (KNBS, 2022). This sector contributed to approximately 22.4% of the national GDP in 2021 (KNBS, 2022). Additionally, the sector contributes about 27.0 % to the GDP through linkages with other sectors. According to Kenya economic survey of 2022, the major contributors in the sector are dairy, tea and horticulture. The horticulture subsector consists of floriculture, vegetables, fruits, nuts and oils crop production, aromatic and medicinal plants. The horticultural subsector contributes enormously to the Kenya economy registering Ksh. 153.7 billion, Ksh. 144.6 billion, Ksh. 150.2 billion and Ksh. 157.7 in 2018, 2019, 2020 and 2021 respectively in export value (KNBS, 2022).

In Kenya's economy, fruits are significant. They are crucial for employment possibilities both directly and indirectly, profits in foreign currencies and nourishment. In 2015, 2016, 2017, 2018, and 2019 correspondingly, the value of fruits in Kenya increased from Ksh. 6.6 billion, Ksh. 7.3 billion, Ksh. 9.0 billion, Ksh. 12.8 billion and Ksh. 13.2 billion (KNBS, 2020). Fruit export revenues have also increased, reaching Ksh 12.8, Ksh 13.2, Ksh 18.4, and Ksh 18.4 billion in 2018, 2019, 2020, and 2021, respectively (KNBS, 2022). Kenya produces a wide assortment of fruits for both domestic and international markets, making up a sizeable percentage of the horticultural industry. The following important fruits are grown in Kenya, along with their percentage contributions: water melon (4.8%), pineapples (18.1%), passion fruits (1.5%), pawpaw (5.0%), mangoes (19.3%), avocado (9.0%), bananas (35.9%), oranges (4%) and passion fruits (HCD, 2017).

Among the fruits produced in Kenya, mangoes serve an important role majorly for domestic use and a small percentage for export. Mangoes constitute 28% of the total fruits export second only to avocado (62%) while the others stand at 12% (HCD, 2010). Kenya’s mango export destination include: United Arab Emirates (53%), Tanzania (20%), Saudi Arabia (22%) and Bahrain (2%) (HCD, 2010).

Kenya has experienced an increase in the value of mango production from Ksh. 7.7 billion achieved in 2013 to Ksh. 8.9 billion in 2014 and 12.2 billion to 11.89 billion in 2015 and 2016

respectively. The area under production has also increased (HCD, 2017) which is attributed to an increase in demand for fresh market fruits and processing. Makueni, Machakos, Kilifi and Kwale counties contribute 30%, 23%, 16% and 8% respectively of the total value of the country mango production (HCD, 2017).

Mango production in Kenya is faced with numerous challenges including low adoption of modern technology, pest and diseases infestations, post-harvest losses, poor infrastructure in mango growing regions and premature harvest of fruits. Additionally, there are inadequate high quality planting materials (HCD, 2017). Poor nutrient management leading to low levels of soil and tissue nutrients among them boron and calcium in certain mango growing regions is another problem affecting productivity and quality of mango fruits (Njuguna, *et al*., 2016). The commercial varieties produced in Kenya have a potential of 15-20 tons/ha. However, due to the various challenges highlighted above, the reported yields for most farmers are below 10 tons/ha.

1.2 Problem statement and justification

An estimated 200,000 farmers in Kenya and many more people along the mango value chain depend on mangoes either directly or indirectly as processors, traders, transporters, village assemblers or exporters. Despite the enormous importance of the fruit, its production is faced with a number of challenges that are hindering full exploitation. Most of the cultivars grown in Kenya have a potential of 15-20 t/ha but farmers are only able to achieve less than 10t/ha (Kehlenbeck, *et al*., 2012). It is further estimated that 40-45% of mangoes harvested are not consumed due to post-harvest losses (KARI, 2012) and this reduces the returns to farmers significantly. Middlemen, brokers and wholesalers offer very little as farm gate prices to the farmers because they take into account the losses they will incur due to the wastage along the value chain (Ambuko, *et al*., 2016). Farmers, on the other hand, do not have the bargaining power as they can only keep the mangoes for a very short period. Mango fruit is perishable with a very short shelf life at ambient conditions depending on the stage of harvesting, variety/cultivar and conditions of storage amongst other factors (Baloch, *et al*., 2012). Physiological disorders in mangoes among them jelly seed also compromise the fruit quality hence marketability thus contributing significantly to the losses (Burdon, *et al*., 1991). These disorders sometimes account for up to 50% loss of the harvested produce (Oosthuyse, 2003) while jelly seed disorder alone

has been reported to contribute to 30% of the mangoes loss in Kenya (Gitonga, *et al*., 2010 a). The most susceptible mango variety to jelly seed disorder is "Van Dyke" (Cracknell, *et al*., 2004; Njuguna, *et al*., 2016), which is widely grown in Kenya.

Calcium has been reported to increase the yield of mango trees by reducing abscission of fruits (Stino, *et al*., 2011) thus increasing retention percentage, influence of various fruit growth parameters among them weight, length, breadth and fruit set (Singh, *et al*., 2017; Karemera, *et al*., 2014). The pectin constitutes calcium as a primary component where it strengthens the membrane structure and cell wall where it is taken as the last barrier before cell separation. Calcium alters intra and intercellular processes hence retarding ripening (Singh, *et al*., 1993) by increasing the strength of the cell wall and reducing the rates of respiration and ethylene production (Karemera, *et al*., 2014; Madani, *et al*., 2016). Calcium therefore plays a major role in influencing the shelf life of fruits. Physiological disorders have been attributed to inadequate calcium deficiency or imbalanced nutrition (Cracknell, *et al*., 2004). Additionally, calcium application has been recommended in the alleviation of jelly seed, blossom end rot and bitter pit in mangoes, tomatoes and apple fruits respectively (De-Freitas, *et al.,* 2012). Previous studies have reported inadequate calcium in some mango growing regions in Kenya (Njuguna, *et al*., 2016). However, there is no current information on calcium deficiency in Kenya and how it affects mango fruit yields and postharvest losses.

Some authors have reported that calcium is available to the fruit at early stages of fruit development while others report effective availability even after physiological maturity (Karemera, *et al*., 2014; Daundasekera, *et al*., 2015). Additionally some authors have reported that calcium does not influence growth, yield and some quality attributes of fruits (Lanauskas, *et al*., 2006). It would therefore be necessary to establish the efficiency of uptake of externally supplied calcium and its effectiveness in enhancing yield and fruit shelf life. The current study therefore focused on establishing the comparative effects of different calcium sources applied at varied rates and timing with a view of developing optimal calcium management options for enhancing yield, growth and reducing post-harvest losses in mangoes.

1.3 Objectives of the study

The main objective of the study was to develop optimal calcium nutrition management options for enhancing yield and postharvest shelf life of mango fruits.

The specific objectives were:

1. To determine the effect of varied calcium sources, application rates and timing of application on yield components and yield of mango fruits.
2. To determine the effect of varied calcium sources, application rates and timing of application on jelly seed incidence, post-harvest quality and shelf life of mango fruits.
3. To determine the effect of pre and post-harvest applications of calcium on the quality and shelf life of physiologically mature mango fruits.

1.4 Hypotheses

1. The source, application rate and timing of calcium application will have an effect on the yield of mango fruits.
2. The source, application rate and timing of calcium application will have an effect on jelly seed incidence, post-harvest quality and shelf life of mango fruits.
3. The rate, mode and timing of calcium application will have an effect on the quality and shelf life of physiologically mature mango fruits.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany, importance and ecology of mango

Mango (*Mangifera Indica L.*) belongs to the Anacardiaceae family; order Sapindales; class Magnoliopsida and division Tracheophyta (Singh, *et al.,* 2016). There are other species in the genus *Mangifera* such as *Mangifera foetida, M. caesia, M. pajang, M. odorata* that are cultivated for fruits but the *M. indica* is the most widely cultivated species. Mango (*M. indica*) production is second to bananas among tropical fruits. It is important for food security because of its nutritive value. The fruit is rich in vitamins C and A, sugars, carbohydrates and other important minerals (Ara, *et al*., 2014; Nabil, *et al.,* 2012). Mango is used for the processing of juice, frozen pulp, nectars and flavoring of products like ice cream and yoghurt (Litz, 1997). Elsewhere in the world, mango is used as cattle and poultry feed, for religious functions and the wood is used as a source of timber (Wauthoz, *et al.,* 2007; Kayode, *et al.,* 2008; Nwinuka, *et al.,* 2008). In Kenya, apart from over 200,000 farmers who derive their livelihood directly from mangoes there are many other beneficiaries along the value chain including: marketers, village assemblers, brokers, processors and exporters.

Mango is produced by over 60 countries in the world but the leading producers include: India, Haiti, Mexico, Philippines, Brazil, Bangladesh, China, Thailand and Pakistan (Ara, *et al*., 2014). The number one producer of mango fruits worldwide is India and it accounts for about 57% of the world produce (FAO, 2009).

Mango can do well in a wide range of soils but for optimal production they need deep and well drained soils. Sandy loam with a clay content of not more than 50% is good for mango production because of lesser water logging cases and easy root penetration (Abercrombie, 1991). The soil should be at least 1 m deep and a water table of 1.8 m-2.4 m (Thomas, 2012). The soil pH should range between 5.5 -7.5 (Griesbach, 2003).

Mango trees are generally drought tolerant and able to withstand flooding; however, an average amount of 500-1000 mm of rainfall (Griesbach, 2003) that is well distributed annually is good for production. A dry spell is necessary during flowering (Varela, *et al*., 2006; Crane, *et al*.,

1997) as this enhances fruit set and fewer cases of fungal infections. Physiological disorders like jelly seed are more prone in very wet conditions (Njuguna, *et al*., 2016).

Mango fruits have various temperature requirements during different phases of growth. However, temperatures in the range of 20- 26^0C are generally ideal for growth and productivity (Griesbach, 2003). Fertilization of mango flowers is greatly affected by very low temperatures of below 12^0C (Thomas, 2012). On the other hand, temperatures above 34˚ C cause sun- burns to fruits (Varela, *et al*., 2006) and stunted growth to mango trees.

Mango fruits are cultivated in a wide range of agro ecological zones. The environmental conditions in a given agro ecological zone affect the maturity indices, quality, shelf life and physiology of mango fruits and other horticultural produce (Ambuko, *et al.,* 2014). Different cultivars of mango fruits, produced in different agro-ecological zones, have different quality attributes (Ara, *et al.,* 2014; Ouma, *et al*., 2014). Mango fruits produced in zones of low rainfall and high light intensity have a longer shelf life than those grown in low light intensity and high rainfall zones (Kemunto, 2013). In Kenya, zones III, IV and V with an altitude of between 900-1800 m are preferred for mango production. However, some cultivars have been observed to do well in altitudes of 1900 m (Griesbach, 2003). Some of the varieties/cultivars grown in Kenya include: Apple, Haden, Sensation, Kensington, Van Dyke, Kent, Tommy Atkins, Ngowe, Boribo, Dodo, Pears and Batawi (Griesbach, 2003; HCDA, 2014). These varieties are spread across all the growing counties including Makueni, Kilifi, Nyeri, Meru and Tharaka Nithi (Griesbach, 2003).

2.2 Challenges facing mango production in Kenya

Despite the enormous importance, production of mangoes, just like other fruits, face a number of challenges that curtail the full realization of its optimal potential. Inadequate high quality planting materials is one of the key challenges hindering the adoption of high yielding cultivars and varieties by farmers (HCD, 2017). This is due to the limited number of registered and certified nurseries in Kenya. There is lack and/or low adoption of appropriate technologies in production, harvesting and post-harvest handling of mangoes. This leads to yields below the

optimal levels and post-harvest losses (Njuguna, *et al.,* 2016). Additionally, there is low adoption of any available technology that could alleviate these losses (HCD, 2017).

Most farmers have little knowledge on orchard management, new technologies, optimal use of fertilizers and other inputs (Njuguna, *et al.,* 2016). Studies indicate that there is very little use of fertilizers among mango farmers in Kenya. Gitonga, *et al*., (2010a) in a study in Embu, Meru and Makueni counties indicated that only 5% of the mango farmers applied mineral fertilizers while only 40% applied organic manure. Similarly, the same authors reported that 85.6% of mango farmers in Kilifi County never applied any form of fertilizer in their orchards. Farmers have a misleading notion that fertilizers should not be used in fruit trees yet the use of fertilizers in mango production has been reported to increase yields (Sarker, *et al*., 2012).

Due to lack of appropriate knowledge on the agronomy of mangoes some farmers grow certain cultivars in areas that are not appropriate. For instance, Apple and Ngowe should be grown in low altitude areas of 0-800 m above sea level while exotic varieties can grow in low and mid altitude areas (Griesbach, 2003).

Mango farmers in Kenya face infrastructural challenges including poor transport network and lack of proper market linkages contributing further to post-harvest losses (Kehlenbeck, *et al*., 2012). This is coupled with underdeveloped appropriate packaging technologies leading to post harvest losses of the produce during freight (National Horticultural Policy, 2012). Various technologies like modified atmosphere packaging (MAP) and use of low temperatures have been reported to be effective in maintaining a long fruit shelf life and other horticultural produce butthey have not been adopted fully (Yuen, *et al*., 1993).

Mango production in Kenya is affected by various insect pests and diseases. Mango weevil and fruit fly are major economic pests that are affecting mango production globally and almost all mango growing areas in Kenya (Ekesi, *et al.*, 2007; Griesbach, 2003; Varela, *et al.,* 2006). Beside pests, powdery mildew (caused by the fungus *Odium mangiferae)* and anthracnose (caused by the fungus *Colletotrichum gloeosporioides)* are still a menace in Kenya and other

mango producing countries globally (Dodd, *et al*., 1997). Other diseases that have been reported occasionally include: stem end rot, spot and sooty mold, mango scab and alternaria (Griesbach, 2003).

Seasonality in mango production is a serious challenge affecting some parts of Kenya whereby there is glut of mangoes in certain periods of the year while in the rest of the time there are no fruits in the market. This seasonality is associated with the mid- altitudes where fruiting season starts in August-September then there is harvesting of the fruits from December to March (Griesbach, 2003). Techniques such as use of foliar potassium nitrate (Maloba, 2016) and paclobutrazol (Crane, *et al*., 1997) to induce flowering during off season have been suggested in Kenya and Australia respectively.

Mango production is also faced with alternate bearing challenges, a situation whereby mango trees bears heavily in one particular season and very little or no crop completely in the succeeding production season. A number of factors have been reported to influence biennial bearing including: nitrogen deficiency (Thomas, 2012), carbon and nitrogen imbalance in the plant, plant growth habits and environmental conditions (Mukherjee, 1953). Proper orchard management through regular pruning (Kumar, *et al.,* 2012), nutrition management, application of growth retardants and use of cultivars that are regular in bearing have been suggested as possible solutions to this problem (Kulkarni, 2004; Sarkar, *et al.,* 2012).

Although mango cultivation can tolerate a number of climatic variables, climate change is a possible threat. Climate change affects a number of important processes in mango including: photosynthesis, vegetation and reproductive development, fruit growth and quality (Normand, *et al*., 2013).

2.3 Role of macro and micronutrients in mango production

Nutrition is very important for optimal production of mango fruits both quantitatively and qualitatively. Various nutrients and their optimum leaf levels are shown in Table 2.1.

Table 2:1 Optimum mango leaf nutrient levels

Nutrient	**Units**	**Desired range**
Nitrogen	(% N)	1.2-1.4
Sulphur	(% S)	0.0-0.2
Phosphorus	(%P)	0.08-0.16
Potassium	(% K)	0.5-1.0
Calcium	(% Ca)	2.0-3.5
Magnesium	(% Mg)	0.25-0.5
Sodium	(% Na)	< 0.2
Chloride	(% Cl)	<0.25
Boron	(ppm B)	50-80
Zinc	(ppm Zn)	20-100
Copper	(ppm Cu)	10-20
Iron	(ppm Fe)	50-200
Manganese	(ppm Mn)	50-100
Molybdenum	(ppm Mo)	0.05-1.0

Source: Quaggio, 1996.

Nitrogen is the main nutrient that affects a number of processes in the mango plant. It is essential for terminal shoots development and increase in leaf area and the number of leaves (Samra, *et al.,* 1997). This nutrient enhances the generation of new shoots to become panicles (Chandra, 1988). Additionally, nitrogen affects growth, yield, and quality of fruits and incidences of diseases. Excess nitrogen leads to delayed maturation, excessive vegetative development and reduced fruit firmness. Deficiency of nitrogen in the soil leads to undersized yellow leaves, retardation and very small fruits that mature early. Nguyen, *et al.* (2004) reported that high rates of pre-harvest nitrogen supply results to greener colored ripe mango fruits and high incidences of anthracnose and this affects fruits marketability. Nafees, *et al.* (2007) found out that higher levels of nitrogen leads to malformation of inflorescence in mango as more nitrate levels was reported in leaves of shoots carrying malformed panicles. Nitrogen is mobile in the phloem hence can be translocated from older to active meristems (Oosthuyse, 2006).

Phosphorus is a major component of structural and energy transfer compounds and nucleotides. Phosphorus is important for root and stem development, early fruit development, maturation and retention of fruits (Samra, *et al*., 1997). Deficiency of phosphorus leads to weaker root and stem hence restricted uptake of nutrients and water leading to premature fall of leaves, branches and slow maturation of fruits (Childers, 1966).

Potassium is important for enhancing various mango fruit quality attributes including: aroma, size, shelf life and plant's ability to resist stressing conditions (Samra, *et al.,* 1997; Silva, *et al.,* 2012; Prado, *et al.,* 2012; Simmons, *et al*., 1998). Deficiency of potassium results to small red spots which are distributed irregularly in the oldest leaves that appear smaller and thinner than normal. Deficient fruits may also develop necrosis and fall off when completely dead (Childers, 1966). The older leaves may develop browning along the edges and apex which is a result of Ca and Mg imbalance that is a result of excessive K. Baiea, *et al.* (2015) while studying different forms of potassium and their effect on mineral content of the leaf, vegetative yield, growth and quality of mango fruits indicated that there was improved retention percentage, weight of pulp and quality attributes with the application of potassium. According to Baiea, *et al.* (2015), this could be attributed to the catalytic role of potassium in many biological processes within the tree thus enhancing the nutritional status of the tree.

Calcium nutrient is important in fruit growth and eventual development as it is a constituent of the cell wall where it imparts cell integrity, stabilizes membranes and strengthens cell wall (White, *et al*., 2003; Conway, *et al.,* 1994, Marschner, 1995). Calcium is also involved as a messenger in a number of signals (McAish, *et al*., 2009). Calcium is needed in all growing points of the plant as it allows the cells to expand as they grow. Calcium is not mobile in the plant and it is found in the old tissues thus deficiency is observed in young growing points (Gilham, *et al.,* 2010). Calcium enhances fruit firmness, internal quality and shelf life; therefore, deficiency is normally associated with reduced shelf life and internal physiological disorders (Prado, *et al.,* 2012). Calcium improves productivity of mango trees by reducing abscission (Kumari, *et al.,* 2018). Deficiency symptoms include: darkened margins along the leaves which

become yellow and finally fall off (Prado, *et al.*, 2012) and the fruits become yellow at the tip and softened pulp (Samra, *et al*., 1997).

Use of zinc, boron, iron, copper and manganese either as a single application or a combination leads to enhanced mango fruit quality and yield. Boron plays an important role in the growth and enlargement of reproductive cells, initiates flowering and seed set (Ahmad, *et al*., 2018). A combined application of iron, zinc and copper applied on Cv. Dashehari mango increased the weight of pulp, total soluble solids, non-reducing sugars, ascorbic acid, less stone weight and low acidity (Anees, *et al*., 2011).

2.4 Post-harvest losses and quality deterioration in fruits

Post-harvest losses are the quantitative and qualitative measurable losses of produce along the supply chain from harvest time till they reach the end user or consumption stage (Kimijwe, 2015). Wastage of lots of produce occurs often in horticultural produce and this happens due to a number of factors that are either pre-harvest, harvest or post- harvest.

2.4.1 Pre-harvest factors

Pre- harvest factors are the conditions and practices the fruit is exposed to before harvest, during the process of growth and development in the growing environment. Climate and weather conditions affect the storage quality that greatly influences the losses. Soil type (Young, *et al*., 1962), temperature, humidity, winds, heavy precipitation and frost influence post-harvest losses in different ways.

Choice of cultivar has great effects on post-harvest losses of mango fruits because some cultivars are more susceptible to post-harvest diseases and physiological disorders than others. This is largely due to the genetic makeup of individual cultivars. For example, Alphonso is resistant to anthracnose while more susceptible to stem end rot than Tommy Atkins (Rehman, *et al*., 2015). Van dyke cultivar, on the other hand, is more susceptible to jelly seed disorder incidence than Tommy Atkins (Njuguna, *et al.*, 2016).

Cultural practices like pruning greatly affect the fruit quality, shelf life and eventual yield. Pruning of mango fruits leads to increased firmness of the fruits decreases the rate of ripening by lowering total soluble solids, respiration rate and ethylene evolution rates and increased titratable acidity than fruits obtained from un-pruned trees (Asrey, *et al.,* 2013). Pruning also reduces both anthracnose and stem end rot incidences in fruits (Asrey, *et al*., 2013; Gu, *et al.,* 2005).

Nutrition is very important in mango production as the balance of various minerals is important in determining the fruit quality and productivity of mango fruit trees. Application of various minerals should be done at the right time and optimally. Use of excessive nitrogen during fruiting encourages the development of various disorders that may compromise on quality and yield. Excessive application of nitrogen has been associated with greening in fruits and other post-harvest diseases (Nguyen, *et al.* 2004). Calcium on the other hand has been associated with a longer shelf and increased fruit firmness (Karemera, *et al.* 2014; El-Alakmy, 2012). A low Ca: K leads to physiological disorders like jelly seed (Cracknell, *et al*., 2004). Low K: Ca ratio on the other hand, improves the shelf life of the fruits while a higher K: Ca ratio enhances the eating acceptability by increasing the aroma, sweetness and reducing the acidity of the fruits (Almelda, *et al.,* 2012; Njuguna, *et al*., 2016; Samra, *et al*., 1997; Silva, *et al*., 2012).

Pests and diseases have detrimental effects on the quality of the produce. Mango fruit fly (*Ceratitis cosyra, C. rosa and C. capitata*) and mango seed weevil (*Sternochetus mangiferae* (F) are a menace in most mango growing regions in Kenya (Griesbach, 2003). The pests cause bruises, skin damage, egg laying and eventual larvae development and this reduces the acceptability of the produce leading to wastage (Kasso, *et al.,* 2016). On the other hand, diseases like stem end rot and anthracnose lead to a decreased shelf life and acceptability of fruits (Onyeani, *et al*., 2012), therefore increased post-harvest losses.

Plant growth regulators have different effects on fruit yield, quality and shelf life. Paclobutrazol, a growth retardant, was found to increase the size of the mango fruit and the edible portion, shelf life, yield, vitamin C content, total soluble solids, fruit acidity and dry matter (Sarker, *et al.,* 2012). Sarker, *et al.* (2012) and Wei, *et al*. (2017) indicated that increasing the frequency of

irrigation of mango fruits decreased the shelf life, TSS and pulp ratio of the fruits and increased titratable acidity of mango fruits.

Crop load influences the incidence and severity of water pulp breakdown. Bally (2007) indicated that maximized mango fruit load reduced the severity of water pulp breakdown hence improved fruit marketability and reduced post-harvest losses.

2.4.2 Harvesting factors

Harvesting and handling techniques employed during harvesting contribute a significant percentage to post harvest losses (Kasso, *et al*., 2016). Use of inappropriate methods during harvesting leads to mechanical injuries to fruits. These injuries may provide an avenue for quality degradation through contamination by microorganisms, heavy metals (Kasso, *et al.,* 2016), loss of water and vitamin C losses and acceleration of fruit ripening and senescence. High temperature during harvesting may lead to heat load which will accelerate ripening, ethylene evolution rates and respiration thus reducing the shelf life. The quality of the fruits is also reduced by the injury that is caused by sap which exudes from the breaking of the pedicel of the fruit during harvesting. The sap causes skin injuries by forming black brownish streaks (Campbell, 1992). The quantity and content of the sap varies from morning to evening (Maqbool, *et al.,* 2007) therefore it's important to harvest when minimal sap injury is caused to the fruits. Amin, *et al.* (2009) indicated that the best time for harvesting and desapping is morning hours compared to harvesting at noon. The same authors indicated that mango wash and lime can be used to reduce sap injury.

Maturity indices vary amongst cultivars and are affected by the location of production (Ambuko, *et al.,* 2014) amongst other factors. The fruit harvesting stage affects the quality of fruit immensely (Ahmad, *et al.,* 2015; Ambuko, *et al*., 2016; Kader, 2002; Medlicott, *et al.*, 1985). Immature or over mature fruits are inferior in quality compared to fruits that are harvested at the right stage hence affecting their market price and storability negatively. Total soluble solids and sugars of straw berry (Rahman, *et al*., 2014) and mangoes (Ambuko, *et al*., 2014; Baloch, *et al*., 2012; Ouma, *et al*., 2014) increase with maturity while the titratable acidity and vitamin C is

high in fruits that are harvested early or immature (Baloch, *et al*., 2012). The shelf life of mango fruits harvested at early maturity stages is increased (Ambuko, *et al.*, 2016) at room temperature but the quality of immaturely harvested fruits is greatly deteriorated (Baloch, *et al.*, 2012; Rahman, *et al*., 2014). Immaturely harvested mango fruits also experience a high percent of weight loss (Baloch, *et al*., 2012) and irregular ripening hence reducing the returns due to decreased customer preference. Over ripe fruits are also prone to short shelf life and increased rates of physiological disorders therefore increased post-harvest losses.

2.4.3 Post-harvest factors

Post-harvest factors are practices that the horticultural produce is exposed to after harvest. These factors affect the fruit quality, shelf life and eventual acceptability thus contributing significantly to post harvest losses. Grading and sorting involves selection and setting aside of the produce that is of low quality in terms of size, injuries and those that are affected by pests and/or diseases. Fruits that are injured have increased enzymatic activities and increased physiological processes hence have to be sorted out. Fruits that are infected by pests and diseases may transfer pathogens and pests to healthy fruits.

Use of inappropriate storage and transportation facilities lead to quality deterioration. Modified atmosphere packaging has been suggested as it reduces the respiration and water loss rates thus preserving the shelf life of fruits (Yang, *et al*., 2022; Yuen, *et al.*, 1993). The equipment used during transportation of produce should be free of contaminants to avoid cross contamination. The equipment should be ventilated enough to avoid accumulation heat that may lead to increased ripening rate thus a decreased shelf life (Baloch, *et al*., 2012).

2.5 The role and uptake of calcium in fruits

Calcium is important in the growth, development and physiology of plants. In soil, calcium is attached loosely to particles that are negatively charged and is soluble (McLaughlin, *et al*., 1999). Soluble calcium is the only form of calcium that is available to plants and it is absorbed by the roots in divalent cation (Silva, 1991). The quantity of this soluble calcium depends on

changes in the pool of calcium that is added externally from fertilizers, bound calcium and the plants' ability to uptake through the roots (McLaughlin, *et al*., 1999).

Uptake of calcium ions from the soil solution happens when they are in close contact with the roots and it is determined by diffusion, mass flow and root interception during growth (De Freitas, *et al.*, 2012; Fageria, *et al*., 1997). The movement of calcium to the roots through mass flow is determined by transpiration and growth processes of the plant hence transpiration is a key process in the uptake of calcium (Ho, *et al.*, 1993). Calcium moves from the root surface to the root endodermal cells through apoplastic or symplastic pathways. In the symplastic pathways, calcium moves from cell to cell through the plasmodesmata across the cortical tissues all the way to the root xylem while in the apoplastic, calcium moves passively with water through the cell wall and intercellular spaces in response to water potential gradient (White, 2001).

The movement of the calcium ions along the xylem vessels is affected by a number of factors among them the formation of lowly soluble or complex compounds, calcium content in the soil, calcium competition with other nutrients, leaf and fruit competion for calcium available in the sap (Al cantar-Gonzalez, *et al.*, 2007; De Freitas, *et al*., 2012; Fageria, *et al*., 1997). Other factors that affect the movement of calcium in the xylem vessel include: the rate of water mass flow in the xylem vessels, genetics of the plant and the plant growth rate (Gilham, *et al*., 2010). Calcium uptake is also affected by climatic factors including: moisture availability, relative humidity and carbon dioxide levels in the atmosphere (Adams, *et al*., 1994; Martinez-Ballesta, *et al.*, 2010). Under high carbon dioxide there is a decline in calcium uptake by plants (Loladze, 2002). De Freitas, *et al*. (2014) indicated that shading of trees increases fruit calcium content. The fruit cortical tissue has a higher capacity to bind calcium ions in the water insoluble pectin network in the cell wall matrix reducing the amount of calcium available for other cellular functions in the fruit cells which make the apple fruits more susceptible to bitter pit (De Freitas, *et al*., 2012).

The transpiration rate of fruits is at its peak during fruit set but it declines in later stages of fruit development (Hocking, *et al*., 2016). Qiu, *et al*. (1995) indicated that calcium uptake in the papaya mesocarp was at the peak in the first 60 days of postanthesis and declined at 60-80 days

postanthesis and increased again from 100-140 days. The high calcium uptake in the first days of fruit development has been attributed to the high transpiration rate due to a high surface area to weight ratio of the fruit (Qiu, *et al.,* 1995). High leaf transpiration restricts calcium uptake by low transpiring fruits (Hocking, *et al*., 2016). De Freitas, *et al*. (2011) indicated that manipulation of leaf and fruit transpiration rate influences the response of the fruit to physiological disorders because it affects the uptake of calcium. Application of abscisic acid reduced the leaf transpiration rate allowing the fruit to take up more calcium reducing incidences of blossom end rot in tomato plants. Therefore, there is competition for calcium between fruits and other growing points on the plant (Gilham, *et al*., 2010).

Calcium plays a role in a number of processes that affect fruit growth and development (McLaughlin, *et al*., 1999; Parra-Terraza, *et al*., 2008). This element is important for cell elongation and division (Burstrom, 1968). Calcium also protects the plant from diseases by resisting pathogenic enzymes that disintegrate the cell wall (Chardonnet, *et al*., 1995; Villegas-Torres, *et al.,* 2007). It binds to the pectin in the cell wall; in the middle lamella thus increasing the strength of the cell wall (Gerasopoulos, *et al.,* 1999; Tzoutzoukou, *et al*., 1997) thus enhancing cell integrity. There are textural and compositional changes that occur during fruit development and ripening that are due to modifications of the polysaccharides that form the cell wall. A fruit cell wall has three types of polysaccharides: hemicelluloses, pectin and cellulose (Owino, *et al*., 2005). Calcium compounds have been shown to extend the longevity while maintaining quality of different fruits including: peach tree fruit (El-Alakmy, 2012), tomatoes (Daundasekera, *et al.,* 2015), guavas and avocados (Penter, *et al*., 2000). Calcium has also been used in the alleviation of blossom end rot and bitter pit in water melon and apple fruits, respectively (De Freitas, *et al*., 2012). In mango fruits, calcium has been reported to improve fruit growth, quality and shelf life (El-Alakmy, 2012; Karemera, *et al.* 2014; Poojapant, *et al.,* 2014; Singh, *et al*., 2017).

Madani, *et al* (2016) while studying how pre harvest application of calcium nitrate and calcium chloride affects papaya fruits reported that increased calcium concentration decreased fruit magnesium and potassium concentrations but both sources increased calcium concentration in

the fruit peel and pulp. The decrease in the levels of magnesium and potassium confirms the antagonistic effects among calcium and other minerals in the plant. Calcium ions can be replaced by high levels of Mg^{2+} and K^{+} hence increasing the permeability of the cell wall and membranes making the fruits susceptible to physiological disorders and a reduced shelf life. The interactions of calcium with other minerals affect both the keeping and eating quality of mango fruits. A high Ca: K is required to achieve a good keeping quality in fruits however a lower Ca: K is preferred for a better eating quality. Madani, *et al.* (2016) further indicated that the use of calcium chloride increased the levels of calcium in the peel and pulp of the papaya fruits and increased nitrogen content in the peel with the use of calcium nitrate as the source of calcium. Sihna, *et al*. (2017) reported that nutrients are not uniformly distributed in different parts of the mango fruit; the fruit peel had the highest percentage of nitrogen followed by the cotyledon, seed coat and pulp. The mango seed coat was reported by Sihna, *et al.* (2017) to be having higher calcium content than the cotyledons, peel and pulp. Additionally, Sihna, *et al.* (2017) reported that magnesium was highest in the peel.

2.6 Effect of different sources of calcium, rates and timing of application on growth, yield and quality of mango fruits

Calcium nutrition has varied effects on various aspects of fruits ranging from growth, yield, shelf life and post- harvest quality. Calcium can either be applied as a pre- harvest spray (Stino, *et al*., 2011) or a post-harvest dip (Anjum, *et al*., 2004; Mounika, *et al*., 2017; Ngamchuachit, *et al.*, 2014). This element can be applied either singly or in combination with other chemicals like Gibberellic acid, bavistin (Poojapant, *et al.*, 2014) among others.

Calcium enhances the yield of mangoes by increasing the the fruit retention per panicle (Stino, *et al*., 2011) due to reduction of abscission (Stino, *et al*., 2011). Additionally, calcium enhances the fruit length, thickness, breadth, volume, weight and the pulp weight (Singh, *et al*., 2017; Karemera, *et al.,* 2014; Madani, *et al*., 2016).

Calcium compounds have been shown to enhance the post-harvest quality of fruits and vegetables including: tomatoes (Chepngeno, *et al*., 2016; Daundasekera, *et al*., 2015), mangoes

(Anjum *et al*., 2004; Poojapant, *et al*., 2014; Singh, *et al*., 2017), peach tree fruit (El-Alakmy, 2012), guavas (Sahar, 2014) and avocados (Penter, *et al.,* 2000). Calcium sources have different effectiveness on the shelf life of fruits as reported by Mounika, *et al.,* (2017). They reported that calcium nitrate was more effective than calcium chloride in quality preservation of fruits. Additionally, Ngamchuachit, *et al*., (2014) reported that calcium chloride was more effective in the maintenance of sensory acceptability and textural aspects of fruits. Effectiveness of any source of calcium depends on a number of factors among them, the duration of contact with the fruit, immersion time and concentration of the calcium (Zhang, *et al.,* 2019). Vacuum and pressure infiltration increases fruit calcium penetration but it has bee reported to cause injury to the fruit. Garcia, *et al.,* (2019) noted that the efficiency of the calcium is also affected by the permeability of the fruit in question. This is because calcium can penetrate through the epidermis and cuticle cracks (Conway, *et al.* 1992).

Calcium enhances fruit shelf life because it increases and maintains the firmness of the fruit (Daundasekera, *et al*., 2015; Karemera, *et al*., 2014) and reduces respiration and ethylene evolution rates that slow the rate of fruit ripening (Njoroge, *et al*., 1998). Calcium maintains the integrity of the membrane hence lowers the fruit weight loss (Karemera et al., 2014; Singh, *et al.,* 2017) thus increasing the acceptability of the fruits.

Various studies indicate that the frequency, time of application, application rate and the calcium compound used have varying effects on the fruit quality and longevity hence the need for optimal application (Anjum, *et al.,* 2004; Karemera, *et al*., 2014; Poojapant, *et al*., 2014; Singh, *et al*., 2017). Anjum *et al*. (2004) reported that fruits sprayed with calcium chloride had a delayed ripening for about three (3) days compared to those that were not sprayed. Fruits spayed 30 days before harvest with calcium chloride (1.5%) had a longer shelf life than than those sprayed 15 days to harvest (Karemera, *et al.,* 2014). This is because calcium is more available during the earlier stages of fruit development than later ones. Dipping mature fruits in calcium compounds increases the shelf of mango fruits but beyond a certain concentration the quality is affected negatively. Calcium chloride (5%) and calcium sulphate (7%) applications leads to increased shelf life for 4 days but there is an increased skin shriveling of the fruits, lowered fruit

flavor and the taste thus compromising the fruit acceptability (Anjum, *et al*., 2004; Mahmud, *et al.*, 2015). Daundasekera, *et al* (2015) reported that the shelf life of tomato fruits sprayed with calcium chloride as a single dose had a longer shelf life than multiple applications.

Karemera, *et al*. (2014) reported that total sugars, total soluble solids, non-reducing and reducing sugars were higher in fruits sprayed with 2% calcium chloride 30 days before harvesting than the control ones. Total soluble solids and sugars increases gradually as the storage period increases (Karemera, *et al*., 2014) and decline gradually beyond a certain period of storage (Poojapant, *et al.*, 2014). The TSS increase is due to the breakdown of polysaccharides and starch while the decline is due to their utilization in transpiration and other biochemical activities inside the fruit (Poojapant, *et al.*, 2014). Fruits treated with calcium chloride have a higher level of total soluble solids, sugars than those not treated with calcium (Poojapant, *et al*., 2014; Karemera, *et al*., 2014). Reduced respiration leads to reduced rate of compositional chemical changes hence decreased percentage of soluble solids and other ripening related compositional changes and a maintained titratable acidity (Singh, *et al*., 1993).

2.7 Jelly seed disorder in mangoes

Fruits are affected by a number of physiological disorders that greatly affect their marketability. A physiological disorder is a breakdown of tissues due to adverse environmental conditions or mineral deficiency during the growth and development of the fruits (Ahlawat, *et al*., 2014). These disorders include: stem end cavity, soft nose, spongy tissue and jelly seed in mangoes (Raymond, *et al*., 1998), blossom end rot in tomatoes and bitter pit in apples.

Stem end cavity, soft nose and spongy tissue disorders in mangoes can be confused with each other but according to Raymond, *et al.* (1998) the three have distinct differences. Stem end cavity is manifested by the formation of a cavity in the proximal area of the fruit and necrosis of the mesocarp around the cavity while soft nose is manifested by ripening of the mesocarp partially at the distal end of the fruit and a breakdown of flesh on the ventral side towards the apex of the affected fruit (Raymond, *et al*. 1998). However, these disorders have similar features; rupture of cell wall, disorganization of the cells and deterioration of vascular

connections between the stone and the mesocarp that is unevenly ripened (Anjum, *et al*., 2004; Raymond, *et al.,* 1998). Stem end cavity, soft nose and jelly seed are largely internal and non-pathogenic (Raymond, *et al.,* 1998).

Physiological disorders have been associated with the deficiency of calcium at the cellular level which affects the integrity of the cell wall and this is manifested by leaking membranes that result in plasmolysis and membrane breakdown (De Freitas, *et al*., 2011). High ratios of Ca: N and Ca: K are said to alleviate physiological disorders (Prado, *et al.,* 2012). The ratio of these elements in the soil also affects the uptake of various elements like Ca and Mg leading to manifestation of physiological disorders (Steiner, 1984).

Due to its influence on the firmness of fruits calcium can also be associated with plant disease resistance. Calcium chloride application reduces fungal rot severity in tomatoes (Daundasekera, *et al.,* 2015). Pectolytic enzymes that are produced by post-harvest pathogens are believed to cause tissues softening (Conway, *et al.,* 1994). Calcium binds to the pectin producing cationic bridges which make the cell wall inaccessible to these enzymes (Conway, *et al.,* 1994).
Jelly seed is a major challenge that faces many farmers in Kenya and elsewhere in the world. This disorder contributes to a loss of about 30% of the mango fruits harvested in Kenya (Gitonga, *et al*., 2010b). Jelly seed manifests itself in the affected fruit through breakdown of tissues around the seed of the affected fruit. Jelly seed in mango has been associated with premature germination caused by reduction in the level of very-long-chain fatty acids in seed. (Rama, *et al*., 2020; Seshadri, *et al.,* 2019).

It is manifested by a yellow color in the affected area that is more pronounced than the rest of the mesocarp which remains whitish or pale green in young fruits (Raymond, *et al.,* 1998). The area around the pericarp is overripe, may eventually turn brown and completely disintegrated while the rest of the unaffected part is just beginning to soften and remains normal (Fig 2.1). The whole fruit may be affected in very severe cases and the fruit will be characterized with an odor and foul smell and it affects only the interior parts of the mesocarp (Ahlawat, *et al.,* 2014). The frequency of jelly seed is higher in tree ripe fruits than artificially ripened ones (Manish, *et al*.,

2015) hence early harvesting is recommended. The severity of the jelly seed disorder is also high in fruits that are more mature (Shivashankar, *et al.*, 2011). This disorder does not develop post-harvest unless it was present during harvest and does not have external symptoms that are visual though sometimes the fruit may soften prematurely around the beak of the fruit (Bally, 2007). The occurrence of jelly seed has been associated with lack of calcium (Prakash, 2012).

The occurrence of jelly seed in mango fruit is influenced by the agro-ecological zone, the fertilizer that is used, environmental conditions (Manish, *et al*., 2015; Njuguna, *et al*., 2016; Torres, *et al.,* 2004) and the cultivar in question (Njuguna, *et al*., 2016; Srivastav, *et al.,* 2015). Some cultivars are more susceptible to jelly seed than others due to variations in genetic makeup affecting the inherent characteristics of the fruit (Njuguna, et al., 2016). Calcium movement within the transpiration stream is greatly decreased by moisture unavailability and low relative humidity (Adams, *et al*., 1994; Torres, *et al.,* 2004) hence the high incidence of physiological disorders in dry conditions. Njuguna, *et al.* (2016) reported that murate of potash increased the incidence of jelly seed disorder and this was attributed to the competition between Ca and K that worked against Ca uptake by the plant hence affecting the Ca levels in the fruit. Dolomitic lime on the other hand, reduced the incidence of jelly seed occurrence in "Van Dyke" and "Tommy Atkins" mango trees and this was attributed to enhanced uptake of Ca by the plant which increases cell wall integrity thus reducing the levels of jelly seed occurrence (Njuguna, *et al*., 2016).

Figure 2:1 Jelly seed affected [A] fruit and a non-infected [B] fruit.

2.8 Summary of knowledge and research gap

While various surveys have been done on the extent of jelly seed disorder in Kenya and the varietal susceptibility to it (Gitonga, *et al.*, 2010b; Njuguna, *et al*., 2016), little research has been done on the role of various calcium formulations and timing of application. The timing of application affects the availability of calcium to the fruit (Karemera, *et al*., 2014; Penter, *et al.*, 2000). Therefore, there is need to establish the possible right formulation, rate and timing of calcium application that could alleviate this disorder. Njuguna, *et al.* (2016) suggests that dolomitic lime can be used to alleviate this disorder but its continuous application would increase the soil pH hence creating mineral imbalance in the soil.

Calcium has been reported to enhance the growth, yield and post-harvest quality of mango fruits and other fruits (Singh, *et al*., 2017; Stino, *et al*., 2011; Madani, *et al*., 2016). On the contrary, some authors have delinked calcium from increase in yield and enhanced fruit quality (Lanauskas, *et al*., 2006; Bonomelli, *et al*., 2010). Additionally, some authors report that calcium is available to the fruit at early stages of fruit development while others report effective availabity of calcium at maturity (Daundasekera, *et al*., 2015; Karemera, *et al*., 2014). Hence there is need to establish the right timing, source and rate of calcium application that would improve growth, yield and post-harvest quality of mango fruits.

CHAPTER THREE: EFFECT OF VARIED SOURCES, RATES AND TIMING OF CALCIUM APPLICATION ON YIELD OF MANGO FRUITS

Abstract

Mango (*Mangifera indica* L) production in Kenya is faced with yield challenges hindering its full exploitation. Calcium improves the yield of mango fruits by enhancing the formation and division of individual cells and reduction of abscission. Calcium has however been reported to be deficient in various mango growing sites in Kenya. Various calcium compounds have been recommended in various fruits for yield enhancement but there has not been a concrete recommendation as regards the time and concentration of calcium application. The effect of different sources of calcium, applied at varied times during growth and rates on mango yield were therefore investigated at Karurumo, Embu County, Kenya using 'Van Dyke' cultivar trees of approximately 10 years old. Calcium chloride, calcium nitrate, easy gro and control applied at concentrations of 1.0%, 1.5%, 2% or 0% were applied either at fruit set, 30 days after setting of fruits or 30 days to maturity of fruits. A randomized complete block design with a split- split plot arrangement replicated thrice was used in this study. The calcium sources formed the main plots; the timing of application formed the subplots while the rates of application formed the sub-sub plots. Data was collected on fruit weight, length and breadth, number of fruits/tree, total weight of fruits/tree, fruit retention percentage, flesh calcium concentration and their relationship thereof. The data collected was analyzed using Genstat software 14th edition. Mean separation was done using the LSD test at $p \leq 0.05$. The results indicated that source, rate and time of calcium application significantly affected yield, yield components and fruit calcium content. Additionally, the interactions among source, timing and rate of calcium application significantly affected most of the studied parameters in both seasons. Application of calcium led to improved yield and yield components relative to control fruits. Application of calcium at 2.0% outperformed other treatments in fruit length (110.8 mm, 104.6 mm), weight (292.5 g, 287.1 g), total weight (29087 g, 34648 g), and flesh calcium content (0.86 mg/mg ,0.68 mg/mg) in seasons 1 and 2 respectively. Application of calcium at fruit set had significantly the highest fruit breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content in both seasons. Application of calcium chloride 2.0%, at fruit set recorded the highest total weight of fruits and number of fruits in season 1. A direct relationship between flesh

calcium concentration and fruit length (r=0.56, r=0.81), fruit weight (r=0.34, r=0.73), fruit breadth (r=0.79, r=0.88), number of fruits (r=0.86, r=0.59), fruit retention percentage (r=0.52, r=0.62) and total weight of fruits (r=0.75, r=0.68) was recorded in both seasons respectively. This study therefore demonstrated that calcium is an important element for enhancing growth and eventual yield and it is more effective when applied during early stages of fruit development.
Key words: Abscission, calcium, mango.

3.1 Introduction

Mango (*Mangifera indica* L.), an important fruit in the Kenya economy for domestic and export markets, is the 2nd most important fruit after bananas (HCD, 2017) and supports livelihoods along the value chain. Besides foreign exchange, it is a good source of vitamins and its production supports an estimated 200,000 farmers directly. Despite this, farmers producing mango fruits face numerous challenges among them low yields. Previous studies indicate that cultivars grown in Kenya have a potential of producing 15-20 ton/ha but reported yields are less than 10 ton/ha (Kehlenbeck, *et al*., 2012). 'Van Dyke,' an attractive cultivar with a regular bearing pattern, early maturity and resistance to powdery mildew and anthracnose is very popular among farmers. This cultivar is however characterized by low yields.

Fruit drop is one amongst many factors that affect yield in mango fruits. In spite of the high initial fruit set, the ultimate fruit retention per panicle is very low due to fruit drop which happens at different fruit development stages. The intensity of fruit drop is highest during the first 15 days after pollination and pea stage (Sankar, *et al*, 2013). At marble stage the percentage drop is 30% and it occurs between 28-35 days after fruit set while the third drop is at 3% and it occurs from 40 days to maturity (Singh, *et al*., 2009). Fruit drop may lead to 90% loss of the fruit set in a given season (Bains, *et al*., 1997).

Calcium enhances the yield of mangoes by increasing the initial fruit set per panicle and reduction of abscission (Sankar, *et al*., 2013) therefore increasing the retention capacity per panicle. Calcium also enhances the physical features of fruits including: length, thickness, breadth, volume and weight. It forms an important constituent of the cell wall where it forms individual cells and prevents cellular cells degeneration (Burdon, *et al*., 1991; Burdon, *et al*.,

1992). Previous studies directly link an increase in yields with calcium application (Njuguna, *et al*., 2016). Calcium chloride and calcium nitrate compounds have been reported to be applied for yield improvement of various fruits including papaya (Madani, *et al*., 2016) and guavas. These salts are applied at varied rates and timing, mostly after physiological maturity. Stino, *et al*. (2011) reported that spraying different mango cultivars with calcium nitrate at bud emergence, full bloom and pea stage increased the average fruit weight and pulp thickness. On the contrary, some studies report that calcium applications are not directly linked to increase in yields of some fruits (Lanauskas, *et al*., 2006, Bonomelli, *et al*., 2010). Lanauskas, *et al*. (2006) reported that calcium nitrate did not increase straw berry yield. While there are studies that link increased flesh calcium concentration with calcium spraying in papaya (Eryani-Raqeeb, *et al*. 2009) among other fruits. Bonomelli, *et al.*, (2010) reports on the contrary. Previous studies have indicated calcium deficiency in various mango growing sites in Kenya (Njuguna, *et al.*, 2016).

The objective of this research was to compare the influence of calcium nitrate, calcium chloride and easygro administered at various rates and periods on the calcium uptake and yield of the mango cultivar "Van Dyke".

3.2 Materials and methods

3.2.1 Site description

This investigation was carried at an orchard in Karurumo situated in Embu County in the Eastern parts of Kenya in two fruiting seasons (2017/2018/2019). The area is classified as lower midland with an elevation of 1174 m asl with coordinates of 00°32 S 37°41 E. This area experiences an average annual rainfall of 1206 mm of bimodal pattern with long rains starting in March and peaks in April or May while short rains start in mid-October with peaks in November. Maximum and minimum temperatures and rainfall during the experiment period is as shown in table 3.1. The soils here have been found to have low levels of calcium (Njuguna, *et al*., 2016) and rich in nitrogen (0.12%), organic carbon (1%) and potassium (1.48 ppm) and are classified as loamy sand to clay (Ferralic Arenosol).

Table 3:1 Monthly rainfall and maximum and minimum temperatures at Karurumo during the experiment period

	Season 1			**Season 2**		
Month	Rainfall (mm)	Max. Temp (ºC)	Min. Temp (ºC)	Rainfall (mm)	Max. Temp (ºC)	Min. Temp (ºC)
July	50.2	23.2	12.1	80.7	19.6	13.2
August	68.4	24.2	13.5	94.8	23.5	12.5
September	100.2	25.4	13.8	154.2	21.4	13.5
October	120.1	24.8	13.4	185.3	23.1	14.8
November	181.4	20.8	15.2	198.7	20.5	15.0
December	110.2	24.2	15.4	98.7	23.4	16.3
January	20.1	25.6	14.4	34.5	24.1	14.2
February	32.4	20.4	15.4	87.9	22.8	13.8
March	202.4	19.4	15.7	140.3	21.8	15.3
April	198.4	18.5	15.9	189.8	20.4	16.2
Monthly mean	108.4	22.7	14.5	126.5	22.3	14.5

Max-Maximum; Min-Minimum; Temp- Temperature

3.2.2 Soil and leaf nutritional analyses

Soil and leaf samples from the mango cultivar tree used in the experiment were taken to establish the plant and soil nutritional status prior to the experiment. The soil samples were scooped using zig zag pattern from ten representative points of the entire plot at a depth of 0-20 cm and thoroughly mixed to get a composite sample for analysis. Leaf samples on the other hand were picked randomly by selecting thirty (30) samples from shoots bearing physiologically mature fruits per treatment. The samples were taken to the Jomo Kenyatta University of Agriculture and Technology post-harvest laboratory for nutritional analysis. The results indicated calcium deficiency in soil (2.3 mg/kg) and leaf (1.5%) (Tables 3.2 and 3.3). This was against recommended optimal leaf calcium levels of 2 to 3.5% and soil calcium levels 3 to 5 mg kg^{-1} (soil) (Quaggio, *et al*., 1996).

Table 3:2 Soil pH, organic carbon and mineral composition at Karurumo orchard experimental site

Nutrient	**Composition**	**Optimum range**	**Comment**
pH	5.24	5.5-7	Low
Organic carbon	1.5%	1-3%	Adequate
Nitrogen	0.39%	<10%	Adequate
Phosphorus	1.5%	1-2.5 %	Adequate
Potassium	1.1 %	0.25-0.4 %	Adequate
Calcium	2.3 mg /kg	3-5 mg/kg	Inadequate
Magnesium	2.8 cmol /kg	0.75-1.25 cmol/kg	Excess
Boron	7.9 mg/kg	1-2 mg/kg	Excess
Copper	3.58 mg/kg	0.3-10 mg/kg	Adequate
Iron	55.2 mg/kg	4-100 mg/kg	Adequate
Manganese	118 mg/kg	4-50 mg/kg	Excess

Table 3:3 Mango leaf mineral content before treatments

Nutrient	**Composition**	**Optimum range**	**Comment**
Nitrogen	1.46 %	1.2 %-1.4%	Adequate
Phosphorus	0.26 %	0.08 %-0.16%	Adequate
Potassium	1.25 %	0. 5 %-1.0%	Adequate
Calcium	1.5 %	2-3 %.5%	Inadequate
Magnesium	0.8 %	0.25 %-0.5%	Adequate
Copper	36.21 ppm	10-50 ppm	Adequate
Iron	46.5 ppm	50-200 ppm	Inadequate
Manganese	63.2 ppm	50-100 ppm	Adequate

3.2.3 Experimental material, crop husbandry treatments and design

The experiment involved use of approximately 10 years aged, already established, uniformly sized in height (15 m -20 m) and spread "Van dyke" cultivar trees with a spacing of 5 m x 5 m. "Van dyke" is characterised by an attractive colour, bears regularly, has a rich and pleasant flavour with an orange yellow flesh and is resistant to powdery mildew and anthracnose. This cultivar is however characterized with poor productivity. All the agronomic practices, (e.g. pruning, pest and disease control) were uniformly applied across the plots in accordance with recommendations by Griesbach (2003).

The experiment involved the application of three varied sources of calcium (calcium chloride, calcium nitrate and Easygro®) at 3 different rates (1%, 1.5% and 2% and 0% (control)) based on recommendations in various studies (e.g. Karemera, *et al*., 2014; Penter, *et al*., 2000). Control fruit trees were sprayed with plain water. Easygro® is a foliar based fertilizer that is in the market with a chemical composition of nitrogen (14%), phosphorus (0%), magnesium (2.5%), potassium (2%) and calcium (13%). These applications were done during different stages of fruit development: at the setting of fruits, 30 days after setting of fruits and 30 days to anticipated maturity of fruits. Fruits were deemed to have attained maturity at 120 days after bloom. At this point, the stone becomes hard, pulp color changes from white to cream to deep yellow starting from the endocarp progressing outward, fruits change their external color from green to yellow. The shoulders of physiologically mature fruits also swell then rise above the stem with swollen cheeks. To obtain the spray volume per tree, the foliage diameter was calculated and the area covered by the foliage used to determine the amount of water per square meter. One square meter was equated to 0.5 litres of water. Application was done using a tractor drawn boom sprayer in the morning, when plant leaves were dry and a low wind velocity to avoid drift. All the sprays were done from the bottom of the canopy till the whole plant was completely watered. The treatments were laid out in a randomized complete block design with a split-split plot arrangement with three trees per replication, replicated three times. The calcium sources formed the main plots; the timing of application formed the subplots while the rates of application formed the sub-sub plots.

3.3 Data collection

Average length of fruits

At physiological maturity 15 fruits were randomly picked from each treatment representative for determination of average fruit length. Fruit length was measured from the stalk end to the apex of the fruit using a vernier caliper (Model Mitutoyo, Japan) (Karemera, *et al*., 2014) as shown in Fig.3.1

Figure 3:1 Measuring the length of a fruit using a vernier caliper

Average breadth of fruits

At physiological maturity, 15 fruits were taken from each treatment for determination of the average fruit breadth by use of a vernier caliper (Model Mitutoyo, Japan). This was measured by taking the maximum linear distance between the two shoulders of the fruit.

Average fruit weight

Fifteen (15) fruits were harvested at physiological maturity from each treatment for the determination of weight using an electronic weighing balance (Model Libror AEG-220, Shimadzu Kyoto, Japan). The average fruit weight per treatment was recorded.

Total yield

At physiological maturity, the number of fruits per tree was counted for each treatment. The weight of the fruits obtained from each treatment was obtained immediately after harvesting and the stalk of the fruits had been removed using an electronic weighing

balance (Model Libror AEG-220, Shimadzu Kyoto, Japan). The number of fruits per tree was multiplied with the average fruit weight for each treatment to obtain the total yield per tree.

Fruit retention percentage

Twenty (20) panicles, randomly selected from all the four directions of the tree, in each treatment were tagged before each treatment. The initial number of fruits per panicle was recorded. At maturity, fruit retention per panicle was determined as shown below (Sankar, *et al*., 2013).

$$\text{Retained fruit}\,(\%) = \frac{\text{Retained number of fruit at harvest}}{\text{Initial number of fruit set}} \times 100$$

Fruit flesh calcium concentration

At physiological maturity, three fruits were taken from each treatment dried and ground to fine powder and ashed in a furnace. The ash was then dissolved with hydrochloric acid and atomic absorption spectrophotometer (AAS) was used to determine calcium concentration. The flesh calcium content was expressed as $\mu g mg^{-1}$

3.4 Data analyses

Analysis of variance (ANOVA) was conducted on the data using Genstat software 14^{th} Edition (Payne, *et al*., 2011). Where ANOVA showed significant differences, at $p \leq 0.05$ fisher's protected Least Significant Difference (LSD) was used to test the differences of the means. Correlations between calcium content in the flesh and yield parameters were carried out.

3.5 Results

3.5.1 Main effects of source, rate and time of calcium application on mango fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content

Source, rate and time of calcium application significantly ($P \leq 0.05$) affected the fruit length, weight and breadth, number and total weight of fruits/tree, fruit retention/tree and flesh calcium content in both seasons (Table 3.4). Application of calcium chloride, calcium nitrate and easygro increased the fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content in both seasons. Total weight of fruits/tree increased 4-5 folds when sprayed with calcium compared to the control fruits in both seasons. Additionally, fruit calcium content, fruit retention/tree and average weight of fruit increased more than 2 folds when sprayed with calcium compared with control in both seasons. There were no significant differences among the three sources in all the studied parameters except fruit weight in season 1 where calcium nitrate sprayed fruits had significantly higher fruit weight than the other calcium sources. Similarly, in season 2 fruits sprayed with easy gro had significantly lower total weight of fruits/tree than those sprayed with calcium nitrate.

Application of calcium at 2.0% outperformed other treatments in fruit length (110.8 mm, 104.6 mm), weight (292.5 g, 287.1 g), total weight (29087 g, 34648 g), and flesh calcium content (0.86 mg/mg ,0.68 mg/mg) in seasons 1 and 2 respectively. There were no significant differences between 1.5% and 2.0% in fruit breadth in season 1 and number of fruits in season 2. No significant differences among the rates in fruit retention were noted in season 1. Additionally, there were no significant differences between application of calcium at 1.0% and 1.5% in fruit weight and breadth in season 1, number of fruits and total weight in both seasons but significantly different in fruit length and flesh calcium content in season 1 and fruit weight, fruit breadth and fruit retention in season 2.

Application of calcium at fruit set had significantly the highest fruit breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content in both seasons and fruit length in season 2. There were no significant differences between

applications of calcium at fruit set and 30 days later in fruit weight in both seasons and fruit length in season 1. Application of calcium at 30 days after fruit set recorded significantly higher values in all the measured parameters than application at 30 days to physiological maturity in both seasons.

Table 3:4 Main effects of source, rate and time of calcium application on fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content during seasons 2017 and 2018 at Karurumo

	Season 1							Season 2						
	L (MM)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca (µg /mg)	L (mm)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca(µg /mg)
Source														
S_1	105.96^{a}	248.60^{b}	60.16^{a}	98.44^{a}	22501^{a}	5.47^{a}	0.76^{a}	99.16^{a}	250.50^{a}	61.27^{a}	110.59^{a}	29761^{ab}	5.88^{a}	0.54^{a}
S_2	107.07^{a}	288.60^{a}	60.26^{a}	106.33^{a}	24174^{a}	4.96^{a}	0.75^{a}	97.13^{a}	275.50^{a}	61.00^{a}	106.33^{a}	31359^{a}	5.73^{a}	0.54^{a}
S_3	103.44^{a}	244.20^{b}	60.10^{a}	110.59^{a}	25339^{a}	4.69^{a}	0.75^{a}	98.61^{a}	256.00^{a}	59.50^{a}	98.44^{a}	24683^{b}	5.89^{a}	0.62^{a}
Control	81.97^{b}	95.70^{c}	51.71^{b}	65.56^{b}	5126^{b}	2.36^{b}	0.32^{b}	81.59^{b}	95.20^{b}	53.17^{b}	65.56^{b}	6355^{c}	2.34^{b}	0.31^{b}
p-value	<.001	<.001	0.01	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$Lsd_{P\leq 0.05)}$	5.60	53.60	5.20	16.91	7004.3	1.42	0.09	7.87	36.48	4.12	20.48	6592.50	1.73	0.16
Cv%	7.10	23.40	11.20	25.80	41.40	38.90	23.60	10.60	19.50	9.00	26.40	46.20	41.10	31.20
Rate														
R_1	100.81^{c}	233.30^{b}	57.05^{b}	79.70^{b}	19422^{b}	4.73^{a}	0.65^{c}	93.32^{b}	235.00^{c}	57.47^{c}	94.96^{b}	23088^{b}	4.23^{c}	0.48^{b}
R_2	104.81^{b}	255.50^{b}	60.14^{ab}	87.89^{b}	23504^{b}	5.02^{a}	0.75^{b}	97.03^{b}	259.90^{b}	60.19^{b}	105.44^{ab}	28067^{b}	5.66^{b}	0.54^{b}
R_3	110.83^{a}	292.50^{a}	63.33^{a}	99.56^{a}	29087^{a}	5.37^{a}	0.86^{a}	104.55^{a}	287.10^{a}	64.11^{a}	114.96^{a}	34648^{a}	7.61^{a}	0.68^{a}
Control	81.97^{d}	95.70^{c}	51.71^{c}	65.56^{b}	5126^{c}	2.36^{b}	0.32^{d}	81.59^{c}	95.20^{b}	53.17^{d}	65.56^{c}	6355^{c}	2.34^{d}	0.31^{c}
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$Lsd_{P\leq 0.05}$	3.40	30.02	3.30	24.60	4525.6	1.01	0.08	5.00	18.00	2.57	14.07	6278.4	0.98	0.14
Cv%	6.10	22.70	10.30	11.40	37.80	39.1	20.4	9.60	23.85	7.90	25.70	44.00	32.90	28.20
Time														
T_1	106.20^{a}	282.30^{a}	65.59^{a}	105.43^{a}	30523^{a}	6.69^{a}	0.87^{a}	105.29^{a}	277.70^{a}	64.49^{a}	127.10^{a}	37635^{a}	7.32^{a}	0.72^{a}
T_2	106.10^{a}	260.00^{a}	58.95^{b}	87.17^{b}	22866^{b}	4.89^{b}	0.70^{b}	98.51^{b}	261.00^{a}	59.99^{b}	99.00^{b}	26396^{b}	5.39^{b}	0.52^{b}
T_3	97.10^{b}	189.60^{b}	53.43^{c}	64.43^{c}	12961^{c}	2.74^{c}	0.58^{c}	86.09^{c}	199.30^{b}	55.07^{c}	77.40^{c}	15098^{c}	3.75^{c}	0.41^{c}
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$Lsd_{P\leq 0.05}$	4.85	34.60	2.52	9.07	4083.9	0.61	0.09	4.12	30.41	2.23	10.78	5429.8	1.02	0.07
Cv%	9.20	27.60	8.30	20.60	36.00	25.00	24.30	8.30	24.10	7.3.00	20.80	40.10	36.20	25.60

S_1=Calcium chloride; S_2=calcium nitrate; S_3= Easygro; L=Length; W=Weight; B=Breadth; NF=Number of fruits; TW=Total weight of fruit/tree; FR=Fruit retention/tree; T_1=Fruit set; T_2= 30 days after fruit set; T_3= 30 days to fruit maturity; R_I=1.0%; R_2=1.5%; R_3=2.0%; LSD=Least significant difference; CV=Coefficient of variation.Treatments with different letters in the same column are significantly different according to LSD at p ≤0.05.

3.5.2 Interactive effects of source, rate and time of calcium application on fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content

The interaction between source and rate did not significantly (P≤0.05) affect fruit weight, breadth, number of fruits/tree, total weight of fruits/tree fruit retention and flesh calcium content in both seasons but significantly (P≤0.05) affected the fruit length in season 1 (Table 3.5). All the calcium sources irrespective of the rate significantly increased fruit length relative to the control. Fruit length significantly increased with increase in Easygro rate. Increasing the rates of calcium nitrate had no effect on fruit length while the fruit length only increased when calcium chloride was applied at 2.0%. There were no significant differences in fruit length between the two rates of calcium chloride applied at 1.0% and 1.5%. The fruit length ranged from 81.97mm (Control) to 112.19mm (2.0% calcium chloride).

Table 3:5 Interactive effects of source and rate of calcium application on fruit length (MM) in season 1 during season 2017 at Karurumo

Treatment	FL (mm)	FL (mm)
S_IR_3	112.19[a]	105.20
S_3R_3	111.87[a]	105.00
S_2R_3	108.40[ab]	103.50
S_2R_2	107.66[abc]	95.80
S_2R_1	105.10[bcd]	92.10
S_1R_2	104.69[bcd]	98.10
S_3R_2	102.09[cd]	97.20
S_1R_1	100.99[de]	94.20
S_3R_1	96.40[e]	93.60
Control	81.97[f]	81.60
p-value	0.02	1
LSD $_{P\leq 0.05}$ S*R	5.59	Ns
Cv%	5.80	9.90

S_1=Calcium chloride; S_2=calcium nitrate; S_3= Easygro; R_1=1%; R_2=1.5%; R_3=2.0%; LSD=Least significant difference; S=Source; R=Rate; CV=Coefficient of variation; FL=Fruit length; ns=Not significant.Treatments with different letters in the same column are significantly different according to LSD at p ≤0.05

Interaction of source and time of calcium application significantly (P≤0.05) affected fruit weight, fruit breadth, number of fruits/tree, total weight of fruits/tree and fruit retention/tree in both seasons but significantly affected fruit length and flesh calcium content in season 2

only (Table 3.6). Fruits that were sprayed at fruit set recorded insignificant differences in all the parameters irrespective of the source except fruit retention/tree in season 1, breadth, number of fruits and total weight of fruits/tree in season 2. There were no significant differences among fruits sprayed with calcium nitrate and calcium chloride at fruit set in all the measured parameters. No significant differences among fruits sprayed at 30 days to physiological maturity in fruit breadth and fruit retention/tree in both seasons and total weight of fruits/tree in season 1, and fruit length and number of fruits/tree in season 2. Fruit retention percentage/tree, number of fruits/tree and fruit breadth of fruit trees sprayed 30 days to physiological maturity, irrespective of the source of calcium, were not significantly different from the unsprayed ones in both seasons as well as fruit length and total weight of fruits in season 2. In most cases, fruits sprayed at fruit set reported significantly the highest values in most of the measured parameters followed by those sprayed 30 days later and 30 days to physiological maturity respectively.

Table 3:6 Interactive effects of source and time of calcium application on fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content during seasons 2017 and 2018 at Karurumo

	Season 1							Season 2						
Treatment	L (mm)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca (µg /mg)	L (mm)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca (µg/mg)
S_1T_1	110.76	305.90^{ab}	66.61^{a}	105.90^{a}	31306^{a}	7.78^{a}	0.93	110.69^{a}	293.10^{ab}	67.58^{a}	151.20^{a}	46985^{a}	8.18^{a}	0.65^{bcd}
S_2T_1	110.73	317.50^{a}	68.53^{a}	112.00^{a}	33333^{a}	7.06^{ab}	0.93	106.34^{ab}	297.00^{ab}	65.67^{ab}	136.10^{ab}	43498^{a}	7.62^{a}	0.68^{bc}
S_3T_1	104.63	285.50^{abc}	66.49^{a}	117.20^{a}	35605^{a}	6.69^{b}	0.86	106.2^{7ab}	303.50^{a}	63.71^{bc}	114.70^{bc}	32826^{b}	8.01^{a}	0.85^{a}
S_1T_2	109.29	283.00^{bc}	60.62^{b}	86.70b^{c}	23934^{b}	5.76^{c}	0.74	101.63^{bc}	271.70^{bcd}	60.30^{d}	109.20^{c}	30948^{bc}	5.83^{ab}	0.57^{cde}
S_3T_2	108.80	255.80^{c}	59.09^{b}	101.90^{ab}	26786^{b}	4.79^{d}	0.77	101.60^{bc}	262.10^{cd}	60.18^{d}	99.10^{cd}	25380^{cd}	5.57^{ab}	0.58^{cd}
S_2T_2	108.29	295.80^{ab}	59.72^{b}	82.80^{c}	23750^{b}	5.00^{cd}	0.74	98.46^{c}	285.80^{abc}	62.23^{cd}	99.80^{cd}	29586^{bc}	5.72^{ab}	0.51^{de}
S_3T_3	96.88	191.40^{d}	54.71^{c}	66.90^{cd}	13627^{c}	2.59^{e}	0.62	87.98^{d}	202.50^{e}	54.62^{e}	81.60^{de}	15842^{ef}	4.10^{bc}	0.43^{ef}
S_2T_3	102.18	252.40^{c}	52.52^{c}	63.20^{d}	15438^{c}	2.82^{e}	0.58	86.60^{de}	243.70^{d}	55.10^{e}	83.10^{de}	20994de	3.86^{bc}	0.41^{fg}
S_1T_3	97.82	156.80^{e}	53.26^{c}	64.90^{ef}	12263^{c}	2.88^{e}	0.62	85.14^{de}	186.60^{e}	55.92^{e}	71.30^{e}	11351^{fg}	3.62^{bc}	0.40^{fg}
$CtrlT_1$	83.2	96.70^{f}	51.03^{c}	49.00^{d}	4504^{d}	2.33^{e}	0.32	82.97^{de}	96.40^{f}	54.00^{e}	65.30^{e}	6425^{g}	1.73^{c}	0.32^{fg}
$CtlrT_3$	80.83	93.70^{f}	52.87^{c}	59.30^{d}	5626^{d}	2.50^{e}	0.35	81.77^{de}	94.70^{f}	53.77^{e}	65.70^{e}	6424^{g}	2.77^{c}	0.33^{fg}
$CtrlT_2$	81.87	96.70^{f}	51.23^{c}	57.70^{d}	5248^{d}	2.23^{e}	0.28	80.03^{e}	94.00^{f}	51.73^{e}	65.70^{e}	6217^{g}	2.53^{c}	0.28^{g}
P-value	0.19	<.001	<.001	<.001	<.001	<.001	0.05	0.002	0.004	0.015	<.001	<.001	<.001	0.004
$Lsd_{P\leq0.05}$S*T	Ns	33.56	3.55	19.05	4476	0.89	Ns	7.54	28.84	3.24	21.44	5999.9	2.63	0.14
Cv%	5.7	14.6	6.4	13.7	21.6	11.5	17	5.9	12.6	5.8	13	24.2	29.4	20

S_1=Calcium chloride; S_2=calcium nitrate; S_3= Easygro; L=Length; W=Weight; B=Breadth; NF=Number of fruits; TW=Total weight of fruit/tree; FR=Fruit retention; T_1=Fruit set; T_2= 30 days after fruit set; T_3= 30 days to fruit maturity; Lsd=Least significant difference; CV=Coefficient of variation;Ctrl=Control;Treatments with different letters in the same column are significantly different according to LSD at $p \leq 0.05$.
Ns=Not significant

The interaction between rate and time of calcium application significantly ($P \leq 0.05$) affected the fruit weight, breadth, number of fruit/tree, total weight of fruits/tree, fruit retention and flesh calcium content in both seasons but fruit length in season 2 only (Table 3.7). Among fruits sprayed with 2.0% calcium, those sprayed at fruit set registered significantly higher values in all the measured parameters than those sprayed at 30 days later, which were in turn significantly higher than fruits sprayed at 30 days to maturity in all the parameters in both seasons. Similarly, among fruits sprayed with calcium at 2.0% and 1.5%, those sprayed at fruit set reported significantly higher values in most of the measured parameters than those sprayed 30 days later and 30 days to maturity respectively in both seasons. Within fruits sprayed at fruit set, fruits sprayed at 2.0% calcium outperformed those sprayed with 1.5% in fruit breadth, total weight of fruits/tree and flesh calcium content in both seasons, fruit weight in season 1, fruit length and fruit retention in season 2. The latter rate was in turn significantly higher in most parameters than 1.0% in most cases in both seasons. Among fruits sprayed at 30 days after fruit set there were no significant differences between fruits sprayed with 1.0% and 1.5% in most of the parameters. Application of calcium at 30 days to physiological maturity did not increase the fruit breadth, number of fruits/tree, fruit retention in both seasons except when applied at 2.0% and 1.5% in some cases.

Table 3:7 Interactive effects of time and rate of calcium application on fruit length, weight, breadth, number of fruits/tree, total weight of fruits/tree, fruit retention/tree and flesh calcium content during seasons 2017 and 2018 at Karurumo

	Season 1							Season 2						
Treatments	L (mm)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca (µg /mg)	L (mm)	W (g)	B (mm)	NF	TW (g)	FR (%)	Ca (µg /mg)
R_3T_1	113.74	329.70^{a}	70.740^{a}	122.56^{a}	384840^{a}	7.73^{a}	1.04^{a}	114.50^{a}	314.00^{a}	70.70^{a}	153.40^{a}	51026^{a}	10.22^{a}	0.93^{a}
R_3T_2	113.23	290.00^{b}	63.34^{c}	107.89^{b}	31131^{b}	5.69^{cd}	0.88^{b}	108.21^{b}	288.70^{bc}	64.52^{b}	108.80^{b}	31596^{c}	7.61^{b}	0.64^{bc}
R_2T_1	109.57	297.40^{b}	67.77^{b}	112.56^{ab}	33409^{b}	7.22^{ab}	0.89^{b}	106.87^{b}	296.80^{ab}	64.53^{b}	136.70^{a}	40701^{b}	7.84^{b}	0.68^{b}
R_1T_1	104.81	281.80^{bc}	63.12^{c}	100.00^{bc}	28350^{c}	6.57^{bc}	0.79^{c}	101.93^{c}	282.80^{bc}	61.72^{c}	111.90^{b}	31581^{c}	5.74^{cd}	0.58^{cd}
R_2T_2	107.36	277.80^{bc}	59.30^{d}	86.56^{cd}	23438^{d}	5.07^{d}	0.75^{cd}	98.73^{d}	271.20^{cd}	60.24^{c}	101.90^{bc}	28325^{cd}	5.54^{cd}	0.54^{def}
R_1T_2	103.79	266.70^{bc}	56.79^{de}	76.89^{de}	19900^{e}	4.79^{d}	0.63^{e}	94.74^{e}	259.80^{d}	57.94^{d}	97.40^{bcd}	25993de	3.97^{e}	0.48^{efg}
R_3T_3	105.52	257.90^{c}	55.89^{ef}	68.22^{ef}	17646^{e}	2.83^{e}	0.68^{de}	90.94^{f}	258.60^{d}	57.12^{de}	82.70^{cde}	21322^{e}	4.99^{d}	0.45^{fg}
R_2T_3	97.51	191.50^{d}	53.36^{fg}	64.56^{ef}	13665^{f}	2.77^{e}	0.61^{ef}	85.50^{g}	211.70^{e}	55.78^{ef}	77.80^{de}	15174^{f}	3.60^{e}	0.41^{gh}
R_1T_3	93.84	151.20^{e}	51.24^{g}	62.22^{f}	10017^{g}	2. 69^{e}	0.54^{f}	83.28^{gh}	162.50^{f}	52.74^{g}	75.60^{e}	11691^{fg}	2.99^{g}	0.38^{h}
Ctrl T_1	83.20	96.70^{f}	51.03^{g}	49.00^{f}	4504^{h}	2.33^{e}	0.32^{g}	82.97^{gh}	96.40^{g}	54.00^{fg}	65.30^{e}	6425^{g}	1.73^{h}	0.33^{hi}
Ctrl T_3	80.83	93.70^{f}	52.87^{fg}	59.33^{ef}	5626^{h}	2.50^{e}	0.35^{g}	81.77^{gh}	94.70^{g}	53.77^{fg}	65.70^{e}	6424^{g}	2.77^{fg}	0.33^{hi}
Ctrl T_2	81.87	96.70^{f}	51.23^{g}	57.67^{ef}	5248^{h}	2.23^{e}	0.28^{g}	80.03^{h}	94.00^{g}	51.73^{g}	65.70^{e}	6217^{g}	2.53^{gh}	0.28^{i}
P-value	0.22	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
LSD $_{P\leq 0.05}$														
R*T	Ns	31.61	2.60	11.71	4533.8	0.90	0.08	3.04	21.57	2.78	20.35	7429.7	1.05	0.09
Cv%	4.4	13.8	4.7	10.3	12.6	11.7	11.6	3.4	9.4	3.5	12.4	21.2	11.8	12.9

S_1=Calcium chloride; S_2=calcium nitrate; S_3= Easygro; L=Length; W=Weight; B=Breadth; NF=Number of fruits; TW=Total weight of fruit/tree; FR=Fruit retention; T_1=Fruit set; T_2= 30 days after fruit set; T_3= 30 days to fruit maturity; R_1=1.0%; R_2=1.5%; R_3=2.0%; LSD=Least significant difference; CV=Co-efficient of variation.Treatments with different letters in the same column are significantly different according to LSD at $p \leq 0.05$; Ctrl= Control.

Interactions of source, rate and time of calcium application had significant ($p<0.05$) effects on fruit weight in both seasons (Table 3.8). Calcium chloride and calcium nitrate, (2.0%) applied at fruit set gave significantly higher fruit mean weight than other treatment combinations in season I. Control (no calcium application) fruits registered significantly the lowest fruit weight in both seasons, except calcium chloride, 1.0% applied 30 days to maturity in season 1.

Table 3:8 Interactive effects of source, rate and time of calcium application on fruit weight (g) during seasons 2017 and 2018 at Karurumo

Source	Rate	Season 1			Season 2		
		T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	R_1	282.0^{e}	268.4^{f}	101.2^{lm}	271.4^{hij}	251.8^{kl}	129.6^{p}
	R_2	289.4^{cde}	289.0^{de}	114.3^{k}	291.4d^{efg}	264.2^{ijk}	169.9^{o}
	R_3	346.3^{a}	291.6^{cde}	254.8^{ghi}	316.4^{a}	299.1^{bcde}	260.4^{jk}
Calcium nitrate	R_1	295.6^{cd}	283.1^{e}	244.7^{i}	281.3f^{gh}	277.3^{ghi}	230.2^{mn}
	R_2	314.2^{b}	292.1^{cde}	253.0^{ghi}	296.2^{cdef}	285.2^{efgh}	243.6l^{m}
	R_3	342.7^{a}	312.1^{b}	259.6^{fg}	313.5^{ab}	294.9^{def}	257.2^{jkl}
Easygro	R_1	267.8^{f}	248.7^{hi}	107.9^{kl}	295.7^{def}	250.2^{kl}	127.6^{p}
	R_2	288.7^{de}	252.1^{ghi}	207.1^{j}	302.6^{abcd}	264.2^{ijk}	221.6^{n}
	R_3	299.9^{c}	266.5^{f}	259.3^{fgh}	312.1^{abc}	272.1^{hij}	258.3^{jkl}
Ctrl	R_0	96.7^{m}	96.7^{m}	93.7^{m}	96.4^{q}	94.7^{q}	94.0^{q}
P-value		<.001			<.001		
$LSD_{P \leq 0.05}$	SxTxR	10.6			16.8		
CV (%)		2.7			4.1		

S_I = Calcium chloride; S_2 = Calcium nitrate; S_3 = Easygro; Ctrl= Control; R_1 = 1.0%; R_2 - 1.5%; R_3 - 2.0%; R_0 - 0%; T_1 - Fruit set; T_2 - 30 days after fruit set; T_3 - 30 days to fruit maturity; S = Source; T = Time; R= Rate; LSD = Least significant difference; CV = coefficient of variationTreatments with different letters are significantly different according to LSD at $p \leq 0.05$.

Interactions between source, rate and time had significant ($p \leq 0.05$) on the mean number of fruits/tree in both seasons (Table 3.9). All fruit trees sprayed at 30 days to maturity did not have significantly different number of fruits from the control irrespective of the rate and source in season 2 and those sprayed with calcium chloride in season 1. Fruit trees sprayed with calcium chloride 2.0% at fruit set had the highest number of fruits in season 1.

Table 3:9 Interactive effects of source, rate and time of calcium application on the number of fruits/tree during seasons 2017 and 2018 at Karurumo

		Season I			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
S_1	R_1	114.0^{def}	105.0^{fgh}	68.3^{o}	84.7^{gh}	68.7^{i}	61.7^{ij}
	R_2	155.7^{b}	108.0^{efg}	71.0^{mno}	109.3^{cde}	79.3^{h}	64.7^{ij}
	R_3	184.0^{a}	114.7^{def}	74.7^{lmno}	123.7^{a}	112.0^{bcd}	68.3^{i}
S_2	R_1	115.7^{de}	93.3^{ij}	81.0^{klm}	104.7^{de}	67.7^{i}	59.7^{jk}
	R_2	140.3^{c}	97.7^{hi}	82.3^{kl}	112.0^{bcd}	80.0^{h}	62.3^{ij}
	R_3	152.3^{b}	108.3^{efg}	86.0^{jk}	119.3^{ab}	100.7^{ef}	67.7^{i}
S_3	R_1	106.0^{efgh}	94.0^{ij}	77.3^{klmn}	110.7^{bcd}	94.3^{fg}	65.3^{ij}
	R_2	114.0^{def}	100.0^{ghi}	80.0^{klm}	116.3^{abc}	100.3^{ef}	66.7^{i}
	R_3	124.0^{d}	103.3^{ghi}	87.3^{jk}	124.7^{a}	111.0^{cd}	68.7^{i}
Control	R_0	65.3^{o}	65.7^{o}	65.7^{o}	49.0^{k}	57.7^{jk}	59.3^{ij}
P-value		0.04				<.001	
$LSD_{p \leq 0.05}$	SxTxR	10.3				9.9	
Cv (%)		6.2				7.3	

S_1 = Calcium chloride; S_2 = Calcium nitrate; S_3 = Easygro; CTRL = Control; R_1= 1.0%; R_2 = 1.5%; R_3 = 2.0%; R_0 - 0%; T_1 = Fruit set; T_2 = 30 days after fruit set; T_3 =30 days to fruit maturity; S = Source; T = Time; R = Rate; LSD = Least significant difference; CV = coefficient of variation.
Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time of calcium application significantly ($p \leq 0.05$) affected the total weight of fruits in both seasons (Table 3.10). Application of calcium chloride (2.0%), at fruit set recorded the highest total fruit weight followed by calcium nitrate (2.0%) sprayed at fruit set in season 1. The highest total fruit weight in season 2 was comparatively lower than the average total fruit weight in season I with the highest recorded weight in season 1 and 2 being 63723 g and 39138 g respectively.

Table 3:10 Interactive effects of source, rate and time of calcium application on the total weight of fruits/tree (g) during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
S_1	R_1	32142^{e}	28184^{fg}	6917^{n}	22912^{i}	17318^{klm}	7984^{qr}
	R_2	45088^{c}	31221^{ef}	8119^{n}	31866^{def}	20970^{ij}	11006^{op}
	R_3	63723^{a}	33438^{e}	19017^{lm}	39138^{a}	33514^{cd}	17798^{kl}
S_2	R_1	34214^{de}	26422^{gh}	19812^{klm}	29435^{fg}	18763^{jk}	13729^{no}
	R_2	44107^{c}	28538^{fg}	20839^{jkl}	33163^{cd}	22814^{i}	15179^{lmn}
	R_3	52172^{b}	33797^{de}	22330^{ijkl}	37400^{ab}	29672^{f}	17408^{klm}
S_3	R_1	28388^{fg}	23372^{hij}	8344^{n}	32704^{cde}	23620^{hi}	8338^{pq}
	R_2	32907^{e}	25216^{ghi}	16564^{m}	35198^{bc}	26531^{gh}	14811^{mn}
	R_3	37183^{d}	27552^{g}	22618^{ijk}	38913^{a}	30206^{ef}	17732^{klm}
Control	R_0	6425^{n}	6217^{n}	6424^{n}	4504^{s}	5248^{rs}	5626^{qrs}
p-value		<.001				<.002	
$LSD_{p \leq 0.05}$	SxTxR	3410.9				2924.6	
CV%		7.9				8.1	

S_1=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; Ctrl=Control; R_1=1.0%; R_2=1.5%; R_3=2.0%; R_0=0%; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to fruit maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV= coefficient of variation.
Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

The interaction between source, rate and time had significant ($p \leq 0.05$) effects on fruit retention in season 2 only (Table 3.11). Application of easygro and calcium nitrate (2.0%) at fruit set had the highest fruit retention. Calcium sprayed at 30 days to maturity at a rate of 1.0%, irrespective of the source, did not have significantly different fruit retention/tree from the control.

Table 3:11 Interactive effects of source, rate and time of calcium application on the percentage fruit retention /tree (%) during seasons 2017 and 2018 at Karurumo

Source	Rate	Season I			Season 2		
		T_1	T_2	T_3	T_1	T_2	T_3
S_1	R_1	7.2	5.4	3.1	7.03^{d}	3.83^{ijk}	2.83^{lm}
	R_2	7.8	5.6	3.1	7.93^{cd}	5.67^{ef}	3.10^{jklm}
	R_3	8.3	6.2	2.5	9.57^{b}	8.00^{c}	4.97^{efg}
S_2	R_1	6.4	4.5	2.9	4.97^{efg}	4.07^{ghi}	3.10^{jklm}
	R_2	7.3	4.8	2.7	7.40^{cd}	5.80^{e}	3.70^{ijkl}
	R_3	7.5	5.7	2.9	10.50^{a}	7.30^{cd}	4.77^{fgh}
S_3	R_1	6.1	4.5	2.5	5.23^{ef}	4.03^{hi}	3.03^{klm}
	R_2	6.6	4.8	2.6	8.20^{c}	5.23^{ef}	4.00^{hi}
	R_3	7.4	5.1	2.7	10.60^{a}	7.53^{cd}	5.23^{ef}
Control	R_0	2.3	2.2	2.5	1.73^{n}	2.53^{mn}	2.83^{lm}
P-value			0.61			<.001	
$Lsd_{p \leq 0.05}$	SxTxR		Ns			0.92	
Cv (%)			9.30			10.10	

S_1-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; CTRL-Control; R_1-1.0%;R_2-1.5%; R_3-2.0%; R_0-0%; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to fruit maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; CV- coefficient of variation; ns-Not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$

Interaction of source, rate and time of calcium application had significant ($p \leq 0.05$) effects on the flesh calcium concentration in season 1 only (Table 3.12). Highest fruit calcium content (1.13 μg/mg) was registered in fruits that were sprayed with easygro (2.0%) at fruit set. Fruits sprayed with calcium 1.0%, applied at 30 days to maturity, irrespective of the source, were not significantly different from control fruits. All fruits sprayed with calcium 1.5%, at 30 days after fruit set, irrespective of the source, did not have significantly different flesh calcium content.

Table 3:12 Interactive effects of source, rate and time of calcium application on flesh calcium content (µg/mg) during seasons 2017 and 2018 at Karurumo

		Season I			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
S_1	R_1	0.55^{fgh}	0.49^{ijk}	0.38^{mno}	0.85	0.58	0.52
	R_2	0.60^{ef}	0.54^{ghi}	0.39^{lmn}	0.90	0.73	0.61
	R_3	0.81^{b}	0.66^{cd}	0.43^{lm}	1.03	0.90	0.69
S_2	R_1	0.57^{efg}	0.44^{jkl}	0.38^{mno}	0.77	0.61	0.49
	R_2	0.62^{cde}	0.52^{hi}	0.40^{lmn}	0.95	0.76	0.60
	R_3	0.86^{b}	0.58^{efg}	0.44^{jkl}	1.08	0.86	0.66
S_3	R_1	0.61^{de}	0.50^{hi}	0.37^{no}	0.76	0.70	0.59
	R_2	0.82^{b}	0.55^{fgh}	0.44^{jkl}	0.82	0.75	0.61
	R_3	1.13^{a}	0.68^{c}	0.49^{ij}	1.00	0.87	0.67
CTRL	R_0	0.33^{op}	0.28^{p}	0.33^{op}	0.26	0.28	0.35
p-value		<.001			0.75		
$Lsd_{p \leq 0.05}$	SxTxR	0.05			Ns		
Cv (%)		6.30			12.0		

S_1-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; Ctrl-Control; R_1-1.0%;R_2-1.5%; R_3-2.0%; R_0-0%; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to fruit maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; CV- coefficient of variation; ns-Not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

3.5.3 Correlation analysis between flesh calcium content and growth attributes

A positive significant ($p \leq 0.05$) correlation between the fruit flesh calcium content and fruit length, weight, breadth, number of fruits, fruit retention and total weight of fruits was observed in both seasons (Table 3.13).

Table 3:13 Correlation between calcium (µg/mg) content in the mango flesh and yield components during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	Pearson correlation (r)	p-value	Pearson correlation (r)	p-value
Fruit length	0.56	0.0000	0.81	0.0000
Fruit weight	0.34	0.0003	0.73	0.0000
Fruit breadth	0.79	0.0000	0.88	0.0000
No. of fruits	0.86	0.0000	0.59	0.0000
Fruit retention	0.52	0.0000	0.62	0.0000
Total weight of fruits	0.75	0.0005	0.68	0.0000

3.6 Discussion

Application of calcium increased fruit length, weight, breadth, number and total weight of fruits/tree, fruit retention/tree and the flesh calcium content of mango fruits. Different calcium sources invariably increased growth attributes, total yield and calcium content. Calcium has a role in cell formation and prevention of cellular degeneration (Burdon, *et al*., 1991; Burdon, *et al*., 1992) hence a probable reason for the increase in yield components and overall fruit yield. Calcium is an important mineral in the formation of cell membrane and development hence critical in increasing the fruit physical attributes. Additionally, calcium increases the productivity of mango fruits because of its role in reducing abscission leading to increased fruit retention (Wahdan, *et al*., 2011). The increase in fruits yields due to application of calcium compounds has been reported (Kumar, *et al.,* 2003; Hafle, *et al.,* 2003; Karemera, *et al*., 2013; Njuguna, *et al*., 2016; Torres, *et al.,* 2004; Kumari, *et al.,* 2018 and Stino, *et al.,* 2011). On the contrary, Lanauskas, *et al.* (2006) and Bonomelli, *et al.* (2010) did not report an increase in fruit weight and yield by application of calcium. This could be attributed to differences in calcium concentrations, calcium compounds used or environmental conditions that have an effect on calcium availability. There were differences among sources of calcium in their effect on yield components and calcium concentration probably because of the differences in calcium availability due to the different chemical formulations.

The increase in fruit yield (total weight of fruits /tree) is as a result of the cumulative effect caused by an increased number of fruits due to the reduction in abscission rate and increase in growth parameters (Kumar, *et al.*, 2006; Wahdan, *et al*., 2011). Calcium increased the weight of the fruit and decreased fruit drop therefore increasing the yield. Fruit drop was high during initial stages of fruit growth with a decreased trend as maturity progressed. Consequently, fruit drop was highest at fruit set as previously found by Sankar, *et al*. (2013).

Time of application also affected yield as well as yield components with early application giving best results relative to late application and the control. Application of calcium at 30 days to anticipated physiological maturity gave poorer results than application at earlier stages perhaps due to poor availability of calcium at this stage. Pre- harvest

calcium applications are easily available at early fruit development period as previously reported in mango (Karemera, *et al*., (2013), apple (Michalezuk, *et al*., 1984) and avocado (Penter, *et al*., 2000) fruits. Therefore, it is apparent that pre harvest calcium is essential for mango fruit development and should be applied at early stages of fruit development for maximum yield. Late application of calcium should be discouraged for better yields and efficient uptake of calcium by the fruit. There are however contradicting studies indicating that mature fruits take up calcium efficiently than young ones because of more lenticels and cracks on the cuticle as the fruit matures (Wojcik, 2001; Lewis, et al., 1973). These contradictions could be due to plant species, calcium formulaton and environmental conditions that affect availability and uptake of calcium among other factors.

This study showed an increase in flesh calcium concentration with calcium application. Similar results of an increase in calcium tissue due to application of calcium have been reported in mango (Kader, *et al.,* 2002), papaya (Eryani-Raqeeb, *et al*. 2009) strawberry (Cheour, *et al*., 1990; Garcia, et al., 1996) and tomato (Cheour, *et al*., 2015) fruits. Results from this study were however not agreeing with those reported by Bonomelli, *et al*., (2010) and Val, *et al.,* (2008) who found that calcium application did not have an effect on the fruit calcium content. The inconsistency in the results could be due to environmental conditions, rate or the frequencies of application, time of application, method of application and the initial content of calcium before application of treatments. Wojcik (2001) also reported that the uptake of calcium applied directly on fruits highly depends on the plant species.

In this study, correlation analysis showed apparent association of yield parameters with calcium content. Additionally, the yield (total weight/tree) increased with an increase in calcium concentration. This suggests that application of calcium fertilizer at the right time could improve yields of mango fruits.

The rate of calcium applied significantly influenced yield and yield components. Increasing rates of calcium chloride, calcium nitrate and easygro from 1.0% to 2.0% increased fruit yield components (fruit weight length, breadth and fruit percentage). It

was established that there is a direct relationship between the yield (kg/tree) and the rate of application in the range of concentrations studied. The best application realized in this study was calcium chloride at 2.0% applied at fruit set.

CHAPTER FOUR: EFFECT OF VARIED SOURCES, RATES AND TIMING OF CALCIUM APPLICATION ON JELLY SEED INCIDENCE, QUALITY AND SHELF LIFE OF 'VAN DYKE' MANGO FRUITS

Abstract

Mango (*Mangifera indica* L.) is often affected by physiological disorders among them jelly seed that may lead to significant losses if not well managed. Jelly seed has an effect on the mesocarp's interior of the fruit affecting the tissues around the seed of the fruit. The affected area appears deep yellow and softer than the rest of the mesocarp. This disorder does not have visual external symptoms. Calcium enhances the tissue of the fruit mesocarp firmness and stability thus reducing cell disintegration within the mesocarp. An experiment was carried out in two successive seasons at Embu County, Kenya, aimed at establishing how different foliar calcium formulations, sprayed at various concentrations and period of growth affect the occurrence of this disorder, distribution of calcium on the fruit parts and quality of mango fruits. Approximately 10 year old 'Van Dyke' cultivar mango trees were used in this study. In order to supply calcium, either calcium nitrate, calcium chloride, or easygro® was used. The Calcium sources were sprayed at three phases of fruit growth (fruit set, 30 days following fruit setting, or 30 days to anticipated fruit maturity) at concentrations of 1.0 %, 1.5 %, 2.0 %, or 0% (control). The treatments were organized in a split-split plot configuration that was reproduced three times using a randomized complete block design. The calcium sources formed the main plots; the timing of application formed the subplots while the rates of application formed the sub-sub plots. At physiological maturity, a sample of fruits was harvested and ripened at ambient conditions (25±2°C, 70±5% RH) for determination of jelly seed incidence, calcium distribution in the fruit mesocarp, exocarp, cotyledon and endocarp, fruit weight and selected organoleptic attributes. Also determined were the total titratable acidity, total soluble solids, peel color and firmness at projected fruit maturity (120 days following full bloom) and after 12 days of storage in ambient settings. The source, rate, time and the interactions among the factors significantly affected most of the studied parameters in both seasons. Fruits treated with calcium showed low scores of jelly seed incidence. Fruits sprayed with calcium at a rate of 2.0% registered significantly the lowest jelly seed scores in both seasons with fruits sprayed with calcium chloride at 2%

at the initial stage of fruit set registering the least scores of 1.2 in season 1 and 2.0 in season 2. All calcium sources increased mesocarp, exocarp and endocarp calcium content in both seasons. Application of calcium at fruit set registered significantly the highest calcium content in fruit mesocarp and exocarp in both seasons. The highest calcium content was found in fruits sprayed with calcium chloride at a rate of 2.0 percent at fruit set (1.32 g mg-1). In seasons 1 and 2, negative correlations between fruit weight (r = -0.55, r = -0.52), calcium content in the exocarp (r = -0.56, r = -0.49), mesocarp (r = -0.52, r = -0.76), endocarp (r = -0.76, r = -0.66), and jelly seed manifestation were found respectively. Additionally, fruits sprayed with calcium chloride 2.0% at fruit set maintained higher peel firmness (4.83 N, 4.77 N), percentage titratable acidity (1.29%, 1.27%), peel hue angle (67.9, 67.2), and total soluble solids (10.47°brix, 9.10°brix) than all other treatments. Calcium chloride application led to an improved peel colour appearance while calcium nitrate and easygro led to a deteriorated peel colour appearance. Further, high rates of all sources of calcium led to a deteriorated taste of fruits. The results of this study indicate that 2% calcium chloride sprayed at fruit set is more effective than other calcium sources for preventing jelly seed and preserving fruit quality and shelf life. Additionally, it was found that calcium is more readily available to the fruit when it is sprayed at an earlier stage of growth than at a later stage.

Key words. Calcium, jelly seed, physiological disorder, mango, quality

4.1 Introduction

Physiological disorders are among the many challenges mango producers in Kenya and elsewhere in the world face. These disorders may cause enormous losses by reducing the quality of fruits which affect their consumer acceptability and marketability. They are characterised by flesh disintegration that is not necessarily pathogenic but can serve as entry point to pathogens (Kumar, *et al*., 2016). These disorders can be caused by among other factors; environmental conditions, imbalanced soil nutrients, minerals, soil pH and drainage.

Stem end cavity, jelly seed and soft nose are among the disorders that affect mango fruits and they have been described to affect different parts of the fruit in different ways (Raymond, *et al*., 1998). While stem end cavity affects the fruit's proximal, jelly seed affects the interior of the mesocarp (Raymond, *et al*., 1998). On the other side, soft nose affects the fruit's distal end.

Jelly seed condition causes the tissues surrounding the infected fruit's seed to break. The damaged deep yellow orange pulp, which is typically softer than the remainder of the mesocarp, develops a jelly-like mass. In addition, according to Raymond, *et al*. (1998), jelly seed affects the area where the fruit's stone and pulp meet. There are no outward signs of the condition other than a jelly-like substance surrounding the affected fruit's seed. Therefore, jelly seed-affected fruits can only be identified by cutting them. Additionally, jelly seed infects fruits during early fruit development, in contrast to other physiological disorders like soft nose, whose symptoms were only found in fruits that are fully developed, according to the same investigators.

This disorder affects the colour, taste, texture and appearance of the pulp and it intensifies with prolonged storage and maturity (Seshadri, *et al*., 2019). The fruit firmness and therefore shelf life are greatly affected by this condition besides consumer acceptability and marketability. Jelly seed has been reported to be varietal and location specific and 'Van Dyke' cultivar is more prone to jelly seed than Tommy Atkins (Njuguna, *et al*., 2016).

Njuguna, *et al.* (2016) proposed dolomitic lime application as a remedy to jelly seed disorder but application of dolomitic lime was not effective immediately due to its low mobility in soil. Seshadri, *et al*. (2019) reported that a decrease in the level of chain fatty acids in the seed of a developing fruit causes the seed to germinate thus causing jelly seed. A formulation V ($NaCl_2$, KCl, H_3BO_3, $CuSO_4$, $ZnSO_4$, $FeSO_4$, $MnSO_4$, and EDTA) by Seshadri, *et al*. (2019) increased accumulation of calcium, among other compounds in the seed which delayed seed germination. A high level of calcium exerts osmotic stress

which disturbs homeostasis (Torrecilla, *et al*., 2001). According to Weidner, *et al*. (2009) osmotic stress induces phenolic compounds accumulation which inhibits seed germination (Colpas, *et al*., 2003).

While some authors reported effective availability of calcium even after physiological maturity, there are reports that fruits accumulate calcium more effectively during the initial days (Bermadac, *et al*., 1996) than later periods of fruit development. Based on the aforementioned results, the objective of this study was to assess the effectiveness of various foliar calcium compounds in minimizing jelly seed while maintaining fruit quality, hence lowering post-harvest losses in mango fruits.

4.2 Materials and methods

4.2.1 Experimental site description

This study was carried at an orchard situated at Karurumo, Embu County in the eastern parts of Kenya in two fruiting seasons; July 2017 to April 2018 and July 2018 to April 2019. The rainfall pattern and soil characteristics are as described in section 3.2.1.

4.2.2 Experimental material, crop husbandry, treatments and design

The study involved use of approximately 10 years old, already established, uniformly sized in height "Van Dyke" cultivar trees. This cultivar has been described to be popular due to its early maturity and resistant to powdery mildew and anthracnose but highly susceptible to jelly seed disorder. Crop husbandry practices (e.g pruning, pests and disease control) were carried out as recommended by Griesbach (2003). The experimental design and treatments were as described in section 3.2.3.

4.3 Data collection

Jelly seed incidence determination

At physiological maturity, 30 fruits were sampled randomly from each treatment. The collected samples were taken to The Jomo Kenyatta University of Agriculture and

Technology (JKUAT) postharvest laboratory immediately after harvesting, pedicels were separated from the fruits which were washed under running water and the surface water allowed to dry. The fruits were then kept under ambient conditions (25±2ºC, 70±5% RH) for a period of 12 days. After the storage period, the fruits were weighed, halved along the endocarp and the jelly seed incidence scored by use of a hedonic scale (Galan, 1984): 0-without symptoms; 1-slight decomposition of the petiole base without affecting the flesh; 2-Slightly affected flesh near the seed; 3-1/3 of the flesh affected; 4-2/3 of the flesh affected and 5-Almost all fruit decomposed.

Calcium distribution determination

A sharp knife was used to separate the peel, mesocarp, seed coat and cotyledon of the fruits for calcium analysis. The mesocarp samples for pulp calcium analysis were taken from the widest parts of the fruit sampled between the skin and the stone. This ensured reduced bias of the concentration of calcium due to gradient change caused by the variation of cell density with the outward movement to the skin from the seed (Bally, 2007). The samples were then dried at 68 °C and ground to obtain a homogenous sample for calcium analysis using atomic absorption (AAS) spectrophotometer (AOAC, 1996) and expressed as µg mg^{-1}.

Physical, biochemical and quality attributes determination

At physiological maturity, 30 fruits were sampled from each treatment. The fruits were harvested, packed in crates made of plastic and transported to the post-harvest laboratory at Jomo Kenyatta University of Agriculture and Technology. The fruits were then washed under cold running water. Surface water was left to dry off and the fruits sorted for size uniformity and freedom from any blemishes. A sample of 5 fruits were then selected from each treatment for titratable acidity (TA), total soluble solids (TSS), peel color and peel firmness determination. The rest of the fruits from each sample were packed in crates lined with newspapers and stored under ambient conditions for 12 days. After the 12^{th} day, five samples were taken from each treatment for determination of changes in

TA, TSS, peel color and peel firmness. Selected organoleptic attributes of the fruits were also determined at the end of the storage period.

Total soluble solids (TSS) determination

At physiological maturity, three (3) fruits were taken from each treatment and a fruit juice obtained. Three (3) millimeters (ml) of the extracted juice was placed on a hand refractometer (Model 500, Atago, Tokyo, Japan). TSS level was recorded in ˚Brix (Dong, *et al*., 2001). The same procedure was used to obtain changes in TSS after 12 days of storage in ambient conditions.

Total Titratable acidity (TTA) determination

Three (3) fruits were obtained from each replica for juice exraction. Five millimeters (ml) of juice was extracted and diluted with distilled water to 30 ML. Phenolphthalein indicator was then used as an indicator in the tiration of 10 ml of the diluted solution using 0.1 N NaOH. The total titratable acidity was calculated as shown below. This was done at physiological maturity and after 12 days of storage in ambient conditions.

$$\text{Citric acid equivalent (\%)} = \left(\text{Sample reading (ml)} \times \frac{\text{Dilution factor}}{\text{Sample weight}} \times 0.0064(\text{citric acid factor})\right)100$$

Peel color determination

Three (3) fruits from each treatment were harvested when they reached physiological maturity in order to determine the peel color. This was done using a Minolta color meter (Model CR-200, Osaka, Japan) that was calibrated using a white and black reference tile (Hernandez-Munoz et al., 2008). The hue angle (H^o) was calculated using the coordinates at L* a* and b*, as shown below (McLellan, *et al*. 1995). After being stored under ambient settings for 12 days, the same process was carried out once more.

Hue angle (H^o) = arctan (b/a)

Peel firmness determination

After 12 days of storage under ambient circumstances and at physiological maturity, three (3) fruits were randomly chosen from each treatment. Using a penotrometer with a 5 mm probe that was allowed to pierce to a depth of 10 mm, peel firmness was assessed. The equivalent force needed to reach this depth was measured in Newtons (N) (Jiang, *et al*., 2001).

Organoleptic attributes determination

After 12 days of storage in ambient conditions, 10 fruits were taken from each replica, cut into equal slices, then placed on a white plan paper and coded anonymously as per the treatment. Fifteen (15) untrained judges were guided on how to score on peel color, pulp taste and general acceptability guided by a 7 point hedonic scale (Galan, *et al.*, 1984): 1-dislike extremely; 2-dislike very much; 3-dislike moderately; 4-neither like nor dislike; 5-like moderately; 6-like very much; and 7-like extremely. The general acceptability of the fruits was determined by adding the scores of the evaluated characteristics (Karemera *et al*., 2014).

4.4 Data analyses

Data collected were analysed using the 14th Edition of the Genstat software (Payne et al., 2011). The differences among the means of the treatments were compared using Fisher's Protected LSD test at 5% probability level. A Pearson's product–moment was run to assess the relationship between weight of fruit, calcium concentration in the various fruit parts and jelly seed incidence using Stata software 12th Edition.

4.5 Results

4.5.1 Main effects of source, rate and time of calcium application on mesocarp, exocarp, endocarp and cotyledon calcium concentration

The source, rate and time of calcium application significantly ($p \leq 0.05$) affected the mesocarp, exocarp and endocarp calcium content but had no significant effect on cotyledon calcium content in both seasons (Table 4.1). All calcium sources increased the exocarp and endocarp calcium content 4-6 fold compared to control fruits in both seasons. Application of calcium chloride and calcium nitrate registered significantly the highest endocarp calcium content in both seasons. The endocarp calcium content due to application of calcium nitrate and easygro were not significantly different in both seasons.

The various rates of calcium (1.0%, 1.5% and 2.0%) increased the calcium content in the studied fruit parts in both seasons except 1.0% which did not increase calcium content in the mesocarp in both seasons. Application of calcium at 2.0% registered significantly higher mesocarp, exocarp and endocarp calcium content than 1.5% and 1.0% in season 1. Application of calcium at 1.0% and 1.5% were not significantly different in mesocarp calcium content in both seasons and endocarp calcium content in season 2.

Application of calcium at fruit set registered significantly the highest calcium content in fruit mesocarp and exocarp in both seasons and exocarp in season 2 only. Application of calcium at fruit set had significantly the highest mesocarp and exocarp in both seasons and endocarp in season 2. Application of calcium at 30 days after fruit set led to higher calcium content in the fruit mesocarp than application at 30 days to physiological maturity in both seasons. The two latter timings of calcium application were however not significantly different in exocarp and endocarp calcium content in both season 1 and season 2 respectively.

Table 4:1 Main effects of source, rate and time of calcium application on mesocarp, exocarp and endocarp calcium concentration (μgmg^{-1}) of 'Van Dyke'mango fruits during seasons 2017 and 2018 at Karurumo

	Season 1				Season 2			
	Meso	Exo	Endo	Coty	Meso	Exo	Endo	Coty
Source								
S_1	0.43	0.88^{ab}	0.77^{a}	0.02^{a}	0.45^{a}	0.81^{b}	1.00^{a}	0.03^{a}
S_2	0.46	0.88^{b}	0.75^{ab}	0.02^{a}	0.35^{a}	0.93^{ab}	0.84^{ab}	0.04^{a}
S_3	0.45	1.04^{a}	0.68^{b}	0.02^{a}	0.31^{a}	1.02^{a}	0.73^{b}	0.03^{a}
Control	0.16	0.15^{d}	0.16^{c}	0.02^{a}	0.04^{b}	0.13^{c}	0.13^{c}	0.03^{a}
p-value	0.07	<.001	<.001	-	0.01	<.001	<.001	-
$Lsd_{(P\leq0.05)}$	Ns	0.16	0.09	Ns	0.17	0.18	0.18	Ns
cv%	32.00	23.60	24.80	0.0	25.00	19.50	41.70	0.0
Rate								
R_1	0.32^{bc}	0.72^{c}	0.62^{c}	0.02^{a}	0.27^{bc}	0.65^{b}	0.73^{b}	0.02^{a}
R_2	0.43^{b}	0.94^{b}	0.72^{b}	0.02^{a}	0.34^{ab}	0.98^{a}	0.83^{b}	0.02^{a}
R_3	0.59^{a}	1.14^{a}	0.86^{a}	0.02^{a}	0.51^{a}	1.13^{a}	1.02^{a}	0.02^{a}
Control	0.16^{c}	0.15^{d}	0.16^{d}	0.02^{a}	0.04^{c}	0.13^{c}	0.13^{c}	0.02^{a}
p-value	<.001	<.001	<.001	-	<.001	<.001	<.001	-
$Lsd_{(P\leq0.05)}$	0.22	0.13	0.08	Ns	0.17	0.15	0.18	Ns
Cv%	27.60	28.50	21.00	0.0	22.20	33.40	41.30	0.0
Time								
T_1	0.76^{a}	1.12^{a}	0.78^{a}	0.02^{a}	0.70^{a}	1.12^{a}	1.08^{a}	0.02^{a}
T_2	0.32^{b}	0.74^{b}	0.66^{ab}	0.02^{a}	0.25^{b}	0.75^{b}	0.76^{b}	0.02^{a}
T_3	0.18^{c}	0.70^{b}	0.59^{b}	0.02^{a}	0.07^{c}	0.66^{b}	0.52^{c}	0.02^{a}
p-value	<.001	<.001	<.001	-	<.001	<.001	<.001	-
$Lsd_{(P\leq0.05)}$	0.10	0.17	0.12	Ns	0.11	0.19	0.17	Ns
Cv%	44.50	38.30	34.30	0.0	61.10	43.30	42.80	0.0

S_1=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; R_1=1.0%; R_2=1.5%; R_3=2.0%; R_0=0% (Control); T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to maturity; LSD =Least significant difference; CV = Coefficient of variation; ns = Not significant. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

4.5.2 Interactive effects of source, rate and time of calcium application on mesocarp, exocarp, endocarp and cotyledon calcium concentration

The interaction between source and rate of calcium application did not significantly ($p \leq 0.05$) affect the fruit mesocarp, exocarp, endocarp and cotyledon calcium content in both seasons. Additionally, interactions among source, rate and time of calcium application did not affect the seed endocarp and cotyledon calcium content in both seasons. Interaction between source and time of calcium application on the other hand, significantly ($p \leq 0.05$) affected fruit mesocarp and endocarp calcium content in both seasons but significantly affected the exocarp calcium content in season 1 only (Table 4.2).

Fruits sprayed at 30 days to physiological maturity, irrespective of the source of calcium, did not have significantly different mesocarp calcium content from the control (unsprayed fruits) in both seasons. In most cases, fruits sprayed at fruit set had significantly higher mesocarp, exocarp and endocarp calcium content than those sprayed 30 days later and those sprayed at 30 days to physiological maturity. In most cases, fruits that were sprayed at 30 days after fruit set did not have significantly different mesocarp and endocarp calcium content.

Fruits sprayed at 30 days after fruit set and those sprayed 30 days to maturity did not register significantly different calcium content in the fruit endocarp irrespective of the source of calcium in season 1.

Table 4:2 Interactive effects of source and time of calcium application on mesocarp, exocarp and endocarp calcium content (μgmg^{-1}) of 'Van Dyke'mango fruits during seasons 2017 and 2018 at Karurumo

	Season 1			Season 2		
Treatments	Mesocarp	Exocarp	Endocarp	Mesocarp	Exocarp	Endocarp
S_2 T_1	0.85^{a}	1.12^{a}	0.87^{ab}	0.72^{b}	1.18	1.16^{b}
S_3 T_1	0.83^{a}	1.29^{a}	0.71^{c}	0.67^{b}	1.32	1.01^{b}
S_1 T_1	0.79^{a}	1.28^{a}	0.97^{a}	0.90^{a}	1.18	1.39^{a}
S_3 T_2	0.37^{b}	0.93^{b}	0.69^{c}	0.19^{de}	0.94	0.76^{c}
S_1 T_2	0.33^{bc}	0.71^{cd}	0.71^{c}	0.37^{c}	0.68	1.01^{b}
S_2 T_2	0.29^{bcd}	0.76^{bcd}	0.73^{bc}	0.26^{cd}	0.82	0.70^{c}
S_2 T_3	0.23^{cd}	0.74^{bcd}	0.64^{c}	0.06^{de}	0.79	0.66^{c}
S_1 T_3	0.18^{d}	0.66^{d}	0.64^{c}	0.09^{e}	0.57	0.61^{cd}
S_3 T_3	0.16^{d}	0.89^{bc}	0.63^{c}	0.07e	0.79	0.42^{de}
Ctrl T_2	0.17^{cd}	0.16^{e}	0.18^{d}	0.04^{e}	0.14	0.16^{ef}
Ctrl T_1	0.17^{cd}	0.15^{e}	0.13^{d}	0.06^{de}	0.13	0.12^{f}
Ctrl T_3	0.14^{cd}	0.14^{e}	0.18^{d}	0.02^{e}	0.14	0.11^{f}
p-value	<.001	0.05	0.05	<.001	0.25	0.00
$Lsd_{(P\leq0.05)\ S*T}$	0.14	0.33	0.13	0.14	Ns	0.28
Cv%	35.0	23.70	21.10	44.80	31.00	26.60

S_1=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to maturity; LSD =Least significant difference; CTRL= Control; ns=not significant; CV=Coefficient of variation; Treatments with different letters within a column are statistically different according to LSD at p ≤0.05 ≤0.05.

The interaction between time and rate of calcium application significantly (p≤0.05) affected mesocarp, endocarp and exocarp calcium content in both seasons (Table 4.3). Application of calcium at fruit set at a rate of 2.0% led to significantly the highest mesocarp, exocarp and endocarp calcium content in season 1 and 2. In most cases, fruits sprayed at fruit set had significantly higher mesocarp, exocarp and endocarp calcium content than those sprayed 30 days later and 30 days to physiological maturity in both seasons. Among fruits sprayed with calcium at 2.0%, those sprayed at fruit set had significantly higher calcium content in all the measured fruit parts than those sprayed 30 days later which in turn had significantly higher calcium content than those sprayed 30 days to physiological maturity except exocarp and endocarp in season 1.

Within fruits sprayed at fruit set and those sprayed at 30 days after fruit set, those sprayed with 2.0% calcium had significantly the highest mesocarp, exocarp and endocarp calcium

content. Fruits sprayed with calcium at 30 days to physiological maturity did not have significantly different calcium content in the mesocarp from control fruits in both seasons.

Table 4:3 Interactive effects of time and rate of calcium application on mesocarp, exocarp and endocarp calcium content (μgmg^{-1}) of 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

Treatments	Season 1			Season 2		
	Mesocarp	Exocarp	Endocarp	Mesocarp	Exocarp	Endocarp
R_3 T_1	1.07^{a}	1.47^{a}	1.09^{a}	1.02^{a}	1.47^{a}	1.41^{a}
R_2 T_1	0.81^{b}	1.20^{b}	0.81^{b}	0.69^{b}	1.27^{b}	1.13^{b}
R_1 T_1	0.58^{c}	1.02^{c}	0.65^{b}	0.58^{c}	0.95^{cd}	1.01^{b}
R_3 T_2	0.46^{d}	1.02^{c}	0.79^{dc}	0.38^{d}	1.07^{c}	0.99^{b}
R_2T_2	0.30^{e}	0.83^{de}	0.71^{cd}	0.26^{e}	0.84^{d}	0.79^{c}
R_1 T_2	0.24^{ef}	0.56^{f}	0.65^{de}	0.18^{ef}	0.54^{e}	0.70^{cd}
R_3 T_3	0.24^{ef}	0.93^{cd}	0.70^{cd}	0.12^{fg}	0.85^{d}	0.64^{cde}
R_2 T_3	0.18^{fg}	0.78^{e}	0.65^{de}	0.06^{g}	0.83^{d}	0.58^{de}
R_1 T_3	0.15^{g}	0.58^{f}	0.56^{e}	0.05^{g}	0.46^{e}	0.47^{e}
Ctrl T_2	0.17^{fg}	0.16^{g}	0.18^{f}	0.04^{g}	0.14^{f}	0.16^{f}
Ctrl T_1	0.17^{fg}	0.15^{g}	0.13^{f}	0.06^{g}	0.13^{f}	0.12^{f}
Ctrl T_3	0.14^{g}	0.14^{g}	0.18^{f}	0.02^{g}	0.14^{f}	0.11^{f}
p-value	<.001	0.00	<.00	<.00	0.02	0.03
R*T	0.09	0.17	0.10	0.11	0.17	0.20
CV%	16.70	15.30	14.90	33.80	21.70	27.00

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to maturity; LSD =Least significant difference; R_1=1.0%; R_2=1.5%; R_3=2.0%; R_0=0%; CV = Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Interactions between source, rate and time of calcium application significantly ($p \leq 0.05$) affected mesocarp calcium content in season 1 only (Table 4.4). All fruits sprayed at 30 days to physiological maturity did not have significantly different mesocarp calcium content from control (unsprayed) fruits.

Table 4:4 Interactive effects of source, rate and time of calcium application on mesocarp calcium content (μgmg^{-1}) of 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	0.65^{ef}	0.23^{jklm}	0.15^{mn}	0.66	0.23	0.05
	1.5%	0.73^{de}	0.31^{ij}	0.18^{lmn}	0.81	0.35	0.07
	2.0%	0.98^{b}	0.46^{g}	0.19^{lmn}	1.23	0.52	0.15
Calcium nitrate	1.0%	0.60^{f}	0.20^{klmn}	0.17^{lmn}	0.52	0.18	0.03
	1.5%	0.83^{cd}	0.26^{ijkl}	0.21^{klmn}	0.64	0.25	0.06
	2.0%	1.13^{a}	0.43^{gh}	0.32^{ij}	1.01	0.36	0.10
Easy gro	1.0%	0.50^{g}	0.29^{ijk}	0.12^{n}	0.56	0.15	0.05
	1.5%	0.88^{c}	0.34^{hi}	0.16^{mn}	0.63	0.19	0.04
	2.0%	1.10^{a}	0.48^{g}	0.20^{klmn}	0.83	0.24	0.11
Control	0%	0.17^{lmn}	0.17^{lmn}	0.14^{mn}	0.06	0.04	0.02
P-value		0.01			0.68		
Lsd ($p \leq 0.05$)	S*R*T	0.10			Ns		
Cv%		14.0			26.9		

T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; CV- Coefficient of variation; ns-Not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time significantly ($p \leq 0.05$) affected the endocarp calcium content in season 2 only (Table 4.5). Calcium chloride 2.0% applied at fruit set registered the highest calcium content (1.32 μgmg^{-1}) followed by calcium nitrate, 2.0% (1.1 μgmg^{-1}) applied at fruit set. Calcium concentration in the seed endocarp ranged from 0.13 to 1.23 μg mg^{-1} ($CaCl_2$, 2.0%, sprayed at fruit set). Control fruits registered the lowest mesocarp calcium content.

Table 4:5 Interactive effects of source, rate and time of calcium application on endocarp calcium content (μgmg^{-1}) of 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	1.23	0.85	0.48	0.65^{ghij}	0.63^{hijk}	0.58^{jk}
	1.5%	1.23	0.92	0.64	0.92^{c}	0.71^{efghi}	0.64^{hijk}
	2.0%	1.70	1.28	0.72	1.32^{a}	0.81cde	0.69^{efghij}
Calcium nitrate	1.0%	0.90	0.63	0.62	0.69^{efghij}	0.68^{ghij}	0.53k
	1.5%	1.13	0.67	0.68	0.80^{def}	0.73^{defgh}	0.65^{ghij}
	2.0%	1.43	0.81	0.69	1.11^{b}	0.80^{def}	0.73^{defgh}
Easy gro	1.0%	0.90	0.62	0.30	0.59^{ijk}	0.63^{hijk}	0.58^{jk}
	1.5%	1.03	0.78	0.43	0.72^{defgh}	0.69^{efghij}	0.65^{ghij}
	2.0%	1.10	0.89	0.52	0.83^{cd}	0.76^{defg}	0.67^{ghij}
Control	0%	0.12	0.16	0.11	0.13^{l}	0.18^{l}	0.18^{l}
P-value		0.5			0.008		
Lsd ($p \leq 0.05$)	S*R*T	Ns			0.12		
Cv %		21.90			10.70		

T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; CV- Coefficient of variation; ns-Not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

4.5.3 Main effects of source, rate and time of calcium application on jelly seed occurrence

Source, rate and time of calcium application significantly ($p \leq 0.05$) affected jelly seed occurrence in mango fruits in both seasons (Table 4.6). Fruits sprayed with calcium chloride registered the lowest jelly seed in both seasons. Fruits sprayed with easy gro and calcium nitrate did not have significantly different jelly seed scores in both seasons. Application of easy gro and calcium nitrate in season 2 did not reduce the occurrence of jelly seed.

Fruits sprayed at 30 days to maturity registered the highest jelly seed scores in both seasons. There were no significant differences in jelly seed occurence among fruits sprayed at fruit set and those sprayed 30 days later in season 1. In season 2 fruits sprayed at fruit set reported the lowest jelly seed occurence. Fruits sprayed with calcium at a rate of 2.0% registered significantly the lowest jelly seed scores in both seasons. There were

no significant differences among fruits sprayed with 1.0% and 1.5% in season 2 but in season 1, 1.5% sprayed fruits had the lowest jelly seed incidence.

Table 4:6 Main effects of source, time and rate of calcium application on jelly seed occurrence in 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

	Season 1	Season 2
	Jelly seed score	Jelly seed score
Source		
Easy gro	3.52[b]	4.63[a]
Calcium nitrate	3.37[b]	4.15[a]
Calcium chloride	2.19[c]	3.07[b]
Control	4.78[a]	4.89[a]
p-value	<.001	<.001
Lsd $_{(P\leq0.05)}$	0.88	1.06
Cv%	29.30	28.00
Time		
Fruit set	2.77[b]	3.20[c]
30 days after fruit set	3.10[b]	4.07[b]
30 days to maturity	3.73[a]	4.87[a]
p-value	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.59	0.58
Cv%	36.10	27.80
Rate		
1.0%	3.78[b]	4.59[b]
1.5%	3.00[c]	3.96[b]
2.0%	2.30[d]	3.30[c]
Control	4.78[a]	4.89[a]
p-value	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.72	0.65
Cv%	29.20	29.50

LSD-Least significant difference; CV-Coefficient of variation; ns-Not significant; Treatments with different letters in the same column are significantly different according to LSD at $p \leq 0.05$.

4.5.4 Interactive effects of source, rate and time of calcium application on jelly seed occurrence in mango fruits

The interaction between source and rate of calcium application and between rate and time of calcium application did not significantly ($p \leq 0.05$) affect jelly seed occurrence in both seasons. On the contrary, interaction between source and time of calcium application significantly ($p \leq 0.05$) affected jelly seed occurrence in both seasons (Table 4.7).

Calcium chloride applied at fruit set registered the lowest jelly seed occurrence in both seasons. Fruits sprayed with calcium nitrate at 30 days to physiological maturity and 30 days after fruit set and those sprayed with easy gro at fruit set and 30 days after fruit set did not have significantly different jelly seed occurrence in both seasons.

Among fruits sprayed at fruit set, those sprayed with calcium chloride registered the lowest jelly seed scores in both seasons. Among fruits sprayed at 30 days after fruit set, those sprayed with easy gro and calcium nitrate were not significantly different while those sprayed with calcium chloride had significantly the lowest jelly seed scores in both seasons. Within fruits sprayed with calcium chloride, those sprayed at fruit set registered significantly the lowest jelly seed scores followed by those sprayed 30 days later and those sprayed 30 days to maturity in that order.

Table 4:7 Interactive effects of source and time of calcium application on jelly seed occurrence in 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

	Season 1	Season 2
	Jelly seed score	Jelly seed score
Ctrl T_1	5.00^{a}	5.00^{a}
Ctrl T_2	4.67^{ab}	4.67^{ab}
Ctrl T_3	4.67^{ab}	5.00^{a}
S_3 T_3	4.00^{abc}	5.00^{a}
S_2 T_3	3.67^{bcd}	4.79^{ab}
S_2 T_2	3.44^{cd}	4.44^{ab}
S_3 T_1	3.33^{cd}	4.11^{b}
S_3 T_2	3.22^{d}	4.79^{ab}
S_1 T_3	3.22^{d}	4.79^{ab}
S_2 T_1	3.00^{d}	3.22^{c}
S_1 T_2	2.11^{e}	2.79^{c}
S_1 T_1	1.22^{f}	1.67^{d}
P-value	0.05	<.001
Lsd $_{(P\leq 0.05)}$S*T	1.08	0.74
Cv%	25.50	19.5

S_I-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; CTRL-Control; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to maturity; S-Source; T-Time; LSD-Least significant difference; Cv- Coefficient of variation. Treatments with different letters in the same column are significantly different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time of calcium application significantly ($p \leq 0.05$) affected jelly seed occurrence in the fruits in season 2 only (Table 4.8). Minimum jelly seed score was observed on fruits treated with calcium chloride 2.0% applied at fruit set. All fruits sprayed at 30 days to physiological maturity were not significantly different from control fruits irrespective of the source and rate. Increasing rates of calcium nitrate and easy gro from 1.0% to 1.5% and 2.0% did not decrease jelly seed occurrence but increasing the rates of calcium chloride decreased jelly seed occurrence except when fruits were sprayed at 30 days to physiological maturity.

Table 4:8 Interactive effects of source, rate and time of calcium application on jelly seed occurrence in 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	2.00	3.00	4.00	3.00^{ef}	4.33^{abc}	5.00^{a}
	1.5%	1.67	2.33	3.00	1.67^{g}	2.67^{f}	5.00^{a}
	2.0%	0.00	1.00	2.67	0.33^{h}	1.33^{g}	4.33^{abc}
Calcium nitrate	1.0%	3.67	4.33	4.33	4.00^{bcd}	5.00^{a}	5.00^{a}
	1.5%	3.00	3.33	3.67	3.00^{ef}	4.67^{ab}	5.00^{a}
	2.0%	2.33	2.67	3.00	2.67^{f}	3.67^{cde}	4.33^{abc}
Easy gro	1.0%	4.00	3.67	5.00	5.00^{a}	5.00^{a}	5.00^{a}
	1.5%	3.33	3.00	3.67	4.00^{bcd}	4.67^{ab}	5.00^{a}
	2.0%	2.67	3.00	3.33	3.33^{def}	4.67^{ab}	5.00^{a}
Control	0%	5.00	4.67	4.67	5.00^{a}	4.67^{ab}	5.00^{a}
P –value		0.38				0.03	
LSD (P≤0.05)	S*R*T	Ns				0.71	
Cv%		16.8				10.7	

T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; Cv- Coefficient of variation.; ns-Not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

Spraying of calcium at 2.0% applied at 30 days to physiological maturity had insignificant effect on jelly seed scores irrespective of the source (Fig. 4.1). Further, fruits sprayed with calcium chloride, 2.0% at fruit set registered the lower jelly seed scores than those sprayed with calcium chloride, 2.0% at 30 days after fruit set and 30 days to physiological maturity in that order (Fig. 4.2).

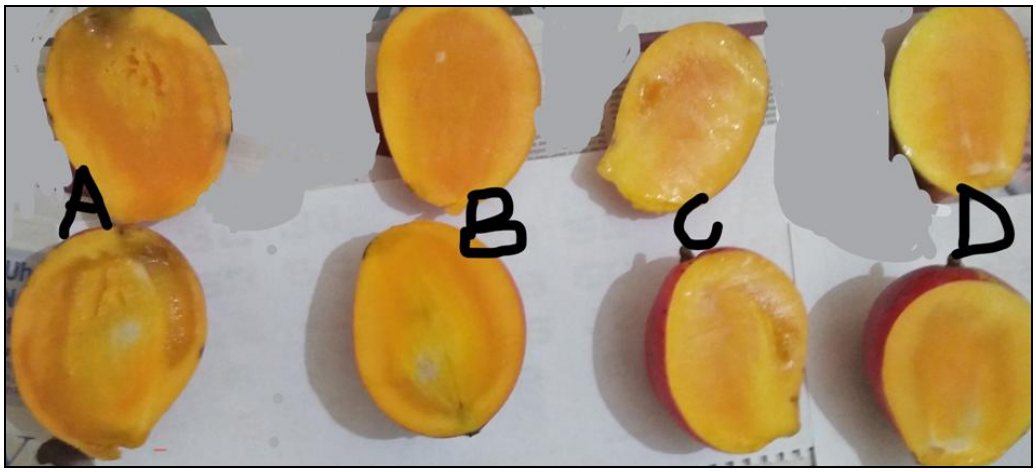

Figure 4:1 Jelly seed occurrence among control and fruits sprayed with calcium at 2.0% at 30 days to maturity

Key: A-Control, B- Easygro®; C-Calcium nitrate; D-calcium chloride

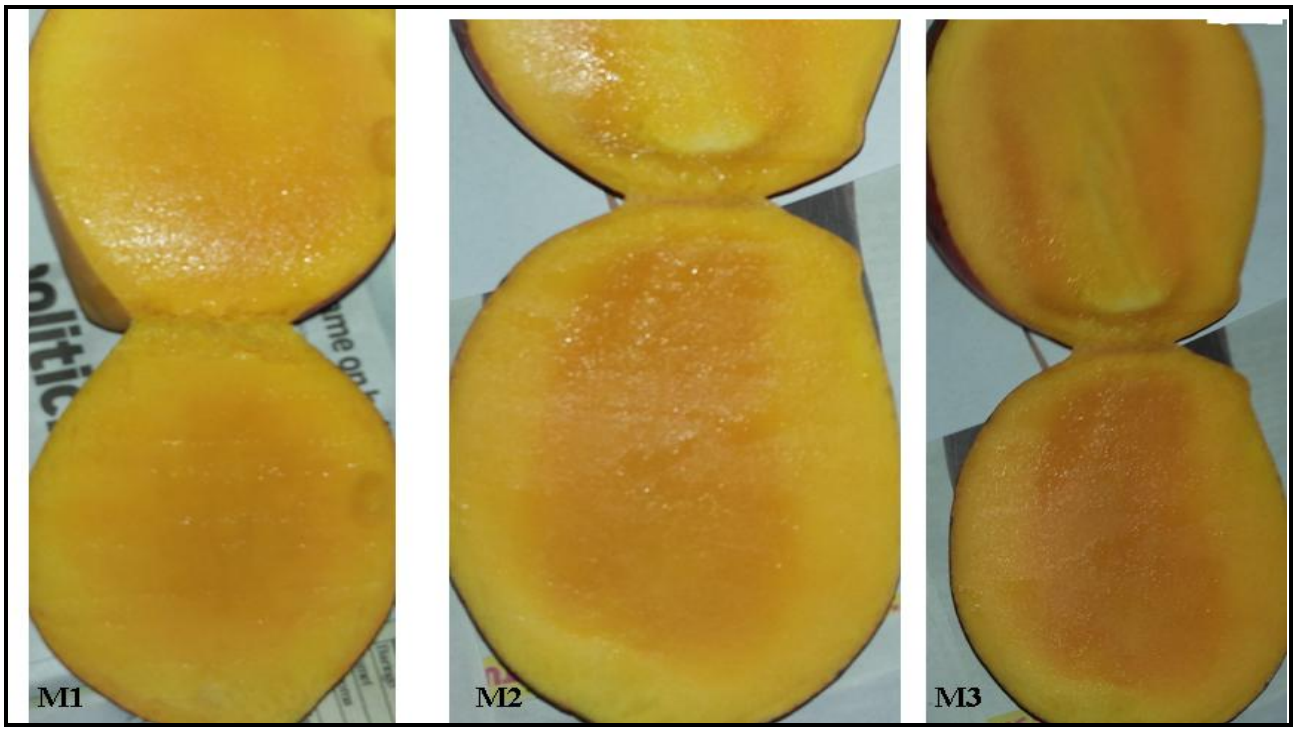

Figure 4:2 Jelly seed occurrence among fruits treated with calcium chloride 2.0% at different times.

Key: M_1-Fruit set; M_2-30 days after fruit set; M_3 - 30 days to physiological maturity.

4.5.5 Correlation coefficient between jelly seed occurrence, weight of fruits and calcium concentration

There was a negative correlation between jelly seed occurrence and fruit weight in seasons I and 2 (Table 4.9). Similarly, a negative correlation was reported between jelly seed occurrence and calcium concentration in the exocarp, mesocarp and endocarp for both seasons.

Table 4:9 Correlation between jelly seed occurrence, weight of fruits and calcium concentration in the pericarp, exocarp and mesocarp of 'Van Dyke' mango fruit during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	Pearson correlation (r)	P	Pearson correlation (r)	P
Weight	-0.55	0.00	-0.52	0.00
Calcium content				
Pericarp	-0.76	0.00	-0.66	0.00
Exocarp	-0.56	0.00	-0.49	0.00
Mesocarp	-0.52	0.00	-0.76	0.00

4.5.6 Main and interactive effects of source, rate and time of calcium application on total soluble solids, total titratable acidity, organoleptic attributes, peel colour, peel firmness, and quality attributes of mango fruits

Total soluble solids

Source, rate and time of calcium application had significant ($P \leq 0.05$) effects on fruit total soluble solids at harvest and after 12 days of storage in ambient conditions in both seasons (Table 4.10). Application of calcium significantly reduced the accumulation of soluble solids at harvest and after storage in both seasons. All fruits sprayed with calcium did not have significantly different total soluble solids in both seasons except at harvest in season 1 where calcium chloride and calcium nitrate reported significantly lower total soluble solids than easy gro.Fruits sprayed at fruit set had significantly lower total soluble solids than those sprayed after 30 days which were in turn significantly lower than those sprayed 30 days to physiological maturity at harvest and after storage in both seasons.

Fruits sprayed with calcium at 2.0% had significantly lower total soluble solids than those sprayed at 1.0% at harvest and after storage in both seasons. Fruits sprayed with the later rate did not have significantly different total soluble solids with those sprayed with 1.5%

in all seasons except at harvest in season 2 in which fruits sprayed with 1.5% had significantly lower TSS than fruits sprayed 1.0%. Additionally, fruits sprayed with 1.5% and 2.0% did not have significantly different TSS at harvest and after storage in both seasons except at harvest in season 2 where fruits sprayed with 2.0% had significantly lower TSS than those sprayed with 1.5%.

Table 4:10 Main effects of source, time and rate of calcium application on total soluble solids (°Brix) of 'Van Dyke' mango fruits at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	At harvest	After storage	At harvest	After storage
Source				
Easy gro	11.73^{b}	15.43^{b}	10.43^{b}	14.37^{b}
Calcium nitrate	11.32^{bc}	15.10^{b}	10.26^{b}	14.16^{b}
Calcium chloride	10.19^{c}	14.50^{b}	9.81^{b}	13.27^{b}
Control	16.44^{a}	18.28^{a}	16.19^{a}	18.21^{a}
p-value	<.001	<.001	<.001	<.001
Lsd $_{(P\leq0.05)}$	1.13	2.08	1.91	2.12
Cv%	18	14.5	18.9	15.7
Time				
T_1	9.20^{c}	12.67^{c}	9.10^{c}	11.78^{c}
T_2	12.24^{b}	16.12^{b}	10.52^{b}	15.09^{b}
T_3	13.41^{a}	17.22^{a}	12.69^{a}	16.21^{a}
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	1.04	0.73	1.18	0.93
Cv%	17.50	9.30	21.40	12.60
Rate				
1.0%	11.82^{b}	15.59^{b}	11.6^{b}	14.84^{b}
1.5%	11.16^{bc}	15.07^{bc}	10.05^{c}	13.87^{bc}
2.0%	10.26^{c}	14.37^{c}	8.86^{d}	13.09^{c}
0%	16.44^{a}	18.28^{a}	16.19^{a}	18.21^{a}
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	1.13	1.19	0.94	1.68
Cv%	18.00	14.30	16.10	15.3

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Interactive effects of source, rate and time of calcium application on fruit total soluble solid at harvest and after 12 days of storage in ambient conditions

The interaction between source and rate of calcium application did not have significant ($P \leq 0.05$) effects on the fruit total soluble solids at harvest and after 12 days of storage in ambient conditions in both seasons. In contrast, interactions between source and time of calcium application significantly ($P \leq 0.05$) affected the fruit total soluble solids at harvest and after 12 days of storage in ambient conditions in both seasons (Table 4.11). Control fruits had significantly higher TSS than all other treatments at harvest and after storage in both seasons except those sprayed with easy gro at 30 days to physiological maturity after storage in season 2. Fruits sprayed at fruit set had significantly lower total soluble solids than those sprayed 30 days later which were in turn significantly lower than those sprayed 30 days to physiological maturity in both seasons except those that were sprayed with calcium nitrate at fruit set and 30 days later in season 2 which were not significantly different.

Among fruits sprayed at fruit set, those sprayed with calcium chloride had significantly lower TSS than those sprayed with easy gro at harvest and after storage in both seasons except at harvest in season 2 in which all the sources did not have significantly different TSS. Calcium chloride sprayed fruits on the other hand had significantly lower TSS than those sprayed with calcium nitrate at harvest and after storage in season 1 but the two sources were not significantly different at harvest and after storage in season 2.

Among fruits sprayed at 30 days after fruit set those sprayed with easy gro and calcium nitrate did not have significantly different TSS at harvest and after storage in both seasons. Fruits sprayed with calcium chloride on the other hand had significantly lower TSS than those sprayed with calcium nitrate at harvest in season 1 and after storage in season 2.

Table 4:11 Interactive effects of source and time of calcium application total soluble solids (°Brix) of 'Van Dyke'mango fruits at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
Treatment	At harvest	After storage	At harvest	After storage
Ctrl T_1	16.67[a]	18.20[a]	16.17[a]	18.30[a]
Ctrl T_3	16.50[a]	18.17[a]	16.13[a]	18.03[a]
Ctrl T_2	16.17[a]	18.22[a]	16.27[a]	18.30[a]
S_3 T_3	13.96[b]	17.58[ab]	12.89[b]	16.13[bc]
S_2 T_3	13.19[c]	17.01[bc]	12.31[b]	16.36[b]
S_3 T_2	12.30[d]	16.06[d]	9.87[cd]	15.37[cd]
S_2 T_2	12.17[d]	16.02[d]	9.79[cd]	14.91[d]
S_1 T_3	12.06[d]	16.77[c]	11.72[b]	15.53[bcd]
S_1 T_2	10.96[e]	15.50[d]	9.99[c]	13.92[e]
S_3 T_1	8.94[f]	12.66[e]	8.54[e]	11.60[fg]
S_2 T_1	8.61[f]	12.28[e]	8.68[de]	11.21[fg]
S_1 T_1	7.57[g]	11.23[f]	7.72[e]	10.34[g]
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$ S*T	0.74	0.64	1.20	0.90
Cv%	6.80	4.40	11.80	6.70

S_I=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; R_1=1.0%; R_2=1.5%; R_3=2.0%; Ctrl=Control; T_1=Fruit set; T_2=30 days after fruit set; T3=30 days to physiological maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interaction between rate and time of calcium application had significant ($P\leq0.05$) effects on the fruit total soluble solids at harvest and after 12 days of storage in both seasons (Table 4.12). All control fruits had significantly the highest fruit total soluble solids at harvest and after storage in both seasons. Among fruits sprayed at fruit set, those sprayed with 2.0% calcium had significantly lower TSS than those sprayed with 1.5% which in turn had significantly lower TSS than those sprayed with 1.0% at harvest and after storage both seasons except at harvest in season 1 where the two latter rates were not significantly different.

Among fruits sprayed at 30 days after fruit set, those sprayed with calcium, 2.0% had significantly lower TSS than those sprayed with 1.0% at harvest and after storage in both seasons. Fruits sprayed with the later rate did not have significantly different TSS from

those sprayed with 1.5% in season but significantly different in season 2, where fruits sprayed with 1.5% had significantly lower TSS than those sprayed with 1.0% at harvest and after storage.

Among fruits sprayed at 30 days to physiological maturity those sprayed with 2.0% had significantly lower TSS than those sprayed at 1.0% at harvest and after storage in both seasons. Additionally, fruits sprayed with 2.0% had significantly lower TSS than those sprayed with 1.5% at harvest but not significantly different after storage in both seasons.

Fruits sprayed at fruit set had significantly lower TSS than those sprayed 30 days later which were in turn lower than those sprayed 30 days to physiological maturity irrespective of the rate of calcium application at harvest and after storage in both seasons.

Table 4:12 Interactive effects of rate and time of calcium application on total soluble solids (°Brix) of 'Van Dyke' mango fruit at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	At harvest	After storage	At harvest	After storage
Ctrl T_I	16.67^{a}	18.20^{a}	16.17^{a}	18.30^{a}
CtrlT_3	16.50^{a}	18.17^{a}	16.13^{a}	18.03^{a}
Ctrl T_2	16.17a	18.47^{a}	16.27^{a}	18.30^{a}
R_1 T_3	13.90^{b}	17.57^{bc}	13.62^{b}	16.98^{b}
R_2 T_3	13.08^{c}	17.09^{cd}	12.36^{c}	15.87^{c}
R_1 T_2	12.32^{d}	16.30^{ef}	11.31^{d}	15.52^{c}
R_3 T_3	12.22^{d}	16.70^{de}	10.94^{d}	15.18^{cd}
R_2 T_2	11.88^{de}	15.83^{fg}	9.73^{e}	14.67^{de}
R_3 T_2	11.22^{e}	15.44^{g}	8.60^{f}	14.01^{e}
R_1 T_1	9.24^{f}	12.90^{h}	9.86^{e}	12.02^{f}
R_2 T_1	8.53^{f}	12.29^{i}	8.07^{f}	11.07^{g}
R_3 T_1	7.34^{g}	10.98^{j}	7.02^{g}	10.07^{h}
P-value	<.001	<.001	<.001	<.001
Lsd $_{(P\leq0.05)}$ R*T	0.75	0.54	0.61	0.75
Cv%	6.8	3.8	6.0	5.5

R_1=1.0%; R_2=1.5%; R_3=2.0%; Ctrl=Control; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time of calcium application significantly ($P \leq 0.05$) affected the total soluble solids of the fruits at harvest in both seasons (Table 4.13). Fruits that were sprayed with calcium chloride (2.0%) at fruit set registered the lowest total soluble solids in season I. Control fruits had the highest TSS in both seasons.

Table 4:13 Interactive effect of source, rate and time of calcium application on total soluble solids (°Brix) of 'Van Dyke' mango fruits at harvest during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	8.30^{pq}	11.53^{ij}	13.40^{cd}	9.17^{jkl}	11.43^{efg}	12.93^{cd}
	1.5%	7.60^{r}	11.00^{jk}	12.10^{ghi}	7.67^{no}	9.83^{ij}	11.77^{ef}
	2.0%	6.80^{s}	10.33^{lm}	10.67^{kl}	6.33^{p}	8.70^{klm}	10.47^{hi}
Calcium nitrate	1.0%	9.47^{no}	12.60^{efg}	13.80^{c}	10.80^{gh}	11.03^{fgh}	13.47^{c}
	1.5%	8.67^{p}	12.20^{gh}	13.17^{de}	8.17^{mn}	9.87^{ij}	12.30^{de}
	2.0%	7.70^{qr}	11.70^{hi}	12.60^{efg}	7.07^{op}	8.47^{lmn}	11.17^{fgh}
Easy gro	1.0%	9.97^{mn}	12.83^{def}	14.50^{b}	9.60^{ij}	11.47^{efg}	14.47^{b}
	1.5%	9.33^{o}	12.43^{fg}	13.97^{bc}	8.37^{lmn}	9.50^{jk}	13.00^{cd}
	2.0%	7.53^{r}	11.63^{hi}	13.40^{cd}	7.67^{no}	8.63^{klm}	11.20^{fgh}
Control	0%	16.67^{a}	16.17^{a}	16.50^{a}	16.17^{a}	16.27^{a}	16.13^{a}
P-value		0.008				0.038	
Lsd ($_{P \leq 0.05}$)	SxTxR	0.63				0.87	
Cv (%)		3.30				4.90	

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation.Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time of calcium application had significant ($P \leq 0.05$) effects on the fruit total soluble solids after 12 days of storage in ambient conditions in season 1 only (Table 4.14). Fruits sprayed with easy gro 1.0% at 30 days to maturity did not have significantly different TSS from unsprayed fruits.

Table 4:14 Interactive effects of source, rate and time of calcium application on total soluble solids (°Brix) of 'Van Dyke' mango fruit after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	11.97^{op}	15.97^{hij}	17.03^{bcd}	11.33	14.90	16.43
	1.5%	11.27^{qr}	15.43^{jk}	16.73^{de}	10.60	13.83	15.33
	2.0%	10.47^{s}	15.10^{k}	16.53^{defg}	9.10	13.03	14.83
Calcium nitrate	1.0%	12.77^{mn}	16.43^{efgh}	17.50^{bc}	12.13	15.90	16.90
	1.5%	12.47^{no}	16.00^{ghi}	16.97^{cde}	11.03	14.63	16.47
	2.0%	11.60^{pq}	15.63^{ijk}	16.57^{def}	10.47	14.20	15.70
Easy gro	1.0%	13.97^{l}	16.50^{defgh}	18.17^{a}	12.60	15.77	17.60
	1.5%	13.13^{m}	16.07^{fghi}	17.57^{b}	11.57	15.53	15.80
	2.0%	10.87^{rs}	15.60^{ijk}	17.00^{cd}	10.63	14.80	15.00
Control	0%	18.20^{a}	18.47^{a}	18.17^{a}	18.30	18.30	18.03
p-value		0.02				0.23	
Lsd $_{P\leq0.05}$	SxTxR	0.58				Ns	
Cv (%)		2.2				4.4	

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Total titratable acidity (TTA)

Source, rate and time of calcium application had significant ($P \leq 0.05$) effects on fruit total titratable acidity at harvest and after 12 days of storage in both seasons (Table 4.15). Control fruits reported significantly the lowest titratable acidity at harvest and after storage in both seasons. Fruits sprayed with calcium chloride had significantly higher TTA than those sprayed with easy gro at harvest and after 12 days of storage in ambient conditions in both seasons. Fruits sprayed with calcium nitrate and easy gro did not have significantly different TTA at harvest and after storage in both seasons. There were no significant differences among fruits sprayed with calcium chloride and those sprayed with calcium nitrate at harvest and after storage in both seasons except season 1 at

harvest where fruits sprayed with calcium chloride had significantly higher TTA than calcium nitrate.

Fruits sprayed at fruit set outperformed those sprayed 30 days after fruit set which in turn outperformed those sprayed 30 days to physiological maturity at harvest and after storage in both seasons. Fruits sprayed at 2.0% had significantly higher TTA than fruits sprayed with calcium at 1.0% at harvest and after storage in both seasons. There were no significant differences in fruit TTA between fruits sprayed with 1.5% and 1.0% at harvest and after storage in ambient conditions in both seasons. Fruits sprayed with calcium at 2.0% had significantly higher TTA than those sprayed at 1.5% in both seasons except at harvest in season 2 in which the two rates were not significantly different from each other.

Table 4:15 Main effects of source, time and rate of calcium application on total titratable acidity (%) of 'Van Dyke' mango fruits at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	At harvest	After storage	At harvest	After storage
Source				
Easy gro	0.41^{b}	0.23^{b}	0.49^{b}	0.26^{b}
Calcium nitrate	0.42^{b}	0.26^{ab}	0.54^{ab}	0.30^{ab}
Calcium chloride	0.59^{a}	0.33^{a}	0.67^{a}	0.35^{a}
Control	0.13^{c}	0.05^{c}	0.18^{c}	0.15^{c}
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.14	0.09	0.13	0.07
Cv %	39.1	26.5	34.5	23.5
Time				
T_1	0.72^{a}	0.41^{a}	0.74^{a}	0.41^{a}
T_2	0.37^{b}	0.24^{b}	0.55^{b}	0.27^{b}
T_3	0.24^{c}	0.10^{c}	0.28^{c}	0.19^{c}
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.10	0.07	0.10	0.05
Cv %	40	34.8	26.5	26.4
Rate				
1.0%	0.35^{b}	0.19^{b}	0.45^{b}	0.23^{bc}
1.5%	0.46^{b}	0.25^{b}	0.56^{ab}	0.29^{b}
2.0%	0.62^{a}	0.38^{a}	0.68^{a}	0.40^{a}
0%	0.13^{c}	0.05^{c}	0.18^{c}	0.15^{c}
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.14	0.09	0.13	0.06
Cv%	37.5	63.7	43.8	39.1

$T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Interactive effects of source, rate and time of calcium application on fruit total titratable acidity at harvest and after 12 days of storage in ambient conditions

The interaction between source and rate of calcium application did not significantly ($P \leq 0.05$) affect the fruit total titratable acidity at harvest and after 12 days of storage in both seasons. On the contrary, interaction between source and time of calcium application significantly ($P \leq 0.05$) affected the fruit total titratable acidity at harvest in both seasons and after storage in season 1 only (Table 4.16).

Among fruits sprayed with calcium chloride, those sprayed at fruit set had significantly higher TTA than those sprayed 30 days later which in turn had significantly higher TTA than those sprayed 30 days to maturity at harvest and after storage in both seasons. Generally, among fruits sprayed with easy gro and calcium nitrate, those sprayed at fruit set had significantly higher TTA than fruits sprayed at the rest of the times.

For fruits sprayed at fruit set, those sprayed with calcium chloride had significantly higher TTA than those sprayed with calcium nitrate which were in turn not significantly different from those sprayed with easy gro except after storage in season 1. Additionally, for fruits sprayed at 30 days after fruit set, those sprayed with calcium chloride had significantly higher TTA than those sprayed with calcium nitrate which were in turn not significantly different from those sprayed with easy gro in season 1. In season 2, all fruits sprayed at 30 days after fruit set did not have significantly different TTA levels at harvest. In most cases, there were no significant responses in TTA to spraying of calcium on fruits at 30 days to maturity.

Table 4:16 Interactive effect of source and time of calcium application on total titratable acidity (%) of 'Van Dyke' at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
Treatment	At Harvest	After storage	At harvest	After storage
S_1 T_1	0.93[a]	0.50[a]	0.99[a]	0.52
S_2T_1	0.74[bc]	0.48[abc]	0.73[bc]	0.40
S_3T_1	0.69[bc]	0.39[abc]	0.69[bcd]	0.38
S_1T_2	0.57[c]	0.36[bc]	0.64[bcd]	0.30
S_3 T_2	0.32[d]	0.20[d]	0.55[d]	0.27
S_2 T_2	0.29[de]	0.22[d]	0.60[cd]	0.29
S_1T_3	0.29[de]	0.13[de]	0.36[e]	0.23
S_3 T_3	0.23[de]	0.09[e]	0.24[f]	0.15
S_2 T_3	0.23[de]	0.10[e]	0.29[ef]	0.21
S_4T_I	0.14[de]	0.04[e]	0.20[f]	0.18
S_4 T_2	0.14[de]	0.08[e]	0.19[f]	0.16
S_4 T_3	0.11[e]	0.02[e]	0.14[f]	0.09
P-value		<.001	<.001	<.001	0.09
$LSD_{(P\leq0.05)}$	S*T	0.18	0.14	0.16	Ns
CV%		31.20	41.40	22.30	21.20

S_I=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; LSD=Least significant difference; CV= Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interaction between rate and time of calcium application significantly ($P\leq0.05$) affected the fruit total titratable acidity at harvest and after 12 days of storage in both seasons (Table 4.17). Application of calcium, 2.0% at fruit set had significantly the highest total titratable acidity at harvest and after 12 days of storage in both seasons.

Among fruits sprayed at fruit set, those sprayed at 2.0% calcium had significantly higher TTA than those sprayed with 1.5% which in turn had significantly higher TTA than those sprayed with 1.0% except at harvest in season 2 where the latter rates were not significantly different.

For fruits sprayed at 30 days at fruit set, those sprayed at 2.0% calcium had significantly higher TTA than those sprayed with 1.0% calcium in all seasons at harvest and after storage. There were no significant differences in fruit TTA among fruits sprayed with 1.5% and 1.0% calcium at fruit set except in season 2 at harvest.

Among fruits sprayed at 30 days to physiological maturity, those sprayed at 2.0% calcium had significantly higher fruit TTA than their counterparts sprayed at 1.0% calcium which were not significantly different from those sprayed with 1.5% calcium except after storage, season 1. Similarly, there were no significant differences among fruits sprayed at 2.0% and 1.5% calcium except after storage in season 1.Control fruits registered significantly the lowest total titratable acidity which was not significantly different from fruits sprayed with calcium, 1.0% and 1.5% at 30 days to physiological maturity at harvest and after 12 days of storage in both seasons.

Table 4:17 Interactive effect of rate and time of calcium application on total titratable acidity (%) of 'Van Dyke' mango fruit at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
Treatment	At harvest	After storage	At harvest	After storage
R_3 T_1	0.99^{a}	0.65^{a}	0.96^{a}	0.53^{a}
R_2 T_1	0.76^{b}	0.41^{b}	0.78^{bc}	0.41^{b}
R_1 T_1	0.61^{c}	0.31^{c}	0.67^{cd}	0.35^{c}
R_3 T_2	0.53^{c}	0.34^{c}	0.71^{bcd}	0.42^{b}
R_2 T_2	0.36^{de}	0.24^{d}	0.59^{de}	0.25^{d}
R_3 T_3	0.33^{de}	0.17^{e}	0.36^{f}	0.24^{de}
R_1 T_2	0.28^{de}	0.20^{de}	0.48^{e}	0.18^{f}
R_2 T_3	0.25^{ef}	0.09^{f}	0.31^{fg}	0.19^{ef}
R_1 T_3	0.17^{fg}	0.06^{g}	0.22^{gh}	0.16^{f}
Ctrl T_1	0.14^{fg}	0.04^{g}	0.20^{gh}	0.18^{f}
Ctrl T_2	0.14^{fg}	0.08^{g}	0.19^{gh}	0.16^{f}
CtrlT_3	0.11^{g}	0.02^{g}	0.14^{h}	0.09^{g}
P-value	<.001	<.001	<.001	<.001
Lsd $_{(P\leq0.05)}$R*T	0.11	0.06	0.15	0.05
Cv%	27	27.1	20.7	19.3

S_1=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; LSD=Least significant difference; CV= Coefficient of variation; Ctrl=Control. Treatments with different letters in the same column are significantly different according to LSD at p $\leq$0.05.

Interactions between source, rate and time of calcium application significantly ($P\leq0.05$) affected the fruit total titratable acidity at harvest in both seasons (Table 4.18). Fruits sprayed with calcium chloride, 2.0% at fruit set registered significantly the highest fruit total titratable acidity at harvest in both seasons. Control fruits registered the least TTA, between 0.11 and 0.20 in both seasons.

Table 4:18 Interactive effects of source, rate and time of calcium application on total titrable acidity (%) of' Van Dyke' mango fruits at harvest during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	0.66^{cd}	0.46^{f}	0.21^{jklm}	0.80^{cd}	0.52^{jk}	0.24^{p}
	1.5%	0.83^{b}	0.55^{e}	0.30^{ghi}	0.91^{b}	0.64^{ghi}	0.37^{mn}
	2.0%	1.29^{a}	0.69^{c}	0.35^{g}	1.27^{a}	0.76^{cdef}	0.48^{kl}
Calcium nitrate	1.0%	0.59^{de}	0.20^{jklm}	0.15^{klmn}	0.64^{ghi}	0.50^{kl}	0.19^{pq}
	1.5%	0.78^{b}	0.30^{ghi}	0.23^{ijk}	0.71^{efg}	0.60^{hij}	0.33^{no}
	2.0%	0.85^{b}	0.37^{g}	0.32^{gh}	0.83^{bc}	0.70^{fg}	0.36^{mn}
Easy gro	1.0%	0.57^{e}	0.18^{jklmn}	0.15^{klmn}	0.56^{ijk}	0.42^{lm}	0.22^{pq}
	1.5%	0.67^{cd}	0.24^{hij}	0.22^{jkl}	0.72^{defg}	0.55^{jk}	0.24^{p}
	2.0%	0.82^{b}	0.54^{ef}	0.33^{g}	0.79^{cde}	0.67^{gh}	0.26^{op}
Control	0%	0.14^{mn}	0.14^{mn}	0.11^{n}	0.20^{pq}	0.19^{pq}	0.14^{q}
P-value		<.001				<.001	
Lsd $_{(P\leq0.05)}$	SxTxR	0.08				0.09	
Cv (%)		11				10	

$T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interactions between source, rate and time of calcium application significantly ($P\leq0.05$) affected the fruit total titratable acidity after 12 days of storage in ambient conditions in season 1 only (Table 4.19). Fruits treated with calcium chloride, 2.0% at fruit set registered the highest titratable acid followed by those treated with calcium nitrate 2.0% at fruit set. All fruits sprayed with calcium at 1.0%, at 30 days to maturity, irrespective of the source did not have significantly different TTA from the unsprayed fruits.

Table 4:19 Interactive effects of source, rate and timing of calcium application on titratable acidity (%) of 'Van Dyke' mango fruits after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	0.32^{gh}	0.28^{hi}	0.07^{op}	0.41	0.19	0.18
	1.5%	0.41^{de}	0.36^{fg}	0.13^{mn}	0.49	0.26	0.21
	2.0%	0.77^{a}	0.45^{cd}	0.20^{jk}	0.67	0.44	0.30
Calcium nitrate	1.0%	0.31^{hi}	0.17^{jkl}	0.04^{pq}	0.35	0.18	0.18
	1.5%	0.43^{cde}	0.21^{j}	0.10^{no}	0.39	0.28	0.21
	2.0%	0.70^{b}	0.28^{i}	$0.15l^{m}$	0.46	0.43	0.24
Easygro	1.0%	0.30^{hi}	0.14^{lm}	0.07^{op}	0.30	0.18	0.11
	1.5%	0.40^{ef}	0.17^{jkl}	0.06^{opq}	0.37	0.22	0.15
	2.0%	0.47^{c}	0.30^{hi}	0.15^{lm}	0.46	0.40	0.19
Control	0%	0.04^{pq}	0.08^{op}	0.02^{p}	0.18	0.16	0.09
p-value		<.001				0.19	
$Lsd_{(P\leq0.05)}$	SxTxR	0.04				ns	
Cv (%)		10.2				11.6	

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; S=Source; T=Time; R=Rate; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$

Organoleptic evaluation

All the calcium sources invariably affected fruit peel color in both seasons (Fig 4.3). Application of calcium chloride led to an improved peel color compared to untreated fruits. The peel color was ranked with superior scores as the rate of calcium chloride increased from 1.0% to 2.0%. Calcium nitrate on the other hand led to higher colour scores than the other treatments for concentration 1.0% and 1.5%. However, as the concentration of calcium increased from 1.5% to 2.0% peel color was given inferior scores irrespective of the time of application. Similarly, application of easygro at higher rates (1.5% and 2.0%) registered statistically lower scores than the control in both seasons.

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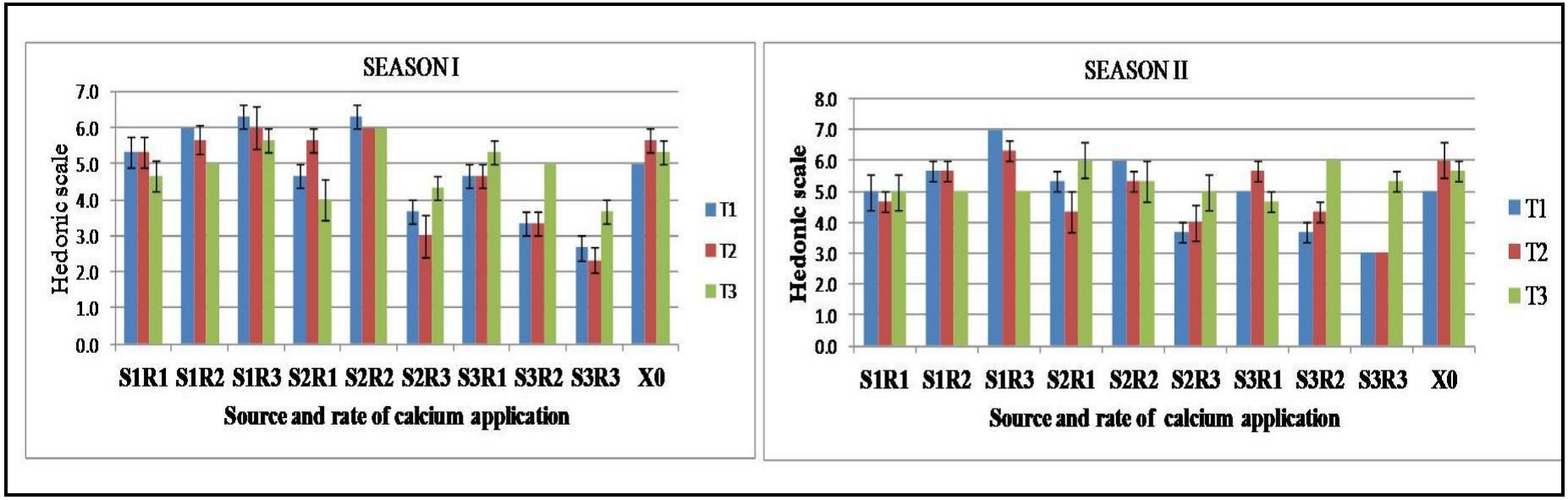

Figure 4:3 Effects of different sources of calcium on the peel color of ripe mango fruits

S_I-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; XO-Control; R_1-1.0%; R_2-1.5%; R_3-2.0%; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to physiological maturity. Bars represent standard errors of the means at $p \leq 0.05$

All the calcium sources affected the taste of the fruits negatively in both seasons as shown in Fig. 4.4. As the rate of calcium concentration for all the sources of calcium increased from 1.0% to 2.0% the taste of the fruit deteriorated irrespective of the time of application. Application of calcium sources at 30 days to maturity had higher taste scores than application at fruit set and 30 days after fruit set.

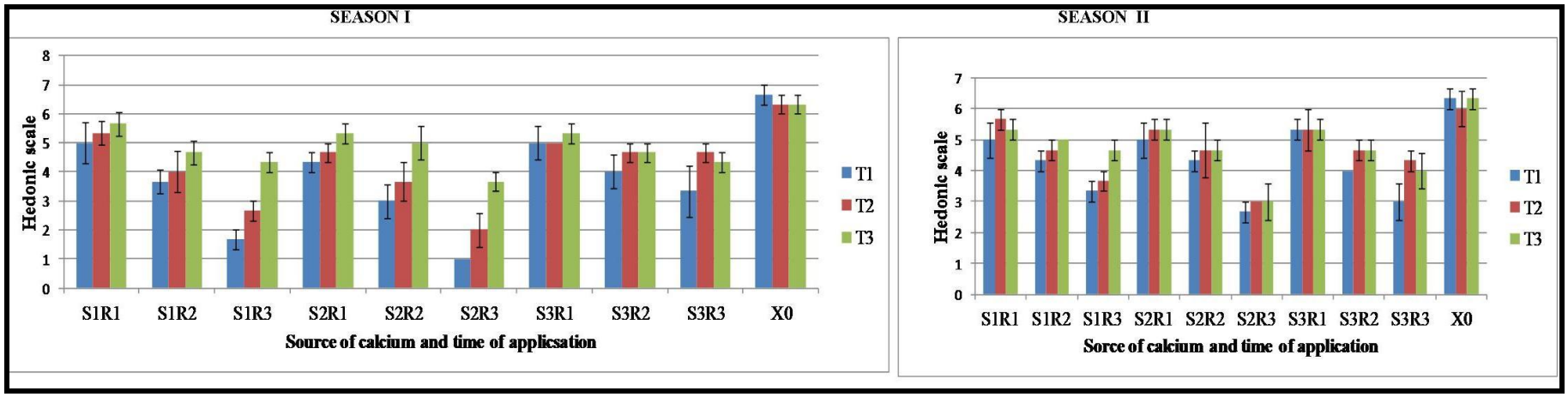

Figure 4:4 Effect of different sources of calcium on the taste of ripe mango fruits

S_I-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; X_O-Control; R_1-1.0%; R_2-1.5%; R_3-2.0%; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to physiological maturity. Bars represent standard errors of the means at $p \leq 0.05$.

The general acceptability of the fruits was significantly affected by the source, rate and timing of application in both seasons (Fig.4.5). Fruits sprayed with calcium nitrate (1.5%) at 30 days to fruit maturity had significantly the highest scores in acceptability which was not significantly different from the control fruits. Application of calcium nitrate (2.0%) had the lowest acceptability rating irrespective of the timing of application in both seasons.

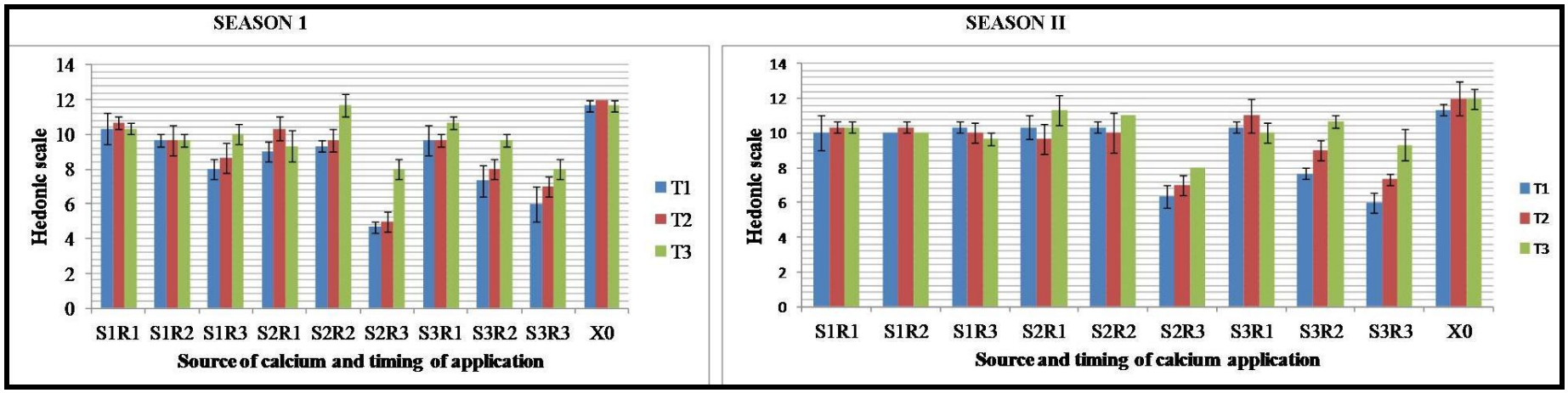

Figure 4:5 Effect of different sources of calcium on the general acceptability of ripe mango fruits

S_I-Calcium chloride; S_2-Calcium nitrate; S_3-Easygro; XO-Control; R_1-1.0%; R_2-1.5%; R_3-2.0%; T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to physiological maturity**.** Bars represent standard errors of the means at $p \leq 0.05$

Peel color

Source, rate and time of calcium application significantly ($P \leq 0.05$) affected the fruit peel colour at harvest and after 12 days of storage in both seasons (Table 4.20). All the calcium sources did not have significantly different hue angle at harvest and after storage in both seasons except in season 1 where fruits sprayed with calcium chloride had significantly higher hue angle than easy gro at harvest and after storage. Control fruits had significantly the lowest hue angle in both seasons.

Fruits sprayed at fruit set had significantly higher hue angle than those sprayed 30 days later which were in turn significantly higher than those sprayed at 30 days to physiological maturity except in season 2 after storage, where fruits sprayed in the latter two periods were not significantly different.

Fruits sprayed with calcium at 2.0% had significantly higher hue angle than those sprayed with 1.0% at harvest and after storage in both seasons. On the other hand, fruits sprayed with 1.5 % and 1.0% did not have significantly different hue angle in both seasons except in season 1, after storage, where fruits sprayed at 1.5% had significantly higher hue angle than those sprayed at 1.0%. Fruits sprayed with calcium at 2.0% had significantly higher hue angle than those sprayed with 1.5% after storage in both seasons but not significantly different at harvest in both seasons.

Table 4:20 Main effects of source, time and rate of calcium application on peel colour (Hue angle, H^o) of 'Van Dyke' mango fruits at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
	At harvest	After storage	At harvest	After storage
Source				
Easy gro	57.67[b]	41.41[b]	58.52[a]	47.95[a]
Calcium nitrate	61.44[ab]	44.98[ab]	59.70[a]	49.35[a]
Calcium chloride	65.67[a]	48.02[a]	62.83[a]	50.39[a]
Control	32.88[c]	24.93[c]	37.93[b]	27.44[b]
P-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	5.83	3.59	5.23	5.45
Cv%	18.3	15.5	16.6	21.4
Time				
T_1	67.99[a]	48.67[a]	67.98[a]	58.09[a]
T_2	61.74[b]	41.45[b]	58.51[b]	44.78[b]
T_3	46.44[c]	38.33[b]	47.83[c]	38.29[c]
P-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	5.54	4.24	4.35	4.43
Cv%	18.4	19.3	14.6	18.3
Rate				
1.0%	56.67[b]	40.33[c]	56.28[b]	44.28[b]
1.5%	61.48[ab]	44.48[b]	60.28[ab]	48.33[b]
2.0%	66.63[a]	49.60[a]	64.49[a]	55.08[a]
Control	32.88[c]	24.93[d]	37.93[c]	27.44[c]
P-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	5.69	3.30	5.01	4.94
Cv%	17.9	14.2	15.9	19.4

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Interactive effects of source, rate and time of calcium application on fruit peel colour at harvesting and after 12 days of storage in ambient conditions

The interaction between source and rate did not significantly ($P \leq 0.05$) affect the fruit peel colour at harvest and after 12 days of storage in ambient conditions in both seasons.

The interaction between source and time on the other hand, significantly ($P \leq 0.05$) affected the fruit peel colour at harvest in both seasons and after storage in season 1 only (Table 4.21). Among fruits sprayed at fruit set, those sprayed with calcium chloride had significantly higher hue angle than those sprayed with easy gro at harvest and after storage in both seasons. Additionally, fruits sprayed with calcium chloride had significantly higher hue angle than those sprayed with calcium nitrate in both season seasons except at harvest where the two were not significantly different. There were no significant differences among fruits sprayed with calcium nitrate and easy gro in both seasons except after storage when calcium nitrate sprayed fruits had significantly higher hue angle than those sprayed with easy gro.

All the fruits sprayed at 30 days after fruit set did not have significantly different hue angle in both seasons except at harvest in season 1 where fruits sprayed with easy gro had significantly lower hue angle than the other two sources. In most cases, fruits sprayed at fruit set had significantly higher hue angles than those sprayed 30 days later which in turn had significantly higher hue angles than those sprayed at 30 days to maturity.

Table 4:21 Interactive effects of source and time of calcium application on peel colour (Hue angle, H^o) of 'Van Dyke' mango fruits at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		Season 2	
Treatment	At harvest	After storage	At harvest	After storage
S_1 T_1	74.77[a]	57.79[a]	74.55[a]	60.96
S_2 T_I	71.25[ab]	50.56[b]	70.02[b]	61.70
S_1 T_2	69.12[bc]	44.44[c]	61.76[c]	48.88
S_3 T_1	69.03[bc]	45.35[c]	69.38[b]	60.54
S_2 T_2	65.29[c]	44.51[c]	61.16[c]	45.59
S_3 T_2	60.94[d]	41.07[cd]	58.70[c]	45.00
S_1T_3	53.11[e]	41.84[cd]	52.18[d]	41.33
S_2 T_3	47.78[f]	39.87[d]	47.91[e]	40.77
S_3 T_3	43.05[g]	37.81[d]	47.48[e]	38.31
Ctrl T_1	34.75[h]	25.61[e]	37.95[f]	31.29
Ctrl T_3	32.58[h]	24.75[e]	35.58[f]	21.68
Ctrl T_2	31.31[h]	24.44[e]	40.25[f]	29.36
P-Value	<.001	0.007	<.001	0.94
$Lsd_{(P\leq0.05)}$S*T	4.30	4.30	3.67	Ns
Cv%	7.80	10.70	6.70	11.1

S_I=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; $T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation; ns=Not significant. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interaction between rate and time significantly affected fruit peel colour in both seasons (Table 4.22). Application of calcium, 2.0% at fruit set led to significantly the highest peel hue angle in at harvest and after storage in both seasons. For fruits sprayed with calcium at 2.0%, those sprayed at fruit set had significantly higher hue angle than those sprayed 30 days later which were in turn significantly higher than those sprayed 30 days to maturity except in season 1 after storage.

Among fruits sprayed with calcium at 1.5%, those sprayed at fruit set had significantly higher hue angle than those sprayed 30 days later and 30 days to maturity. Fruits sprayed with 1.5% at 30 days after fruit set had significantly higher hue angle than those sprayed with 1.5% calcium at 30 days to maturity at harvest in both seasons and after harvest in season 2 but not significantly different after storage in season 1. For fruit sprayed with calcium at 1.0%, those sprayed at fruit set had significantly higher hue angle than those sprayed 30 days later which were in turn significantly

higher than those sprayed 30 days to maturity in both seasons.Fruits sprayed with calcium at 2.0% had significantly higher hue angle than those sprayed with 1.5% which were in turn significantly higher than those sprayed with calcium at 1.0% in most cases. Control fruits had significantly the lowest hue angle at harvest and after storage in both seasons.

Table 4:22 Interactive effects of rate and time of calcium application on peel colour (Hue angle, H^o) of 'Van Dyke' mango fruit at harvest and after 12 days of storage in ambient conditions during season 2017 and 2018 at Karurumo

	Season 1		Season 2	
Treatments	At harvest	After storage	At harvest	After storage
T_1 R_3	75.95^{a}	58.44^{a}	74.61^{a}	66.60^{a}
T_1 R_2	71.81^{b}	50.53^{b}	71.37^{b}	60.61^{b}
T_2 R_3	69.28^{bc}	46.75^{c}	64.33^{d}	53.63^{c}
T_1 R_1	67.29^{cd}	44.74^{cd}	67.97^{c}	55.99^{c}
T_2 R_2	64.96^{d}	42.86^{de}	60.72^{e}	44.74^{d}
T_2R_1	61.11^{e}	40.41^{e}	56.58^{f}	41.11^{e}
T_3 R_3	54.67^{f}	43.62^{cde}	54.54^{f}	45.02^{d}
T_3 R_2	47.66^{g}	40.05^{e}	48.73^{g}	39.65^{e}
T_3 R_1	41.60^{h}	35.84^{f}	44.30^{h}	35.74^{f}
CtrlT_1	34.75^{i}	25.61^{g}	37.95^{ij}	31.29^{g}
CtrlT_3	32.58^{i}	24.75^{g}	35.58^{j}	21.68^{h}
CtrlT_2	31.31^{i}	24.44^{g}	40.25^{i}	29.36^{g}
P-value	<.001	0.006	<.001	<.001
$Lsd_{(P\leq0.05)}$ R*T	3.56	3.62	2.48	2.58
Cv%	6.5	9.0	4.50	5.80

R_1=1.0%; R_2=1.5%; R_3=2.0%; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation; Cltr=Control.Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$

Interaction among source, rate and time of calcium application significantly ($P\leq0.05$) affected the fruit peel hue angle at harvest in both seasons (Table 4.23). Fruits sprayed with calcium chloride (2.0%) at fruit set had significantly the highest hue angle in seasons.

Table 4:23 Interactive effects of source, rate and time of calcium application on peel color (Hue angle, H^o) of 'Van Dyke' mango fruits at harvest during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T1	T2	T3
Calcium chloride	1.0%	70.36^{def}	63.99^{ij}	48.05^{o}	70.41^{cd}	58.21^{jk}	48.55^{n}
	1.5%	73.91^{bc}	69.64^{ef}	52.44^{n}	74.37^{b}	61.00^{hi}	51.98^{m}
	2.0%	80.05^{a}	73.74^{bc}	58.83^{kl}	78.87^{a}	66.09^{f}	56.02^{jkl}
Calcium nitrate	1.0%	67.08^{gh}	62.26^{j}	40.53^{q}	67.31^{ef}	56.03^{jkl}	41.27^{op}
	1.5%	71.24^{de}	65.56^{hi}	46.97^{o}	70.64^{cd}	62.43^{gh}	48.21^{n}
	2.0%	75.42^{b}	68.05^{fg}	55.84^{m}	72.12^{bc}	65.02^{fg}	54.24^{lm}
Easy gro	1.0%	64.44^{ij}	57.08^{lm}	36.21^{r}	66.20^{f}	55.49^{kl}	43.07^{o}
	1.5%	70.28^{def}	59.68^{k}	43.58^{p}	69.11^{de}	58.74^{ij}	46.01^{n}
	2.0%	72.37^{cd}	66.06^{ghi}	49.35^{o}	72.84^{bc}	61.88^{h}	53.36^{lm}
Control	0%	34.75rs	31.31^{t}	32.58^{st}	37.95^{qr}	40.25^{pq}	35.58^{r}
P-value			0.003			0.04	
$LSD_{P\leq0.05}$	SxTxR		2.46			2.74	
Cv (%)			2.60			2.90	

$T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$

At the conclusion of the storage time the peel color of the fruits was significantly ($P\leq0.05$) affected by the interaction between source, rate and time of calcium application in both seasons (Table 4.24). Application of calcium chloride at fruit set (2.0%) had higher hue angle than all other treatments in seasons I. In season 2, fruits sprayed with the three sources at a rate of 2.0% at fruit set registered significantly the highest hue angle 2 respectively.

Table 4:24 Interactive effects of sources, rate and time of calcium application on peel color (Hue angle, H^o**)** of 'Van Dyke' mango fruits after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride							
	1.0%	50.21^{de}	40.68^{jkl}	37.81^{m}	55.10^{e}	43.38^{hi}	36.21^{lm}
	1.5%	55.25^{bc}	44.35^{hi}	41.00^{jkl}	60.59^{c}	47.81^{fg}	40.48^{ijk}
	2.0%	67.92^{a}	48.29^{ef}	46.70^{fgh}	67.20^{a}	55.45^{de}	47.29^{fg}
Calcium nitrate	1.0%	43.24^{ij}	42.07^{ijk}	34.82^{n}	56.24^{de}	39.13^{jkl}	36.48^{lm}
	1.5%	52.47^{cd}	44.23^{hi}	40.85^{jkl}	62.24^{bc}	41.41^{hij}	40.98^{ik}
	2.0%	55.98^{b}	47.23^{fg}	43.95^{hi}	66.61^{a}	56.24^{de}	44.85^{gh}
Easy gro	1.0%	40.78^{jkl}	38.47^{lm}	34.89^{n}	56.61^{de}	40.82^{ijk}	34.54^{mn}
	1.5%	43.86^{i}	39.99^{klm}	38.30^{l}	59.01^{cd}	45.00^{gh}	37.49^{klm}
	2.0%	51.41^{d}	44.74^{ghi}	40.23^{klm}	65.99^{ab}	49.19^{f}	42.91^{hij}
Control	R0	25.61^{o}	24.44^{o}	24.75^{o}	31.29^{no}	29.36^{o}	21.68^{p}
P-value			0.016		0.015		
$LSD_{P\leq0.05}$	SxTxR		2.78		3.81		
CV (%)			4		5		

S_I=Calcium chloride; S_2=Calcium nitrate; S_3=Easygro; R_1=1.0%; R_2=1.5%; R_3=2.0%; $T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$

Peel firmness

The source rate and time of calcium application had significant ($P\leq0.05$) effects on fruit peel firmness at harvest and after 12 days of storage in ambient conditions in both seasons (Table 4.25). Fruits sprayed with calcium chloride had significantly higher peel firmness than those sprayed with easy gro at harvest and after 12 days of storage in both seasons. There were no significant differences in fruit peel firmness among fruits sprayed with calcium nitrate and easygro at harvest and after storage in both seasons. Additionally, fruits sprayed with calcium chloride and those sprayed with calcium nitrate did not have significantly different peel firmness at harvest but significantly different after storage in both seasons. All control fruits had significantly the lowest peel firmness at harvest and after 12 days of storage in both seasons.

Fruits sprayed at fruit set had significantly the highest peel firmness than those sprayed 30 days later which were in turn significantly higher than those sprayed 30 days to maturity at harvest and after storage in season 1. Fruits sprayed at fruit set and those sprayed 30 days later did not have significantly different peel firmness but significantly higher than those sprayed at 30 days to maturity at harvest and after storage in season 2.

Table 4:25 Main effects of source, time and rate of calcium application on peel firmness (N) of' Van Dyke' mango fruit at harvest and after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

	Season 1		**Season 2**	
	At harvest	After storage	At harvest	After storage
Source				
Easy gro	3.64[b]	2.17[b]	3.74[b]	2.38[b]
Calcium nitrate	3.96[ab]	2.59[b]	4.25[ab]	2.67[b]
Calcium chloride	4.46[a]	3.21[a]	4.56[a]	3.27[a]
Control	2.09[c]	1.02[c]	1.88[c]	1.33[c]
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.76	0.50	0.61	0.56
Cv%	26.00	37.50	28.40	39.60
Timing				
T_1	4.77[a]	3.17[a]	4.75[a]	3.29[a]
T_2	3.78[b]	2.69[b]	4.28[a]	3.01[a]
T_3	2.93[c]	1.61[c]	2.83[b]	1.59[b]
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.47	0.47	0.55	0.46
Cv%	24.00	36.70	27.30	34.40
Rate				
1.0%	3.39[c]	2.02[c]	3.46[c]	2.10[c]
1.5%	3.97[b]	2.60[b]	4.07[b]	2.75[b]
2.0%	4.70[a]	3.33[a]	5.03[a]	3.47[a]
Contrl	2.09[d]	1.02[d]	1.88[d]	1.33[d]
p-value	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.49	0.47	0.53	0.52
Cv%	23.60	35.10	24.90	36.30

$T_{1=}$Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation; H_O=Harvest. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$

Interactive effects of source, rate and time of calcium application on fruit peel firmness at harvest and after 12 days of storage in ambient conditions

The interaction between source and rate of calcium application and between source and time did not significantly ($P \leq 0.05$) affect the fruit peel firmness at harvest and after 12 days of storage in ambient conditions in both seasons. The interaction between rate and time of calcium application on the other hand significantly ($P \leq 0.05$) affected the fruit peel firmness at harvest and after 12 days of storage in season 1 only (Table 4.26).

Application of calcium, 2.0% at fruit set had significantly the highest peel firmness at harvest and after 12 days of storage.Among fruits sprayed at fruit set, those sprayed with calcium 2.0% had significantly higher peel firmness than those sprayed at 1.5% which in turn had significantly higher peel firmness than those sprayed at 1.0% at harvest and after storage. For fruits sprayed at 30 days after fruit set, those sprayed with 2.0% had significantly higher peel firmness than those sprayed with 1.0% and 1.5%, which were not significantly different at harvest and after storage. For fruits sprayed at 30 days to maturity, those sprayed with 2.0% had significantly higher peel firmness than those sprayed at 1.5% and 1.0% at harvest and after storage. Fruits sprayed with 1.0% and 1.5% at 30 days to maturity did not have significantly different peel firmness from the control fruits at harvest for 1.0% and 1.0% and 1.5% after storage. Irrespective of the rate of application, fruit sprayed at fruit set had significantly higher peel firmness than those sprayed 30 days later which in turn had significantly higher peel firmness than those sprayed 30 days to maturity except a few cases.

Table 4:26 Interactive effect of rate and time of calcium application on peel firmness (N) of 'Van Dyke' mango fruits at harvest and after 12 days of storage in ambient conditions during season 2017 at Karurumo

Treatment	At harvest	After harvest
R_3 T_1	5.60[a]	4.06[a]
R_2 T_1	5.11[b]	3.47[b]
R_3 T_2	4.77[b]	3.54[b]
R_1 T_1	4.33[c]	2.70[c]
R_2 T_2	3.76[d]	2.76[c]
R_3 T_3	3.72[d]	2.40[c]
R_1 T_2	3.43[de]	2.29[c]
R_2 T_3	3.06[e]	1.59[d]
R_1 T_3	2.40[g]	1.08[d]
Ctrl T_1	2.53[f]	1.03[d]
CtrlT_2	1.97[gh]	1.10[d]
Ctrl T_3	1.77[h]	0.93[d]
p-value	0.05	0.05
$Lsd_{(P\leq0.05)}$	0.42	0.51
Cv%	11.8	21.7

R_1=1.0%; R_2=1.5%; R_3=2.0%; T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interactions of source, rate and time of calcium application had significant ($P \leq 0.05$) effects on the fruit peel firmness at harvest in season 1 only (Table 4.27). Application of calcium chloride, 2.0% at fruit set, 30 days later, and calcium chloride 1.5% applied at fruit set and calcium nitrate, 2.0% applied at fruit set had significantly the highest peel firmness.

Table 4:27 Interactive effect of source, rate and time of calcium application on peel firmness (N) of 'Van Dyke' mango fruits at harvest during seasons 2017 and 2018 at Karurumo

		Season 1			Season 2		
Source	Rate	T_1	T_2	T_3	T1	T2	T3
Calcium chloride	1.0%	4.87^{b}	3.77^{ef}	2.50^{k}	4.50	4.13	2.60
	1.5%	5.70^{a}	4.13^{cde}	3.27^{gihj}	5.13	4.77	3.37
	2.0%	5.93^{a}	5.70^{a}	4.23^{cd}	6.37	5.83	4.37
Calcium chloride	1.0%	4.27^{c}	3.37^{gh}	2.47^{k}	4.50	3.93	2.27
	1.5.%	5.23^{b}	3.60^{fg}	2.93^{j}	5.23	4.40	2.93
	2.0%	5.77^{a}	4.43^{c}	3.60^{fg}	5.97	4.97	4.07
Easy gro	1.0%	3.87^{def}	3.17^{hij}	2.23^{kl}	4.00	3.43	1.73
	1.5%	4.40^{c}	3.53^{fgh}	2.97^{ij}	4.43	4.33	2.03
	2.0%	5.10^{b}	4.17^{cd}	3.33^{ghi}	5.23	4.90	3.57
Control	0%	2.53^{k}	1.97^{lm}	1.77^{m}	2.17	2.07	1.40
P-value			0.03			0.40	
$LSD_{P\leq0.05}$	SxTxR		0.39			Ns	
Cv (%)			6.20			9.20	

T_1=Fruit set; T_2=30 days after fruit set; T_3=30 days to physiological maturity; LSD=Least significant difference; CV=Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

The interaction of source, rate and time of calcium application had significant effect on fruit firmness after 12 days of storage in ambient conditions in season 1 only (Table 4.28). Fruits sprayed with calcium chloride, 2.0% at fruit set registered significantly the highest fruit peel firmness.

Table 4:28 Interactive effect of source, rate and time of calcium application on peel firmness (N) of 'Van Dyke' mango fruits after 12 days of storage in ambient conditions during seasons 2017 and 2018 at Karurumo

Source	Rate	Season 1			Season 2		
		T_1	T_2	T_3	T_1	T_2	T_3
Calcium chloride	1.0%	3.10^{fghi}	3.17^{fgh}	1.27^{pqr}	2.80	2.77	1.73
	1.5%	4.40^{b}	3.47^{ef}	1.77^{no}	3.93	3.47	2.30
	2.0%	4.83^{a}	4.07^{bc}	2.80^{hijk}	4.77	4.43	3.23
Calcium nitrate	1.0%	2.77^{ijk}	2.07^{mn}	1.00^{r}	2.83	2.33	1.13
	1.5%	3.23^{fg}	2.53^{kl}	1.43^{opq}	3.30	3.00	1.37
	2.0%	4.00^{cd}	3.63^{de}	2.60^{jkl}	4.23	3.73	2.13
Easy gro	1.0%	2.23^{lm}	1.63^{op}	0.98^{r}	2.20	2.27	0.82
	1.5%	2.77^{ijk}	2.27^{lm}	1.53^{op}	3.50	2.90	0.98
	2.0%	3.33^{ef}	2.93^{ghij}	1.80^{no}	4.00	3.40	1.33
Control	0%	1.03^{r}	1.10^{qr}	0.93^{r}	1.33	1.77	0.88
p-value			0.004			0.66	
Lsd $_{P\leq 0.05}$	SxTxR		0.39			Ns	
Cv (%)			9.5			14.6	

T_1-Fruit set; T_2-30 days after fruit set; T_3-30 days to physiological maturity; S-Source; T-Time; R-Rate; LSD-Least significant difference; CV-Coefficient of variation; ns-not significant. Treatments with different letters are significantly different according to LSD at $p \leq 0.05$.

4.6 Discussion

Application of calcium led to increased calcium accumulation in the fruits. However, different fruit partitions showed varied calcium concentrations with the endocarp and cotyledons registering the highest and lowest accumulation of calcium respectively. The increase in fruit calcium content as reported in this experiment has been reported previously by Cheour, *et al*. (1990); Madani, *et al*. (2016) and Garcia, et *al*. (1996) who reported that application of calcium on strawberry increased calcium content in the fruits. Similarly, Manganaris, *et al.* (2007) showed an increase in flesh and peel calcium concentration due to application of calcium salts on peach fruits. The maximum accumulation of calcium in the endocarp could be due to its role in ensuring the firmness and hardiness of the seed cover. Similar results in which accumulation of minerals varied in different parts of the fruit have been reported by Clark, *et al*., (1989), Sinha, *et al*. (2017), Burdon, *et al*. (1991), and Joyce, *et al.* (1997).

Application of calcium salts at fruit set resulted in a higher calcium concentration in the exocarp, mesocarp and pericarp than applications that were done 30 days and 60 days later respectively. This reinforces the fact that calcium is more available at early stages of fruit development. Similar findings on the availability of calcium at early stages of fruit development have been reported in mango (Amin, *et al*., 2007; Karemera, *et al.*, 2013) and avocado fruits (Penter, *et al*., 2000).

Fruits sprayed with calcium at the initial stages of fruit development reported lower jelly seed incidence than those sprayed at later stages of fruit development. This reinforces the role of calcium in enhancing tissue stability and firmness and availability of calcium at early stages of fruit development. Similar results on the suppressed internal breakdown by application of calcium have been reported in mango (Amin, *et al*., 2007; Burdon, *et al.*, 1991; 1992; Kadiya, 1995 and Seshadri, *et al.* 2019) and apple (Gago, *et al*., 2016; Lotze, *et al*., 2008) fruits.

Fruits sprayed at early stages of development had low jelly seed incidence probably because the fruits were actively taking up calcium. Effective use of calcium at early stages in combating bitter pit in apples has been reported by Lotze, *et al*., (2008). Amin, *et al.* (2007) reported that pre-harvest application of calcium salts reduced soft nose incidence in mango fruits underscoring the role of calcium in enhancing tissue and cell wall firmness thus preventing disintegration and cell deterioration. The differences from the various sources, timing and rates could be due to environmental factors, formulation or other factors that may have affected the availability of calcium to the fruit. Njuguna, *et al.* (2016) reported that the occurrence of jelly seed is greatly affected by environmental factors. Additionally, Lotze *et al*. (2008) reported varied effectiveness of calcium products absorption and suppression of bitter pit in apple fruit due to different stages of application. Fruits with less or no jelly seed occurrence had high calcium content in the fruit endocarp, mesocarp and exocarp as indicated by the inverse relationship between calcium content and jelly seed.

There were generally lower levels of TSS in fruits sprayed with calcium than control fruits. The low TSS among fruits sprayed with calcium implies that they could be stored longer than the fruits with low TSS because they had not ripened fully. Similar results of an increased level of TSS with advancement of storage have been reported by Karemera, *et al*., (2014) and Wahdan,

et al., (2011). The lower levels of TSS at the end of the storage period in calcium sprayed fruits could be because of the role of calcium in delaying metabolic activities of fruits during storage as aluded to by Conway, *et al*., (1984). Singh, *et al*., (2017) reported a decreased rate of TSS accumulation in calcium sprayed mango fruits. The increase in TSS with storage is because of the conversion of carbohydrates to sugars through enzymatic activities. This explains the reason why fruits had higher TSS level at the end of the storage period than they had at harvest. Fruit sprayed at fruit set had lower accumulation of TSS than those that were spayed later during development showing that pre-harvest application of calcium is more available to the fruit when applied in the early periods of fruit development as reported by Karemera, *et al*., (2014).

Calcium chloride led to an improved peel color appearance as scored by the judges but calcium nitrate and easy gro applied at 2.0% led to deterioration in peel color appearance. The improved peel color appearance due to calcium chloride application has been reported by Anjum, *et al*., (2004). The authors reported deteriorated skin colour due to application of calcium ammonium nitrate. The deterioration in color when calcium nitrate and easy gro was used, could be due to nitrogen in easy gro and calcium nitrate that affected color formation as reported by Anjum, *et al*. (2004). Fruit color decreases as the rate of nitrogen increases (Week, *et al*. (1952; Fallahi, *et al*., 2001) because nitrogen inhibits anthocyanin synthesis and accumulation (Cheng, *et al*., 2011). Application of calcium sources at later stages during fruit development (30 days to maturity) was given superior taste scores than earlier application. This could be because early application led to more availability of calcium than later application as earlier alluded to in this study and other studies (Karemera, *et al*., 2014; Penter, *et al*., 2000). Gofure, *et al*., (1997) indicated that an increase in calcium salts concentration led to negative effects on taste of fruits.

Fruits treated with calcium had significantly higher TTA content than control fruits probably due to a delay in the ripening of the fruits associated with calcium (Madani, *et al*., 2016). The high acidity in fruits treated with calcium has been reported previously (Dhillon, *et al*., 2013; Singh, *et al*., 2017). Ripening leads to the accumulation of TSS that is a result of breakdown of starch to sugars. The ripening process was probably slower in calcium treated fruits than control thus a high acidity comparatively even after storage. Similar results in a declined TTA after

storage has been reported by Ngamchuachit, *et al*. (2014); Islam, *et al*., (2013) and Karemera, *et al*., 2014).

Application of calcium led to a reduced loss in weight because calcium maintains the cell integrity hence a lowered loss in weight. Calcium chloride applied at fruit set was the most effective in decreasing weight loss probably because calcium is more available during early stages of fruit development. Similar results in a decreased loss in weight due to calcium application has been reported in apples (Shirzadeh, *et al*., 2011)

Application of calcium led to significant effects on the fruit peel firmness at harvesting and after 12 days of storage in ambient conditions. Fruit sprayed at fruit set had higher peel firmness both at harvest and after storage. This is probably because calcium was more available at this stage of fruit development. Similarly, higher concentration of calcium reported a higher firmness. Calcium binds with pectic acid in the cell wall generating a compound that maintains the structure of the fruit. Fruit firmness has been reported to be maintained by application of calcium in apple (Hussain, *et al*., 2012) loquat (Akhtar, *et al.*, 2010).

Fruits sprayed with calcium had a higher hue angle at harvesting and after 12 days of storage in ambient conditions than unsprayed ones. Hue angle increased with increase in calcium application rate. Calcium retards chlorophyll degradation of fruits hence the delayed colour development of the calcium sprayed fruits. Calcium suppresses the effect of ethylene (Ishaq, *et al*., 2009) hence the retained colour even after storage.

It can therefore be concluded that application of calcium led to an increase in fruit calcium content with different fruit parts accumulating different amount of calcium. Calcium applied at early stages of fruit development was more available with the calcium content increasing with increase in calcium concentration. The reduction of jelly seed by application of calcium salts indicates that calcium salts can be used in its alleviation. Additionally, application of calcium salts proved to be more effective in reducing the accumulation of total soluble solids, maintenance of fruit firmness, enhanced fruit color maintenance and reduced loss in weight. Calcium chloride improved fruit color appearance while calcium nitrate and easygro led to deterioration in fruit color appearance. The taste of the fruits was negatively affected by calcium

application with fruits that received calcium later tasting better than fruits that received it earlier. This indicates that optimal rates need to be applied to achieve desired results.

CHAPTER FIVE: EFFECT OF PRE AND POST HARVEST APPLICATION OF CALCIUM CHLORIDE ON THE SHELF LIFE AND QUALITY OF MANGO FRUITS

Abstract

In Kenya, the cultivation of mangoes (*Mangifera indica* L.) directly benefits more than 200,000 farmers and many others along the value chain. Despite the enormous importance of this fruit, its short shelf life in ambient environments causes post-harvest losses thus hindering full exploitation. Calcium keeps cell walls and membrane structures strong, maintains cell integrity therefore enhancing the shelf life of fruits. An experiment was set to compare the effect of spraying and submerging of mango fruits in calcium chloride at various concentrations and growth timeframes on the fruit ripening rate and organoleptic acceptance. Randomized complete block design with a split plot arrangement was used. The time of calcium chloride application formed the main plot while the rate of calcium chloride applied formed the sub plots. At maturity or 15 days later, "Van Dyke" mango fruits were sprayed or submerged in calcium chloride (0.5 percent, 1 percent, 1.5 percent, or 0 percent). At times 0 and every 2 days up to 8 days of storage in ambient conditions, changes in fruit peel firmness (N), total soluble solids (^{0}Brix), titratable acidity (percent), flesh color (H^o), beta carotene (mg/100 ml), cumulative weight loss (%), carbon dioxide and ethylene evolution (ml/kg/hr), were examined. Ripening period and selected organoleptic attributes, flesh firmness, calcium concentration and their relationships were also determined. In comparison to the other treatments, fruits immersed in calcium chloride (1.5%) at maturity had a longer ripening period (31 days), higher peel firmness (10.6 N, 10.3 N), flesh color (37.45 H^o, 36.78 H^o), titratable acidity (0.72 %, 0.70 %), lower total soluble solids (14°Brix, 13.8°Brix), reduced carbon dioxide evolution (30.7 ml/kg/hr), higher beta carotene and colour appearance rating. When compared to fruits sprayed 15 days later, fruits sprayed at maturity had higher fruit firmness, color, total soluble solids, titratable acidity, beta carotene, lower carbon dioxide evolution and ripening rate. Flesh calcium content reported a positive correlation with flesh firmness (r= 0.913, r= 0.852), peel color (r= 0.828, r= 0.841), fruit aroma (r=0.8199, r=0.841) skin shriveling (r=0.778, r= 0.806) and a negative correlation with fruit flavor (r=-0.811, r=-0.829) in season 1 and 2 respectively. Flesh firmness exhibited a positive correlation with skin shriveling (r=0.868, r=0.788), peel color (r=0.9115, r=0.856) and aroma (r=0.907, r=0.848) and a negative correlation with fruit flavor

(r=-0.8869, r=-0.821). Skin shriveling showed a negative relation with peel color (r=-0.944, r=-0.93) and aroma (r=-0.944, r=-0.938) and a positive relation with fruit flavor (r=0.933, r=0.947). Peel color exhibited positive and negative correlations with aroma (r=0.979, r=0.977) and fruit flavor (r=-0.962, r=-0.950) respectively. Despite the effectiveness of post-harvest immersion in calcium chloride in enhancing fruit shelf life through increased firmness, delayed skin color development and soluble solids accumulation, decreased carbon dioxide evolution and increased calcium concentration, optimal use is recommended to avoid deteriorated pulp flavor and increased shriveling. Further research needs to be done on how best calcium chloride can be made available to the fruit while still attached onto the tree.

Key words: Calcium chloride, shelf life, mango, ripening.

5.1 Introduction

Mango (*Mangifera indica* L.) is an important fruit in Kenya and elsewhere in producing countries. Despite this, this fruit has a short shelf life in ambient conditions thus affecting its production and commercialization due to high losses after harvest. Mangoes fetch low prices during glut as farmers can not stay with the fruit for long. This is occasioned by the short shelf of mango fruits of 7-10 days which depends on handling, storage and shipping conditions and harvesting stage (Baloch, *et al*., 2012). Further, small scale farmers do not have storage facilities that are equipped with modern technologies hence they have to give away the fruits even at low prices.

Fruit cell wall has three types of polysaccharides; hemicelluloses, pectin and cellulose (Owino, *et al*., 2005). The cell wall has calcium as a major component where it forms calcium pectate that creates linkanges ensuring that the cell wall is rigid and of high integrity. Due to the rigidity and high intergrity the cell wall undergoes degradation and senescence at a slow rate. Calcium reduces the rate of ethylene evolution by the fruit, fruit respiration and fruit weight loss (Karemera, *et al*., 2014; Zhang, *et al*., 2019; Thakur, *et al*., 2019), reflecting the ripening process and increasing the fruit shelf life. Calcium chloride has been reported to decrease the

ripening rate and decay of various fruits and vegetables (Karemera, *et al*., 2014, Gangle, *et al*., 2019; Hussain *et al*., 2019). Various factors influence the effect of calcium on fruit shelf life and consumer acceptability. They include; mode of calcium application, the calcium compound used, stage of fruit growth when the calcium is applied and rate or frequency of application (Anjum, *et al*., 2004; Singh, *et al*., 2017). Calcium chloride, as a source of calcium, enhances the shelf life of mango fruits by enhancing fruit firmness, decreasing fruit weight loss (Karemera, *et al*., 2014; Sajid, *et al*., 2014) respiration and ethylene evolution (Hussain, *et al*., 2012).

Pre-harvest spraying as well as post-harvest immersion in calcium chloride for quality preservation has been well reported in mango (Karemera, *et al*., 2014, Singh, *et al*., 2017, Dhillon, *et al*., 2013) and guava (Mahajan, *et al*., 2011) amongst other fruits and vegetables. Post-harvest immersion of fruits in calcium chloride ensures fruit quality and longevity through reduction of the rate of soluble solids accumulation and weight loss. Post harvest application of calcium has been reported to be better than preharvest in enhanced shelf life in apple (Conway, *et al*., 2002) and lemon (Tsantili, *et al*., 2002) fruits. Though there have been reports of negatively affected fruit taste (Anjum, *et al*., 2004, Mahmud, *et al.*, 2015; Ngamchuachit, *et al*., 2014). The use of post-harvest immersion of fruits in calcium chloride is however limited among farmers.

Further, some authors have reported that calcium is available to the fruit at early stages of fruit development (Stino, *et al*., 2011) while others report effective use of calcium even after physiological maturity (Karemera, *et al*., 2014). This study therefore sought to ascertain the effect of calcium chloride applied by spraying or immersion at varied concentrations and times on shelf life indicators and the overall effect on fruits' organoleptic attributes.

5.2 Materials and methods

5.2.1 Experimental site description

This study was carried out at an orchard situated at Karurumo, Embu County in the eastern parts of Kenya in two fruiting seasons; July 2017 to April 2018 and July 2018 to April 2019. The rainfall pattern and soil characteristics are as described in section 3.2.1.

5.2.2 Experimental material, design and treatments

The study involved use of approximately 10 year old "Van Dyke" mango cultivar trees. Completely randomized block design was used to lay the treatments which were arranged in a split-plot manner having 3 trees per replica with 3 replications.The time of calcium chloride application formed the main plot while the rate of calcium chloride applied formed the sub plots. Cultural practices (e.g. pruning, pests and disease control) were carried out uniformly according to Griesbach, 2003. Uniformity in sampling was ensured on the basis of size and shape of fruits.

Fruits were sprayed with calcium chloride (0%, 0.5%, 1.0% and 1.5%) at maturity or 15 days later. Another set of mature fruits was immersed in calcium chloride (0%, 0.5%, 1.0% and 1.5%) for 10 minutes. The rate and timing of calcium application were determined according to various studies (Stino, *et al*., 2011; Karemera, *et al*., 2014). Control fruits were either sprayed with water or immersed in water. Maturity was determined by counting 120 days after full bloom (Griesbach, 2003). Fruits were transported in cartons lined with wet newspapers to the Jomo Kenyatta University of Agriculture and Technology Post-harvest Laboratory and stored for 8 days under ambient room conditions (25^0C $\pm 2^0$C and 70%±5% RH) for assessment.

5.3 Data collection

Data was collected on changes in peel firmness, total titratable acidity (TTA), total soluble solids (TSS), flesh color, beta carotene, selected organoleptic attributes, number of days the fruits took to ripen, respiration and ethylene evolution rates and percentage cumulative weight loss. Flesh calcium concentration, firmness and their relationship with organoleptic attributes were also determined at the end of the storage period.

Peel firmness

A penetrometer fitted with a 5mm probe was used to measure peel firmness changes during the storage period at a two days interval. The corresponding average force used to penetrate the fruit peel was recorded in Newton (N) (Jiang et al., 2001).

Titratable acidity

This was determined at an interval of 2 days as described in section 4.2.3.

Total soluble solids (TSS)

A hand refractometer (Model PAL-S, Atago, Tokyo, Japan) was used to determine the changes in fruit TSS and recorded in ^{0} Brix (Dong *et al*. (2001).

Flesh color

Flesh colour changes were determined at a 2 days interval during the 8 days storage period as described in section 4.2.3.

Beta carotene

This was determined using a modified paper chromatographic procedure as described by Heionen (1990) and the beta carotene content was determined using the following formula

$$\text{Beta carotene} = \frac{A \times \text{volume (ml)} \times 104}{A1\%1\text{cm} \times \text{sample weight (g)}}$$

Where:

A= Absorbance, Volume = Total volume of extract (25 ml)

A_1% 1cm = Absorption coefficient of β−carotene in Petroleum ether (2592).

Flesh calcium, firmness and organoleptic quality determination

After 8 days of storage in ambient conditions, 25 fruits were taken from each replica, sliced into equal sized slices; for flesh firmness determination using a penotrometer that was fitted with a 5mm probe. The readings were taken from 5 different spots and the average was recorded. Flesh calcium concentration was determined by drying the slices in a furnace and grinding them to fine powder which was then dissolved in hydrochloric acid and calcium was determined using atomic absorption spectrophotometer (Shimadzu-AA-670, Shimadzu, Kyoto, Japan).

Another sample of equal sized slices, taken from a representative of each treatment, placed on a white paper and anonymously coded for organoleptic attributes determination. A panel consisting of 100 people, (70 males and 30 females) was guided on how to score skin shriveling, taste/flavor, color of pulp and aroma using a 7- point hedonic scale (Jiang *et al*. 2001) where; 1=Dislike extremely, 2=Dislike very much, 3=Dislike moderately, 4=Neither like nor dislike, 5=Like moderately, 6=like very much and 7=like extremely.

Days taken to ripen

A sample of three fruits from each replica was labeled and monitored for ripening. The average days the fruits took to ripen was recorded.

Respiration and ethylene evolution rate

Three mangoes were randomly picked from each set of treatment at a 2 days interval and stored in airtight plastic containers of volume 1450 ml-4500 ml fitted with self-sealing rubber septum for 1 hour. Approximately 1 ml of headspace sample was withdrawn from the container using a syringe and injected into gas chromatograph (Models GC-8A, Shimadzu Corp., Kyoto, Japan). The GC column (120℃) was filled with porapak, carrier gas helium and fitted with a thermal conductivity detector. Respiration rate was calculated as below

$$Carbon\ dioxide\ production\ rate\ (\mathrm{mlkg-1hr-1}) = K \times \frac{1}{R} \times H \times (V - W) \times \frac{1}{TW}$$

Where:

K –calibration value, H-Peak height, R-volume of gas injected for sample, W –Weight of sample, V-Volume of incubation container (ml) and T- Incubation time.

Ethylene gas evolution from the plastic jars with three fruits was also injected into chromatograph (GC-9A, Shimadzu Corp., Kyoto, Japan) and the rate calculated using the formula above.

Percentage weight loss*:*

Three fruits were picked randomly at an interval of 2 days for percentage weight determination. Percentage weight loss of the 3 fruits was calculated on the basis of initial weight and the weight of the fruit on observation as shown below (Okoth *et al*., 2013).

$$\text{Percentage weight loss (\%)} = \left\{\frac{W1 - W2}{W1}\right\} \times 100$$

Where:

W_1-initial fruit weight

W_2-weight of fruit on observation day

5.4 Data analyses

Collected data was subjected to analysis of variance using Genstat, 14th edition. Differences among the treatments were compared using Fisher's Protected LSD test at $p \leq 0.05$ probability level (Payne *et al*., 2011). A Pearson's product–moment was run to assess the relationship among flesh calcium concentrations, firmness and organoleptic attributes using Stata software 12th edition.

5.5 Results

5.5.1 Effects of calcium chloride treatment on fruit respiration and ethylene evolution during the storage period

Fruit respiration increased as the storage period progressed up to a certain peak then followed a declining trend irrespective of the treatment (Fig 5.1). Fruits treated with calcium chloride by immersion and spraying at 120 days had their peak in day 4 while those that were treated 15 days after maturity had their peak at day 2 which was similar to the control fruits. Application of calcium chloride (1.5%) by spraying at 120 days had significantly the lowest respiration of 18.73 ml/kg/hr which rose to 30.7 ml/kg/hr in day 4 then declined to 15.0 ml/kg/hr at the end of the storage period.

The trend exhibited in carbondixide is similar to the ethylene evolution (Fig 5.2). All fruits sprayed with or immersed in calcium chloride at 120 days had their peak in day 6 while those spayed 15 days after had their peak in day 4 except those sprayed with calcium chloride at 1.5%. Control fruits had their peak in day 4 and registered the highest amount of ethylene throughout the storage period. Fruits sprayed with calcium chloride (1.5%) at maturity had the lowest amount of ethylene (1.5 ml/kg/hr) at peak while untreated fruits reported the highest (3.6 ml/kg/hr - 3.8 ml/kg/hr).

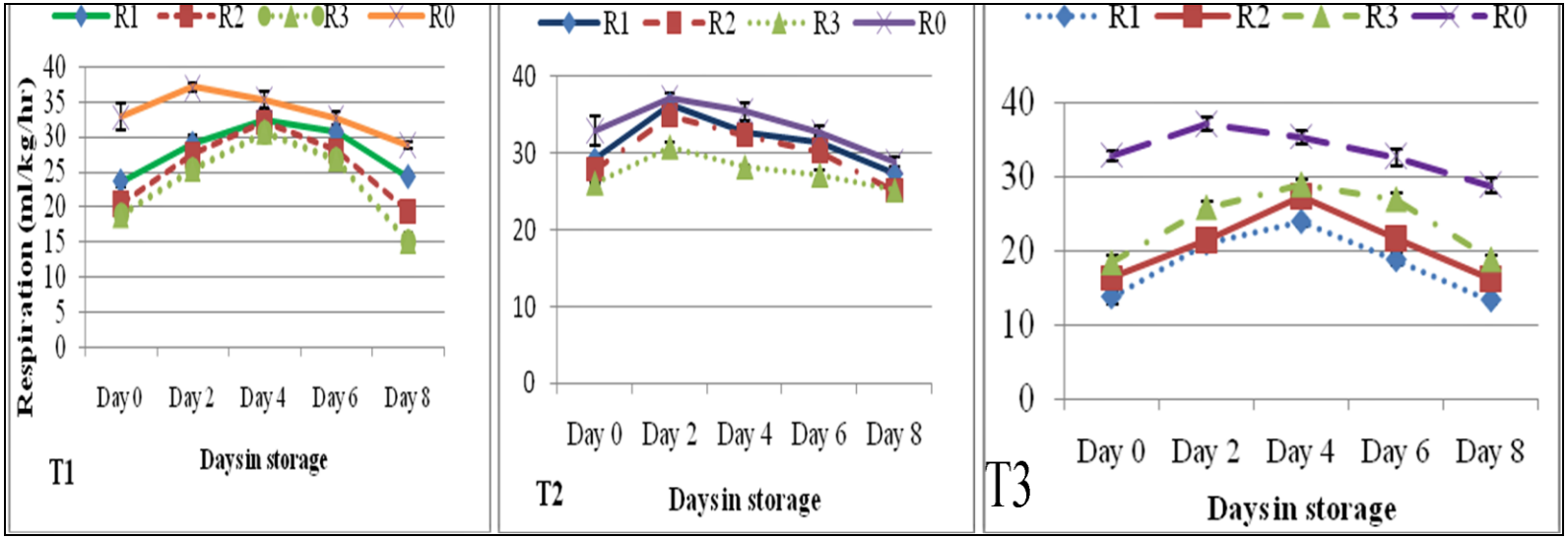

Figure 5:1 Effect of calcium chloride application at different times and rates on the respiration of mango fruits

Key: R_1- calcium chloride 0.5%; R_2- calcium chloride 1.0%; R_3- calcium chloride 1.5%. T_I-Application by spraying at maturity; T_2-Application by spraying at 15 days after maturity; T_3-Application by immersion at maturity

Bars represent standard errors of the means at $p \leq 0.05$

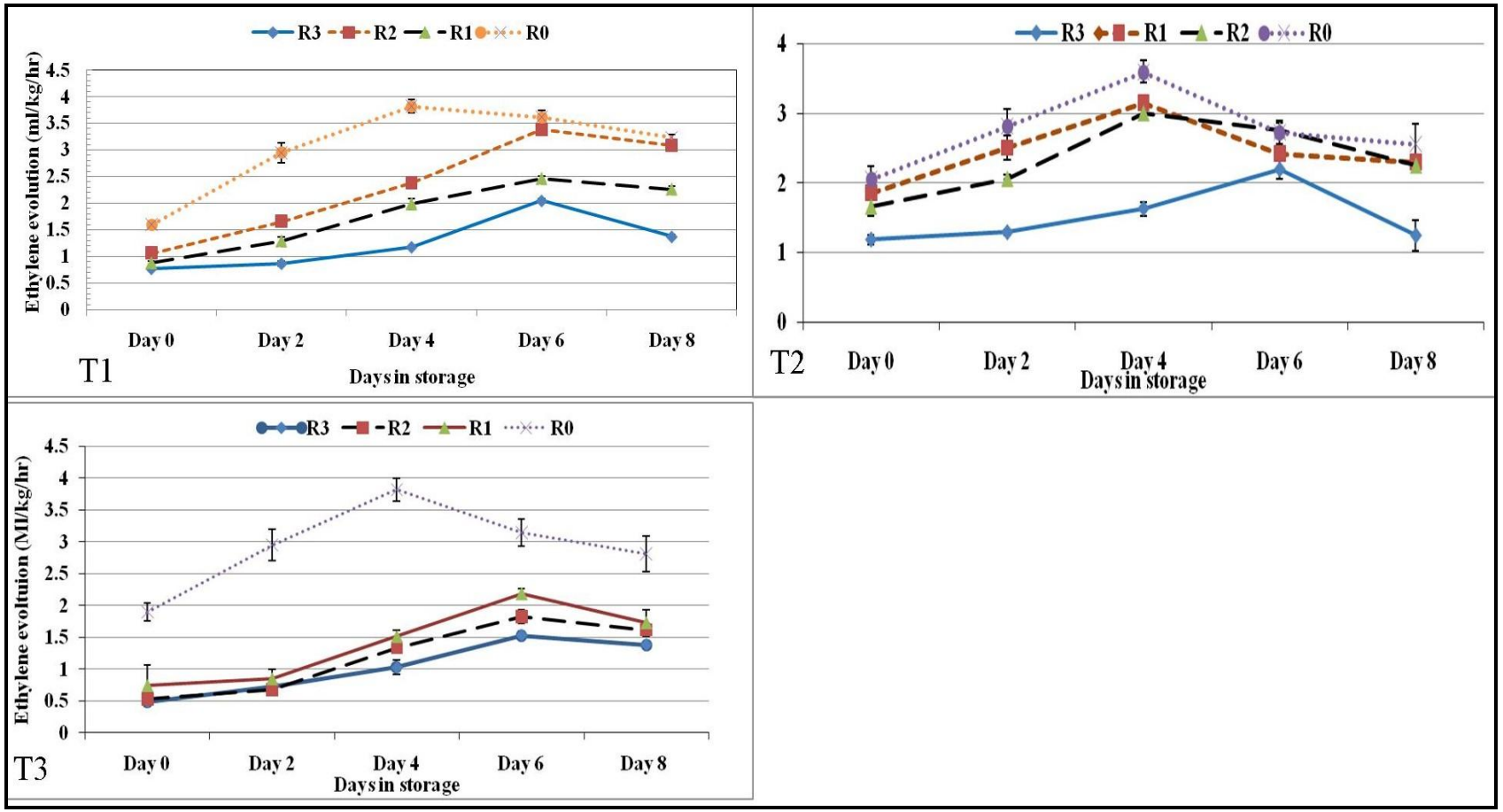

Figure 5:2 Effect of calcium chloride application at different times and rates on ethylene evolution of mango fruits

Key: R_1- calcium chloride 0.5%; R_2- calcium chloride 1.0%; R_3- calcium chloride 1.5%. T_I-Application by spraying at maturity; T_2-Application by spraying at 15 days after maturity; T_3-Application by immersion at maturity. Bars represent standard errors of the means at $p \leq 0.05$

Percentage cumulative weight loss

All the fruits exhibited an increased cumulative weight loss (%) with the advancement of the storage period irrespective of the treatment (Fig 5.3). Fruits treated with calcium chloride retained a higher percentage of their initial weight than control (un treated) fruits. Fruits immersed in calcium chloride at physiological maturity and ripened at ambient conditions lost less weight than those that were sprayed at maturity and 15 days later. In this study fruits treated with calcium chloride 1.5% by immersion registered a slower rate of fruit weight loss than all the other treatments.

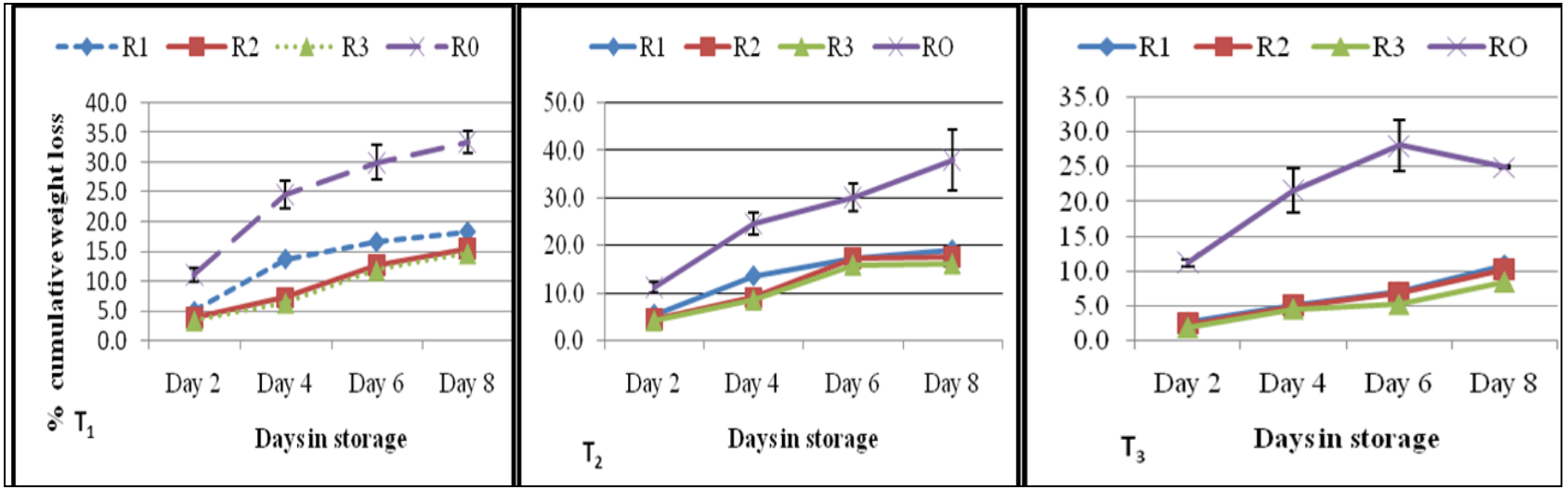

Figure 5:3 Effect of calcium chloride application at different times and rates percentage cumulative weight loss.

Key: R_1- calcium chloride 0.5%; R_2- calcium chloride 1.0%; R_3- calcium chloride 1.5%. T_I-Application by spraying at maturity; T_2-Application by spraying at 15 days after maturity; T_3-Application by immersion at maturity.Bars represent standard errors of the means at $p \leq 0.05$

5.5.2 Main and interactive effect of rate, time and mode of calcium chloride application on peel firmness, flesh colour, total soluble solids, total titratable acidity during the storage period

Peel firmness

The rate, time and mode of calcium chloride application significantly ($p \leq 0.05$) affected the fruit peel firmness during the storage period except day 8 where the peel firmness was not affected significantly by the rate of application in both seasons (Table 5.1). Calcium chloride treated fruits maintained high fruit peel firmness relative to control fruits throughout the storage period in both seasons. All the rates of calcium chloride application were not significantly different in respect to fruit peel firmness throughout the storage period in both seasons.

Fruits immersed in calcium chloride at maturity had significantly higher peel firmness than those sprayed with calcium chloride 15 days after maturity throughout the storage period in both seasons. Application of calcium chloride at maturity by immersion had significantly higher peel firmness than application of calcium chloride at maturity by spraying throughout the storage period in both seasons except days 1 and 2 in both seasons where the two were not significantly different. Fruits sprayed with calcium chloride at maturity and 15 days later did not have significantly different peel firmness throughout the storage period in both seasons except days 1 and 2 where fruits sprayed with calcium chloride at maturity had significantly higher fruit peel firmness than those sprayed 15 days later.

Table 5:1 Main effects of rate and mode of calcium chloride application on changes in peel firmness (N) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day4	Day 6	Day 8	Day 0	Day 2	Day4	Day 6	Day 8
Rate										
1.5%	11.87[a]	10.84[a]	9.28[a]	8.07[a]	6.07	11.48[a]	10.41[a]	9.34[a]	8.07[a]	5.78
1.0%	10.79[a]	9.58[a]	8.59[a]	7.27[a]	5.29	10.24[a]	9.20[a]	8.12[a]	7.12[a]	5.23
0.5%	9.57[a]	8.40[a]	7.09[a]	6.01[a]	4.52	8.97[a]	7.87[a]	6.87[a]	5.99[a]	4.56
CTRL	3.77[b]	3.37[b]	2.91[b]	2.53[b]	2.04	3.66[b]	3.24[b]	2.68[b]	2.37[b]	1.99
p-value	<.001	<.001	<.001	<.001	0.07	<.001	<.001	<.001	0.002	0.06
Lsd (p≤0.05)	2.68	2.80	2.85	2.85	Ns	2.51	2.64	2.78	2.85	Ns
Cv%	30.90	36.20	42.50	49.70	68.40	30.40	35.70	42.80	50.20	67.4
Mode/time										
M_3	11.34[a]	10.78[a]	9.92[a]	9.10[a]	7.80[a]	11.02[a]	10.17[a]	9.51[a]	8.97[a]	7.64[a]
M_2	6.07[b]	5.25[b]	4.28[b]	3.63[b]	2.58[b]	6.08[b]	5.13[b]	4.09[b]	3.40[b]	2.48[b]
M_1	9.58[a]	8.11[a]	6.71[b]	5.18[b]	3.07[b]	8.66[ab]	7.74[ab]	6.66[b]	5.29[b]	3.04[b]
p-value	0.004	0.002	<.001	<.001	<.001	0.006	0.003	<.001	<.001	<.001
Lsd (p≤0.05)	3.03	2.84	2.55	2.29	1.92	2.91	2.75	2.59	2.31	1.81
Cv%	40.50	42.40	44.00	46.00	51.30	40.70	43.00	46.10	47.10	49.50

M_1= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05; CV=Coefficient of variation.

Interaction among rate, mode and time of calcium chloride application significantly (p ≤0.05) affected the fruit peel firmness throughout the storage period in both seasons (Table 5.2). For fruits immersed in calcium chloride at maturity, those that were treated at a rate 1.5% had significantly higher peel firmness than those treated with a rate of 0.5% in all days of storage in both seasons except day 4 in both seasons in which the two rates were not significantly different. In most cases, fruits immersed in calcium chloride at 1.0% and 0.5% did not have significantly different peel firmness during the storage period. Additionally, there were no significant differences among fruits immersed in 1.5% and 1.0% calcium chloride throughout the storage period in both seasons.

Among fruits sprayed at maturity, those that were sprayed with calcium chloride (1.5%) had significantly higher peel firmness than those sprayed with calcium chloride (0.5%) throughout the

storage period in both seasons. Fruit sprayed with 1.0% had significantly higher peel firmness than those sprayed with a rate of 0.5% in all days except day 8 in both in which the two rates were not significantly different. Additionally, fruits sprayed at maturity with a rate of 1.5% had significantly higher peel firmness than those sprayed at a rate of 1.0% in all days of storage in both seasons except days 4 in season and day 8 in season 1 and 2.

Among fruits sprayed at 15 days after maturity those that were sprayed with calcium chloride (1.5%) had significantly higher peel firmness than those that were sprayed at 0.5% in all days in both seasons except day 8 of both seasons and day 2 in season 2. Additionally, fruits sprayed at maturity with the later rate did not have significantly different peel firmness with those sprayed at 1.0% in most cases. Fruits sprayed with calcium chloride (1.5%) and 1.0% did not have significantly different peel firmness in all days of storage in both seasons.

Among fruits treated with calcium chloride at 1.5%, those treated by immersion at maturity had significantly higher peel firmness than those at maturity by spraying which in turn had significantly higher peel firmness than those sprayed 15 days after maturity except days 0 and 8 in season 1.

Among fruits treated with calcium chloride at 1.0% and 0.5%, those treated by immersion had significantly higher peel firmness than those treated by spraying at maturity which in turn had significantly higher peel firmness than those sprayed 15 days after maturity in both season except day 8 of both seasons.

Table 5:2 Interactive effects of rate and mode of calcium chloride application on changes in peel firmness (N) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
Treatment	Day 0	Day 2	Day 4	Day 6	Day 8	Day 0	Day 2	day 4	Day 6	Day 8
$R_3 M_3$	14.3^{a}	13.8^{a}	12.6^{a}	11.8^{a}	10.6^{a}	14.1^{a}	13.2^{a}	12.2^{a}	11.5^{a}	10.3^{a}
$R_2 M_3$	13.9^{a}	13.2^{ab}	12.3^{a}	11.4^{ab}	10.0^{a}	13.4^{ab}	12.7^{a}	11.9^{a}	11.3^{a}	9.8^{a}
$R_3 M_1$	13.7^{ab}	12.1^{c}	9.4^{b}	7.7^{c}	4.4^{c}	12.9^{b}	11.8^{b}	10.2^{b}	8.1^{b}	4.1^{c}
$R_1 M_3$	13.1^{b}	12.7^{bc}	11.6^{a}	10.6^{b}	8.4^{b}	12.6^{b}	11.6^{b}	11.0^{ab}	10.4^{a}	8.4^{b}
$R_2 M_1$	11.6c	9.7^{d}	8.6^{b}	6.2^{d}	3.1^{cd}	10.2^{c}	9.3^{c}	8.1^{c}	6.3^{c}	3.2^{cd}
$R_1 M_1$	9.2^{d}	7.1^{e}	6.0^{c}	4.3^{e}	2.7^{d}	8.1^{d}	6.4^{d}	5.8^{d}	4.6^{d}	3.0^{de}
$R_3 M_2$	7.6^{e}	6.6^{ef}	5.8^{cd}	4.7^{e}	3.1^{cd}	7.4^{de}	6.3^{d}	5.6^{de}	4.5^{d}	2.9^{def}
$R_2 M_2$	6.9^{ef}	5.9^{fg}	4.9^{d}	4.2^{e}	2.8^{cd}	7.1^{e}	5.6^{d}	4.4^{ef}	3.7^{d}	2.7^{def}
$R_1 M_2$	6.4^{f}	5.5^{g}	3.7^{e}	3.1^{f}	2.4^{d}	6.2^{f}	5.6^{d}	3.8^{fg}	3.0^{e}	2.3^{def}
Ctrl M_3	4.1^{g}	3.5^{h}	3.1^{e}	2.6^{f}	2.1^{d}	4.0^{g}	3.1^{e}	2.9^{g}	2.6^{e}	2.1^{def}
Ctrl M_1	3.8^{g}	3.6^{h}	2.9^{e}	2.5^{f}	2.0^{d}	3.4^{g}	3.5^{e}	2.5^{g}	2.1^{e}	1.8^{f}
CtrlM_2	3.4^{g}	3.0^{h}	2.8^{e}	2.5^{f}	2.0^{d}	3.5^{g}	3.1^{e}	2.6^{g}	2.3^{e}	2.0^{ef}
p-value	<.00 1	<.001	<.001	<.001 1	<.00 1	<.001	<.00 1	<.00 1	<.00 1	<.00 1
Lsd $_{(p\leq0.05)}$	0.7	0.8	1.1	1.1	1.5	0.8	0.8	1.3	1.1	1.1
CV%	4.8	5.9	8.9	10.4	19.2	5.6	6.2	11.7	10.5	4.9

R_1=$CaCl_2$ (0.5%); R_2=$CaCl_2$ (1.0%); R_3=$CaCl_2$ (1.5%); Ctrl=Control; M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; CV -Coefficient of variation; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05.

Flesh color

The rate, time and mode of calcium application significantly (p ≤0.05) affected fruit flesh colour changes throughout the storage period in both seasons (Table 5.3). Treatment of fruits with calcium chloride maintained the fruit hue angle throughout the storage period. Fruits treated with calcium chloride at 1.5% had significantly higher hue angle than those treated with 0.5% calcium chloride throughout the storage period in both seasons except day 0 in both seasons. On the other hand, fruits treated with 1.0% and 1.5% did not have significantly different hue angle in all days of both seasons except in day 4 season 1 where fruits treated with the later rate had significantly higher hue angle than the former. Additionally, fruits treated with 0.5% and 1.0% did not have significantly different hue angle throughout the storage period in both seasons. Control fruits registered significantly the lowest hue angle throughout the storage period in both seasons.

Fruits treated with calcium chloride by immersion had significantly higher hue angle than those treated by spraying at maturity and 15 days later throughout in both seasons except in day 0 both seasons where fruits immersed and those sprayed at maturity did not have significantly different hue angle. There was no significant difference among fruits sprayed at maturity and 15 days later in flesh colour during the storage period in both seasons.

Table 5:3 Main effects of rate and mode of calcium chloride application on changes in flesh colour (Hue angle, H^o) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 0	Day 2	Day 4	Day 6	Day 8
Rate										
1.5%	42.17^{a}	39.27^{a}	35.98^{a}	33.69^{a}	30.37^{a}	40.79^{a}	37.61^{a}	34.88^{a}	32.34^{a}	30.09^{a}
1.0%	38.46^{a}	33.75^{ab}	30.10^{b}	28.36^{ab}	25.73^{ab}	36.59^{a}	33.86^{ab}	30.82^{ab}	28.44^{ab}	26.22^{ab}
0.5%	36.66^{a}	32.34^{b}	28.65^{b}	25.63^{b}	23.19^{b}	35.20^{a}	31.71^{b}	28.99^{b}	26.10^{b}	23.62^{b}
Control	23.85^{b}	21.67^{c}	19.59^{c}	18.24^{c}	17.47^{c}	23.00^{b}	21.01^{c}	19.10^{c}	17.97^{c}	17.05^{c}
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
LSD($p\leq0.05$)	6.44	6.18	5.61	5.46	5.60	5.65	5.19	4.97	5.02	4.94
Cv%	19.0	20.2	20.4	21.4	25.0	17.3	17.4	18.1	19.9	21.1
Time/mode										
M_3	41.50^{a}	38.05^{a}	34.18^{a}	31.66^{a}	29.63^{a}	39.49^{a}	36.33^{a}	33.63^{a}	31.28^{a}	29.39^{a}
M_2	29.74^{b}	26.34^{b}	23.97^{b}	21.94^{b}	20.14^{b}	29.01^{b}	26.74^{b}	24.36^{b}	22.25^{b}	20.63^{b}
M_1	34.62^{ab}	30.87^{b}	27.59^{b}	25.85^{b}	22.81^{b}	33.19^{ab}	30.07^{b}	27.36^{b}	25.10^{b}	22.72^{b}
p-value	0.01	0.003	0.01	0.01	0.003	0.01	0.01	0.01	0.01	0.003
Lsd($p\leq0.05$)	7.04	6.46	6.01	5.81	5.22	6.60	6.12	5.74	5.39	4.96
Cv%	24.0	24.2	25.3	26.4	25.9	23.4	23.7	24.2	24.7	24.5

M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD=Least significant difference at $p \leq 0.05$; Ctrl=Control. CV =Coefficient of variation; Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Interaction among rate, time and mode of calcium chloride application significantly ($p\leq0.05$) affected hue angle of the fruits throughout the storage period as the fruits changed from green to yellow in both seasons (Table 5.4). Fruits treated with 1.5% calcium chloride had significantly higher hue angle than those treated with 1.0% in both seasons irrespective of the time and mode except those treated 15 days after maturity by spraying in season 1. In most cases, fruits treated

with 0.5% and 1.0% did not have significantly different hue angle irrespective of the mode and time of treatment. Fruits treated with 0.5% calcium chloride at 15 days after maturity did not have significantly different hue angle with control fruits in days 6 and 8 in both seasons and day 4 in season 1.

Table 5:4 Interactive effects of rate and mode of calcium chloride application on changes in flesh color (Hue angle, H^o) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
Treatment	Day 0	Day 2	Day 4	Day 6	Day 8	Day 0	Day 2	day 4	Day 6	Day 8
R_3M_3	50.9^{a}	46.5^{a}	42.2^{a}	39.6^{a}	37.5^{a}	48.7^{a}	44.4a	41.1^{a}	38.1^{a}	36.8^{a}
R_2M_3	48.0^{a}	43.5^{ab}	38.4^{b}	36.9^{b}	35.5^{a}	44.5^{b}	41.2^{ab}	38.2^{b}	35.8^{ab}	33.2^{b}
R_1M_3	42.3^{b}	40.1^{b}	36.9^{b}	33.0^{c}	29.2^{b}	42.1^{bc}	38.7^{b}	36.0^{bc}	33.4^{b}	30.6^{b}
R_3M_2	33.5^{de}	31.2^{c}	28.7^{c}	25.8^{d}	22.81^{c}	32.8^{de}	30.4^{c}	28.5^{d}	25.7^{c}	23.4^{c}
R_2M_2	32.2^{de}	26.0^{d}	24.8^{de}	22.6^{ef}	19.9^{cde}	30.3^{ef}	28.9^{cd}	26.6^{d}	24.2^{c}	22.2^{cd}
R_1M_2	29.1^{ef}	25.9^{d}	22.3^{ef}	20.3^{g}	19.3^{def}	29.2f	26.3^{d}	23.3^{e}	20.9^{de}	19.6^{de}
R_3M_1	42.2^{b}	40.1^{b}	37.1^{b}	35.7^{b}	30.9b	41.0c	38.1^{b}	35.1^{c}	33.3^{b}	30.1^{b}
R_2M_1	38.6^{c}	31.7^{c}	27.1^{cd}	25.6^{d}	21.8^{cd}	35.1d	31.5c	27.6^{d}	25.3^{c}	23.3^{c}
R_1M_1	35.2^{cd}	31.1^{c}	26.8^{cd}	23.6^{de}	21.1^{cd}	34.3d	30.2c	27.7^{d}	24.1^{cd}	20.7^{cd}
R_0M_1	22.5^{g}	20.6^{e}	19.4^{f}	18.4^{gh}	17.5^{ef}	22.5g	20.5e	19.1^{f}	17.8^{e}	16.8^{e}
R_0M_2	24.2^{g}	22.20^{e}	20.13^{f}	19.10^{gh}	18.53^{def}	23.8g	21.4e	19.1^{f}	18.2^{e}	17.3^{e}
R_0M_3	24.8^{fg}	22.2^{e}	19.3^{f}	17.2^{h}	16.3^{f}	22.7g	21.1^{e}	19.2^{f}	17.9^{e}	17.0^{e}
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$Lsd_{(p\leq0.05)}$	4.80	3.51	3.31	2.68	3.2	3.33	3.27	2.79	3.31	3.24
Cv (%)	8.0	6.50	6.80	6.00	7.90	5.80	6.20	5.80	7.50	7.90

M_I= Spraying at 120 days; M_2= Spraying 135 days; M_3= Immersion at 120 days; R_1=$CaCl_2$ (0.5%); R_2=$CaCl_2$ (1.0%); R_3=$CaCl_2$ (1.5%); R_0=Control; CV =Coefficient of variation; LSD=Least significant difference at $p \leq 0.05$. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Total soluble solids

The rate, time and mode of calcium chloride application significantly ($p \leq 0.05$) affected the fruit total soluble solids throughout the storage period in both seasons except days 6 and 8 in season 1 and days 4 and 8 in season 2 where time/mode of application did not significantly affect the fruit's total soluble solids (Table 5.5). Control fruits exhibited significantly higher total soluble solids than other treatments till day 4 then they started declining to significantly lowest total soluble solids at the end of the storage period in both seasons. Fruits treated with 1.5% chloride

did not have significantly different total soluble solids from those treated with 1.0% calcium chloride throughout the storage period in both seasons. Similarly, those treated with the later rate did not have significantly different total soluble solids from those treated with 0.5% calcium chloride throughout the storage period in both seasons. There were no significant differences among fruits treated with calcium chloride by immersion at maturity and those treated with calcium chloride by spraying at maturity throughout the storage period in both seasons in total soluble solids. Fruits treated with calcium chloride by spraying at maturity and 15 days later did not have significantly different total soluble solids in most cases.

Table 5:5 Main effects of rate and mode of calcium chloride application on changes in fruit total soluble solids (^{0} Brix) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day4	Day 6	Day 8	Day 0	Day 2	Day4	Day 6	Day 8
Rate										
1.5%	8.84^{c}	9.4^{1c}	11.29^{c}	13.60^{a}	12.59^{a}	8.86^{b}	9.82^{b}	11.72^{c}	13.13^{b}	12.69^{a}
1.0%	9.71^{bc}	10.61^{bc}	12.32^{bc}	12.70^{ab}	11.76^{a}	9.27^{b}	10.43^{b}	12.47^{bc}	13.40^{ab}	12.12^{a}
0.5%	10.54^{b}	11.44^{b}	13.02^{b}	13.5^{a}	12.01^{a}	10.16^{b}	11.31^{b}	13.46^{b}	14.12	11.97^{a}
Control	12.46^{a}	13.50^{a}	16.74^{a}	11.73^{b}	8.77^{b}	12.54^{a}	13.69^{a}	17.34^{a}	11.73	8.51^{b}
p-value	<.001	<.001	<.001	0.002	<.001	<.001	<.001	<.001	<.001	<.001
Lsd (p≤0.05)	1.247	1.422	1.54	1.02	1.18	1.33	1.53	1.32	0.99	1.04
Cv%	12.50	13.10	12.00	8.20	10.90	13.60	14.00	10.00	7.80	9.50
Timing/mode										
M_3	9.44^{b}	10.07^{b}	11.77^{b}	12.67	11.83	9.18b	10.00^{b}	12.68	12.63^{b}	11.81
M_2	11.56^{a}	12.63^{a}	14.77^{a}	13.21	10.68	11.58a	12.73^{a}	15.09	14.01^{a}	11.03
M_1	10.17^{ab}	11.02^{b}	13.49^{ab}	12.77	11.33	9.86b	11.22^{ab}	13.48	12.65^{b}	11.13
P-value	0.03	<.001	<.001	0.565	0.358	0.006	0.005	0.065	0.01	0.598
Lsd (p≤0.05)	1.39	1.53	1.98	Ns	Ns	1.45	1.56	Ns	0.99	Ns
Cv%	16.10	16.40	17.8	10.10	17.20	17.10	16.50	18	9.1	17.9

M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; CV -Coefficient of variation; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05.

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The interaction between time/mode and rate of calcium application significantly (p≤0.05) affected accumulation of total soluble solids throughout the storage period in both seasons (Table 5.6). Among fruits sprayed at 15 days after maturity those that were treated with 1.5% calcium

chloride had significantly lower fruit TSS than those sprayed at 0.5% throughout the storage period in both seasons except days 2 and 8 in season 2 where they were not significantly different. There were no significant differences in TSS among fruits sprayed with calcium at 1.5% at 15 days after maturity and those sprayed at 1.0% 5 days after maturity in most cases in both seasons.

Fruits immersed in 1.5% calcium chloride at maturity had significantly higher TTS than those immersed in 1.0% calcium chloride which in turn did not have significantly different TSS from those immersed in 0.5% calcium chloride in day 6 in season 1 and 2 day 8 in season 1. There were no significant differences among fruits sprayed at 0.5% and 1.5% at maturity in all days except day 8 in season 1 and 6 in season 2.There were no signififcant differences among fruits treated by immersion at maturity in days 0, 2 and 4 in season 1 and days 2 and 6 in season 2.

Among fruits sprayed at maturity; those that were sprayed with 1.5% had significantly lower TSS than those sprayed with 0.5% from day 0 to day 4 in season 1 and 2 and day 6 in season 2. After day 4 of storage, fruits sprayed at 1.5% at maturity had significantly higher TSS than those sprayed at 1.0% and 0.5% in day 6 and 8 in season 1 and day 8 in season 2.

Among fruits treated with 1.5% calcium chloride, those that were sprayed at 15 days after maturity had significantly lower TSS than those sprayed at maturity which in turn did not have significantly different TSS from those immersed at maturity up to day 4 of storage in both seasons except day 4 of season 1. After day 4 of storage, fruits treated at 1.5% chloride by immersion and spraying at maturity had significantly higher TSS than those sprayed with 1.5% calcium chloride 15 days after maturity in day 6 and 8 of season 1 and day 8 season 2.

Among fruits treated with calcium chloride 1.0%; those that were sprayed 15 days after maturity had significantly higher TSS than those sprayed at maturity which were in turn not significantly different from those immersed at maturity in days 0 and 2 in both seasons and day 4 of season 2. Control fruits had significantly higher TSS than all treatments ecxept in a few cases upto day 4 in both seasons after which they started declining to sifnificantly than most treatments in day 8 in both seasons.

Table 5:6 Interactive effect of rate and mode of calcium chloride application on changes in total soluble solids (^{0} Brix**)** of of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
Treatments	Day0	Day 2	Day 4	Day 6	Day 8	Day 0	Day 2	Day 4	Day 6	Day 8
R_3 M_3	8.2^{e}	8.5f	9.6^{h}	14.7^{a}	14.0^{a}	7.7^{f}	8.6^{d}	10.5^{e}	13.2^{cde}	13.8^{a}
R_3 M_1	8.5^{e}	9.1^{ef}	11.3^{fg}	13.3^{abc}	13.3^{ab}	8.0^{ef}	9.2^{d}	11.2^{de}	12.4^{efg}	13.0^{ab}
R_2 M_3	8.4^{e}	9.0^{ef}	10. 3^{gh}	11.7de	12.8^{bc}	8.0^{ef}	8.9^{d}	11.3^{d}	13.1^{cdef}	12.7^{abc}
R_2 M_1	9.0^{de}	10.1^{cde}	12.6^{ef}	12.8^{bcd}	12.2^{cd}	8.6^{e}	9.8^{d}	11.9^{d}	14.6b	12.3^{bc}
R_1 M_3	9.0^{de}	9.6d^{ef}	10.9^{gh}	13.1^{bcd}	12.1^{cd}	8.5^{e}	9.5^{d}	11.9^{d}	13.1^{cdef}	12.0^{bc}
R_3 M_2	9.9^{cd}	10.6^{cd}	12.9^{de}	12.8^{bcd}	10.5^{e}	10.9^{cd}	11.7^{c}	13.5^{c}	13.8^{bc}	11.3^{c}
R_1 M_1	10.2^{c}	11.4^{bc}	13.2^{de}	12.9^{bcd}	11.7^{d}	10.1^{d}	11.5^{c}	13.2^{c}	13.5^{cd}	11.3^{c}
R_2 M_2	11.7^{b}	12.7^{ab}	14.1^{cd}	13.60^{ab}	10.2^{e}	11.2^{bc}	12.6^{bc}	14.1^{bc}	14.6b	11.4c
R_1 M_2	12.2^{ab}	13.3^{a}	15.0^{bc}	14.53^{a}	12.2^{cd}	11.9^{ab}	12.9^{abc}	15.2^{b}	15.8 a	12.6^{abc}
CtrlM_2	12.3^{ab}	13.8^{a}	17.1^{a}	11.87^{cde}	9.8^{e}	12.4^{a}	13.7^{ab}	17.5^{a}	11.9^{gh}	8.7^{d}
Ctrl M_3	12.4^{ab}	13.2^{a}	16.2^{ab}	11.23^{e}	8.4^{f}	12.6^{a}	13.0^{abc}	16.9^{a}	11.2^{h}	7.9^{d}
Ctrl M_1	12.9^{a}	13.4^{a}	16.9^{a}	12.10^{cde}	8.0^{f}	12.6^{a}	14.4^{a}	17.6^{a}	12.1^{fgh}	8.9^{d}
P-value	<.001	<.001	0.04	0.016	<.001	<.001	0.036	0.04	0.01	0.05
LSD($p\leq0.05$)	1.08	1.37	1.29	1.47	1.0	0.79	1.51	1.22	1.03	1.53
CV%	6.20	7.20	5.70	6.70	5.60	4.60	7.90	5.30	4.60	8.00

R_1=$CaCl_2$ (0.5%); R_2=$CaCl_2$ (1.0%); R_3=$CaCl_2$ (1.5%); Ctrl=Control; M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at $p \leq 0.05$; Ctrl=Control; CV -Coefficient of variation. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$.

Total titratable acidity

The rate and time of calcium chloride application significantly ($p\leq0.05$) affected fruit total titratable acidity throughout the storage period in both seasons except day 0 season 2 in which time did not affect the fruit total titratable acidity (Table 5.7). There were no significant differences among fruits treated with 1.5%, 1.0% and 0.5% in both seasons except day 0 in season 1 and days 0, 2 and 4 in season 2 in fruit titratable acidity. There were no significant differences in fruit titratable acidity among fruits treated with 0.5% calcium chloride and control fruits in most cases.

Fruits treated with calcium chloride by immersion at maturity had significantly higher TTA than those treated by spraying at maturity and 15 days after maturity throughout the storage period in both seasons except day 0 in season 1 and day 2 in season 2. There were no significant differences among fruits sprayed at maturity and those sprayed 15 days later throughout the storage period in both seasons.

Table 5:7 Main effects of rate and mode of calcium chloride application on changes in total titratable acidity (%) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day4	Day 6	Day 8	Day 0	Day 2	Day4	Day 6	Day 8
Rate										
1.5%	1.02^{a}	0.74^{a}	0.57^{a}	0.49^{a}	0.42^{a}	0.89^{a}	0.79^{a}	0.63^{a}	0.49^{a}	0.42^{a}
1.0%	0.84^{a}	0.59^{a}	0.47^{a}	0.43^{a}	0.36^{a}	0.76^{b}	0.65^{b}	0.50^{ab}	0.41^{a}	0.33^{a}
0.5%	0.63^{b}	0.50^{ab}	0.43^{ab}	0.37^{ab}	0.27^{ab}	0.59^{c}	0.51^{c}	0.44^{b}	0.35^{ab}	0.26^{ab}
Control	0.32^{c}	0.27^{b}	0.21^{b}	0.17^{b}	0.13^{b}	0.30^{d}	0.22^{d}	0.21^{c}	0.17^{b}	0.12^{b}
p-value	<.001	0.01	0.02	0.03	0.003	<.001	<.001	<.001	<.001	0.00
LSD	0.20	0.26	0.23	0.21	0.16	0.12	0.14	0.18	0.21	0.16
Cv%	29.8	50.8	55.5	60.1	54.5	20.3	27.1	42.4	60.5	60.3
Time/mode										
M_3	0.88^{a}	0.78^{a}	0.68^{a}	0.60^{a}	0.46^{a}	0.76	0.68^{a}	0.64^{a}	0.59^{a}	0.46^{a}
M_2	0.53^{b}	0.32^{b}	0.28^{b}	0.23^{b}	0.19^{b}	0.53	0.43^{b}	0.38^{b}	0.22^{b}	0.17b
M_1	0.70^{ab}	0.46^{b}	0.31^{b}	0.27^{b}	0.23^{b}	0.62	0.51^{ab}	0.31^{b}	0.26^{b}	0.21^{b}
p-value	0.03	<.001	<.001	<.001	<.001	0.09	0.05	<.001	<.001	<.001
LSD(p≤0.05)	0.26	0.20	0.16	0.15	0.13	Ns	0.20	0.16	0.14	0.13
Cv%	44.4	46.6	44.9	48.1	52.3	39.5	45.4	43.4	47.9	53.3

M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; CV=Coefficient of variation; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05.

The interaction between rate and time/mode of calcium chloride application significantly (p≤0.05) affected the fruit titratable acidity throughtout the storage period in both seasons (Table 5.8). Among fruits treated by immersion at maturity,those immersed in 1.5% calcium chloride had significantly higher TTA than those immersed in 0.5% throughout the storage period in both seasons. Fruits immersed in 1.5% had significantly higher TTA than those immersed in 1.0% in

all days except days 1 and 2 in season 1 and day 4 in season 2 only. Additionally,fruits immersed in 1.0% calcium chloride had significantly higher TTA than fruits immersed in 0.5% calcium chloride immersed ones in some cases and not significantly different in other cases.

For fruits sprayed at maturity,those treated ith 1.5% calcium chloride had significantly higher TTA than those treated with 0.5 % calcium chloride in all days except days 6 and 8 season 1. Those treated with 1.5% on the other hand had significantly higher TTA in all days except day 6 in both seasons and day 8 in season 1. No significant differences in fruit TTA were noted among fruits sprayed with 1.0% and 1.5% in most cases. There were no significant differences among fruits sprayed with calcium chloride 15 days after maturity in most days during the storage period.

For fruits treated with 1.5% calcium chloride, those treated by immersion at maturity had significantly higher TTA than those treated at maturity which in turn had significantly higher TTA than those sprayed 15 days later in all days ecxept day 8 in season 1. Among fruits treated with 1.0% calcium chloride,those immersed in calcium chloride at maturity had significantly higher TTA than those sprayed at maturity which in turn did not have significantly different TTA with those sprayed 15 days later in most cases.

Among fruits treated with 0.5% calcium chloride, those immersed in calcium chloride at maturity had signifcantly higher TTA than those sprayed at maturity which in turn were not significantly diifernt from those treated 15 days after maturity except days 0 and 2 of season 2.

Most of the fruits treated with calcium chloride by spraying at 15 days ater maturity did not have significantly different TTA with the unsprayed days in both seasons.

Table 5:8 Interactive effect of rate and mode of calcium chloride application on changes in total titratable acidity (%) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season I					Season 2				
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 0	Day2	Day 4	Day 6	Day 8
M_3R_3	1.21^{a}	1.05^{a}	0.92^{a}	0.85^{a}	0.70^{a}	0.98^{a}	0.89^{a}	0.86^{a}	0.85^{a}	0.72^{a}
M_3R_2	1.07^{ab}	0.98^{ab}	0.79^{b}	0.76^{b}	0.61^{b}	0.92^{ab}	0.83^{ab}	0.78^{ab}	0.72^{b}	0.58^{b}
M_3R_1	0.92^{bc}	0.82^{bc}	0.77^{b}	0.62^{c}	0.38^{c}	0.82^{c}	0.78^{b}	0.72^{b}	0.60^{c}	0.44^{c}
M_1R_3	1.06^{ab}	0.74^{c}	0.45^{c}	0.36^{d}	0.32^{cd}	0.91^{b}	0.82^{b}	0.45^{d}	0.36^{d}	0.31^{d}
M_1R_2	0.83^{c}	0.49^{d}	0.34^{d}	0.29^{de}	0.26^{de}	0.74^{d}	0.60^{c}	0.34^{ef}	0.29^{de}	0.23^{e}
M_1R_1	0.56^{ef}	0.37^{de}	0.29^{de}	0.28^{def}	0.24^{def}	0.54^{f}	0.42^{e}	0.29^{efg}	0.25^{ef}	0.20^{ef}
M_2R_3	0.78^{cd}	0.42^{de}	0.34^{d}	0.27^{ef}	0.24^{def}	0.79^{cd}	0.66^{c}	0.59^{c}	0.25^{ef}	0.22^{ef}
M_2R_2	0.62^{de}	0.30^{e}	0.29^{de}	0.23^{efg}	0.21^{efg}	0.62^{e}	0.51^{d}	0.38^{de}	0.23^{ef}	0.19^{efg}
M_2R_1	0.41^{fg}	0.30^{de}	0.24^{def}	0.22^{efgh}	0.18^{fgh}	0.40^{g}	0.32^{f}	0.30^{efg}	0.20^{fg}	0.16^{fgh}
Ctrl	0.32^{g}	0.25^{e}	0.17^{f}	0.14^{h}	0.10^{h}	0.31^{h}	0.21^{g}	0.17^{h}	0.14^{g}	0.10^{h}
Ctrl	0.33^{g}	0.27^{e}	0.26^{def}	0.20^{fgh}	0.15^{gh}	0.28^{h}	0.22^{g}	0.26^{fgh}	0.19^{fg}	0.13^{gh}
Ctrl	0.32^{g}	0.27^{e}	0.21^{ef}	0.17^{gh}	0.13^{h}	0.31^{h}	0.22^{g}	0.21^{gh}	0.18^{fg}	0.12^{h}
P-value	0.10	0.10	0.05	0.04	0.04	0.03	0.04	0.05	0.04	0.03
$Lsd_{(P\leq0.05}$	0.20	0.20	0.10	0.09	0.08	0.07	0.07	0.10	0.08	0.06
Cv%	16.8	22.2	14.50	14.30	15.80	6.30	7.70	13.30	14.1	13.6

R_1=$CaCl_2$ (0.5%); R_2=$CaCl_2$ (1.0%); R_3=$CaCl_2$ (1.5%); Ctrl=Control; M_1= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; CV -Coefficient of variation; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05.

Beta carotene

The fruits' beta carotene was significantly (P≤0.05) affected by the rate and time/mode of calcium chloride application throughout the storage period in both seasons (Table 5.9). Fruits treated with 1.5% calcium chloride had significantly higher beta carotene than those treated with 0.5% calcium chloride throughout the storage period in both seasons. There were no significant differences among fruits treated with 1.0% and 0.5% throughout the storage in both seasons. Fruits immersed in calcium chloride at maturity had significantly higher beta carotene than those sprayed with calcium chloride 15 days after maturity throughout the storage period in both seasons. There were no significant differences among fruits sprayed at maturity and those treated 15 days after maturity throughout the storage period in both seasons. Fruits immersed in calcium chloride had significantly higher beta carotene than those sprayed with calcium chloride at maturity in most cases.

Table 5:9 Main effects of rate and mode of calcium chloride application on changes in beta carotene (mg/100ml) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day4	Day 6	Day 8	Day 0	Day 2	Day4	Day 6	Day 8
Rate										
R_3	0.33^{a}	0.40^{a}	0.48^{a}	0.56^{a}	0.67^{a}	0.30^{a}	0.38^{a}	0.46^{a}	0.55^{a}	0.65^{a}
R_2	0.27^{ab}	0.33^{ab}	0.39^{ab}	0.45^{b}	0.53^{ab}	0.24^{ab}	0.31^{b}	0.37^{b}	0.43^{b}	0.52^{b}
R_1	0.22^{b}	0.27^{b}	0.33^{b}	0.39^{b}	0.46^{b}	0.19^{b}	0.25^{b}	0.32^{b}	0.37^{b}	0.45^{b}
Ctrl	0.11^{c}	0.17^{c}	0.22^{c}	0.25^{c}	0.28^{c}	0.11^{c}	0.17^{c}	0.22^{c}	0.26^{c}	0.30^{c}
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$LSD_{(P\leq0.05)}$	0.09	0.09	0.10	0.11	0.14	0.07	0.07	0.09	0.11	0.13
Cv%	39.5	31.8	28.7	28	29.8	32.2	27.1	26.6	27.5	27.3
Time/mode										
M_3	0.32^{a}	0.38^{a}	0.46^{a}	0.52^{a}	0.61^{a}	0.28^{a}	0.34^{a}	0.43^{a}	0.49^{a}	0.59^{a}
M_2	0.16^{b}	0.28^{b}	0.29^{b}	0.33^{b}	0.37^{b}	0.16^{b}	0.23^{b}	0.28^{b}	0.33^{b}	0.37^{b}
M_1	0.22^{b}	0.22^{b}	0.32^{b}	0.39^{b}	0.48^{ab}	0.19^{b}	0.27^{ab}	0.32^{b}	0.38^{ab}	0.48^{ab}
p-value	0.002	0.003	0.003	0.01	0.01	0.00	0.02	0.01	0.02	0.01
$LSD_{(P\leq0.05)}$	0.09	0.09	0.10	0.12	0.15	0.07	0.08	0.09	0.11	0.14
Cv%	43.8	36.50	33.50	34.3	36	39.7	35.5	32.1	34.2	34.2

M_1= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at p ≤0.05; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at p ≤0.05. CV -Coefficient of variation.

The fruits beta carotene was significantly (P≤0.05) affected by the interaction between rate and time/mode of calcium chloride application throughout the storage period in both seasons (Table 5.10).

Among fruits treated by immersion in calcium chloride at maturity, those that were immersed in 1.5% calcium chloride had significantly higher beta carotene than the rest of the rates in all days of storage except day 0 in season 2 where 1.0% and 1.5% were not significantly different. Fruits immersed in 1.0% calcium chloride had significantly higher beta carotene than those immersed in 0.5% in most cases in both seasons.

For fruits treated by spraying at 15 days after maturity, there were no significant differences in respect to beta carotene among fruits sprayed with 0.5% and 1.0%. Fruits sprayed with 1.5% calcium chloride 15 days after maturity had significantly higher beta carotene than those sprayed

with 0.5% in all days except days 0 and 6 in season 2 and those sprayed with 1.0% in most cases. Fruits sprayed with 0.5% 15 days after fruit set did not differ significantly from control fruits in both seasons.

Among fruits sprayed at maturity, those sprayed with 1.5% had significantly higher beta carotene than those sprayed with 0.5% calcium chloride in both seasons which were in turn not significantly different from those sprayed with 1.0% in both seasons except day 8 season 2. Among fruits treated with 1.5% and 1.0%, those immersed in calcium chloride had significantly higher beta carotene than those than were sprayed at maturity which in turn had significantly higher beta carotene than those sprayed 15 days after maturity in most cases.

Among fruits sprayed treated with 0.5%, those that were immersion in calcium chloride had significantly higher beta carotene than those that were sprayed at maturity in all days except day 8 in season 1. Fruits sprayed at maturity did not have significantly different beta carotene from those sprayed 15 days after maturity in all days except day 8 in season 1 in which those sprayed at maturity had higher beta carotene than those treated 15 days later.

Table 5:10 Interactive effects of rate and mode of calcium chloride application on changes in beta carotene (mg/100ml) of 'Van Dyke' mango fruits stored in ambient conditions during seasons 2017 and 2018

	Season 1					Season 2				
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 0	Day 2	day 4	Day 6	Day 8
M_3R_3	0.42^{a}	0.49^{a}	0.60^{a}	0.72^{a}	0.87^{a}	0.45^{a}	0.54^{a}	0.66^{a}	0.76^{a}	0.94^{a}
M_3R_2	0.32^{b}	0.40^{b}	0.48^{b}	0.57^{b}	0.68^{b}	0.39^{ab}	0.44^{b}	0.52^{b}	0.59^{b}	0.66^{b}
M_3R_1	0.26^{c}	0.32^{c}	0.43^{b}	0.45^{cd}	0.52^{c}	0.33^{bc}	0.38^{b}	0.42^{c}	0.49^{cd}	0.57^{c}
M_2R_3	0.22^{cd}	0.31^{cd}	0.36^{cd}	0.41^{de}	0.48^{c}	0.22^{de}	0.28^{c}	0.35^{d}	0.40^{def}	0.45^{d}
M_2R_2	0.18^{de}	0.21^{ef}	0.28^{ef}	0.31^{fgh}	0.36^{d}	0.18^{defg}	0.25^{cd}	0.30^{de}	0.33^{efg}	0.37^{e}
M_2R_1	0.14^{ef}	0.20^{ef}	0.24^{fg}	0.30^{fgh}	0.34^{de}	0.14^{efgh}	0.19^{de}	0.27^{ef}	0.32^{fgh}	0.35^{ef}
M_1R_3	0.26^{c}	0.35^{bc}	0.42^{bc}	0.51^{bc}	0.61^{b}	0.32^{bc}	0.38^{b}	0.43^{c}	0.53^{bc}	0.61^{bc}
M_1R_2	0.22^{cd}	0.31^{cd}	0.34^{de}	0.39^{def}	0.51^{c}	0.25^{cd}	0.30^{c}	0.34^{d}	0.42^{de}	0.56^{c}
M_1R_1	0.18^{de}	0.24^{de}	0.30^{def}	0.36^{efg}	0.48^{c}	0.20^{def}	0.25^{cd}	0.29^{de}	0.38^{ef}	0.46^{d}
Ctrl	0.10^{f}	0.18^{ef}	0.22^{g}	0.27^{gh}	0.31^{de}	0.10^{gh}	0.18^{de}	0.22^{f}	0.24^{h}	0.28^{g}
Ctrl	0.11^{f}	0.18^{ef}	0.24^{fg}	0.30^{fgh}	0.31^{de}	0.10^{gh}	0.17^{e}	0.23^{f}	0.26^{gh}	0.30^{fg}
Ctrl	0.12^{f}	0.16^{f}	0.20^{g}	0.22^{h}	0.27^{e}	0.13^{fgh}	0.16^{e}	0.22^{f}	0.25^{gh}	0.28^{g}
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
$Lsd_{(P\leq0.05)}$	0.04	0.07	0.07	0.09	0.09	0.08	0.07	0.06	0.09	0.07
Cv%	12.62	15	11.80	13.40	10.7	20.60	14.1	10.3	13.5	8.4

R_1-$CaCl_2$ (0.5%); R_2- $CaCl_2$ (1.0%); R_3-$CaCl_2$ (1.5%); M_I= Spraying at maturity; M_2= Spraying at 15 days after maturity; M_3= Immersion at maturity; LSD-Least significant difference at $p \leq 0.05$; Ctrl=Control. Treatments with different letters within a column are statistically different according to LSD at $p \leq 0.05$. CV -Coefficient of variation.

Sensory quality of fruits

The sensory evaluation results are as shown in Fig. 5.4. Fruits immersed in calcium chloride at maturity had significantly ($p \leq 0.05$) the highest pulp colour scores followed by those that were sprayed at maturity (120 days after fruit set). Control fruits and those that were sprayed 15 days after maturity (135 days after fruit set) had the lowest pulp colour scores. On the contrary, control fruits had the highest pulp taste and flavour scores compared to calcium treated ones. Higher concentrations of calcium chloride affected the flavour of fruits negatively than lower concentrations. Additionally, fruits that were immersed in calcium chloride had inferior flavour/taste scores compared to those that were spayed with calcium chloride.

Fruits that were sprayed 15 days after maturity and control ones did not show shriveled skin surfaces. On the other hand, fruits that were treated by immersion in calcium chloride had a more

shriveled skin surface than those treated by spraying. The rate of shriveling of the fruit skin surface increased as the calcium chloride concentration increased from 0.5% to 1.5%.

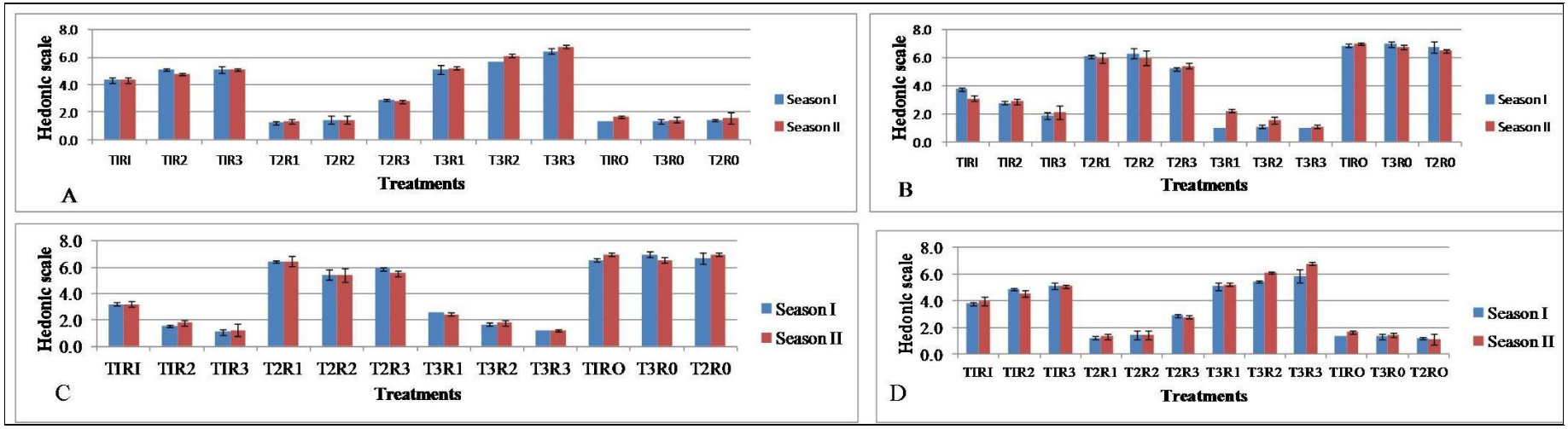

Figure 5:4 Effect of calcium chloride on the organoleptic acceptability of mango fruits

A-Pulp color; B-Pulp flavor/taste; C-Shriveling; D-Aroma ;T_1R_1-Calcium chloride (0.5%) sprayed at maturity; T_IR_2-Calcium chloride (1.0%) sprayed at maturity; T_IR_3-Calcium chloride (1.5%) sprayed at maturity; T_2R_1-Calcium chloride (0.5%) sprayed 15 days after maturity; T_2R_2-Calcium chloride (1.0%) sprayed 15 days after maturity; T_2R_3-Calcium chloride (1.5%) sprayed 15 days after maturity; T_3R_1-Calcium chloride (0.5%) immersion at maturity; T_3R_2- Calcium chloride (1.0%) immersion at maturity, T_3R_3- Calcium chloride (1.5%) immersion at maturity; T_IR_O-Sprayed with water at maturity; T_2R_0-Sprayed with water 15 days after maturity;T_3R_0-Immersed in water at maturity**.** Bars represent standard errors of the means at $p \leq 0.05$.

Number of days taken for ripening of fruits

The ripening rate of the mango fruits was significantly affected ($p \leq 0.05$) by the application of calcium chloride as shown in Fig 5.5. Spraying of fruits with calcium chloride (1.5%) at maturity, significantly delayed ripening (32 days, 24 days) and was almost at par with fruits immersed in calcium chloride (1.5%) (31 days, 27 days) at maturity. Control fruits ripened earlier at between 12 to 16 days and closely followed by fruits sprayed at 15 days after maturity.

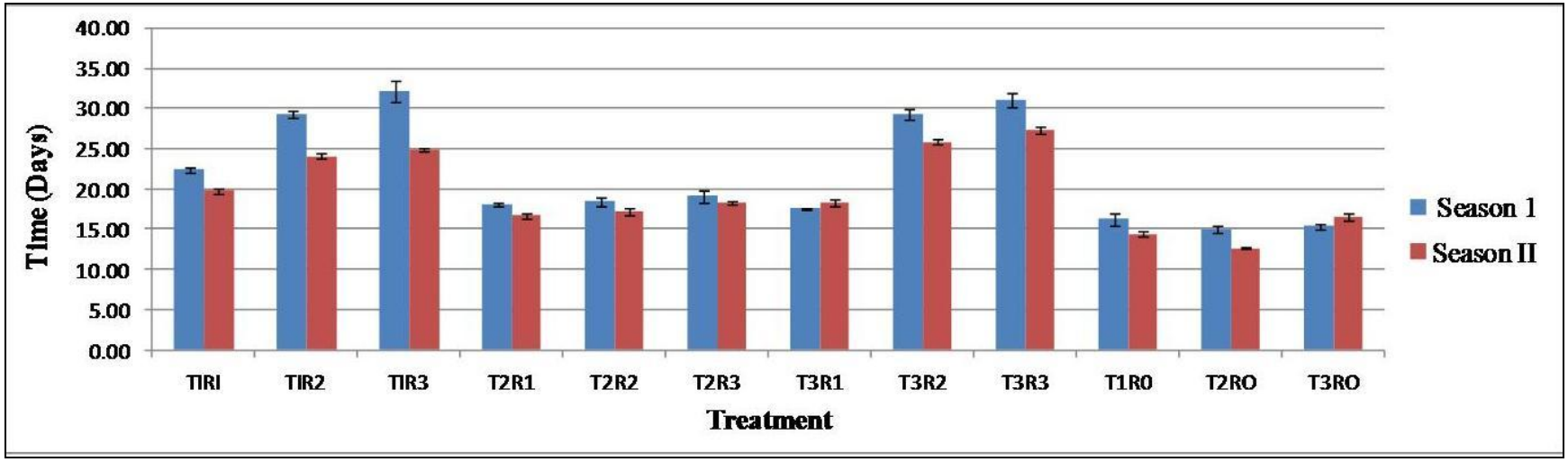

Figure 5:5 Effect of calcium chloride on the ripening period of mango fruits.

Bars represent standard errors of the means at $p \leq 0.05$. T_1R_1-Calcium chloride (0.5%) sprayed at 120 days; T_IR_2-Calcium chloride (1.0%) sprayed at 120 days; T_IR_3-Calcium chloride (1.5%) sprayed at 120 days; T_2R_1-Calcium chloride (0.5%) sprayed at 135 days after maturity; T_2R_2-Calcium chloride (1.0%) sprayed at 135 days; T_2R_3-Calcium chloride (1.5%) sprayed at 135 days; T_3R_1-Calcium chloride (1.0%) immersion 120 days; T_3R_2- Calcium chloride (1.5%) immersion, 120 days; T_IR_O-Sprayed with water at 120 days; T_2R_0-Sprayed with water at 15 days after maturity: T_3R_0-Immersed in water at 120 days. Bars represent standard errors of the means at $p \leq 0.05$.

Relationship between sensory quality of fruits and flesh calcium concentration

Flesh calcium content was positively correlated with flesh firmness, peel color, skin shriveling and aroma but negatively correlated with fruit flavor in both seasons (Table 5.11). Flesh firmness was positively correlated with peel color, skin shriveling and aroma but negatively correlated with flavor in both seasons. Skin shriveling on the other hand negatively correlated with peel color and aroma but positively correlated with flavor in both seasons. Peel color positively correlated with aroma but negatively with flavor in both seasons while aroma positively correlated with flavor in both seasons.

Table 5:11 Correlation among firmness, flesh calcium content and organoleptic attributes

	Season 1					Season 2				
	FC	FF	SS	PC	A	FC	FF	SS	PC	A
FC	1					1				
FF	0.9127*	1				0.852*	1			
SS	0.778	0.868	1			0.806	0.788	1		
PC	0.8282*	0.9115*	-0.944	1		0.841*	0.856*	-0.931	1	
A	0.8199*	0.9068*	-0.944	0.9792*	1	0.841*	0.848*	-0.938	0.977*	1
F	-0.811	-0.8869	0.9335*	-0.962	-0.959	-0.829	-0.821	0.947*	-0.95	-0.95

FC= Flesh calcium; FF=Flesh firmness; PC=Peel color; A=Aroma SS= Skin shriveling; F=Flavour

5.6 Discussion

All the fruits exhibited a decrease in peel firmness during the storage period. Calcium treated fruits maintained a higher peel firmness throughout the study period than control fruits. Fruits immersed in calcium chloride maintained higher peel firmness than sprayed ones probably because those immersed accumulated more calcium in their cells than those that were sprayed. The calcium accumulated in the cell walls may have facilitated the cross linking of pectic substances that increased cell cohesion and strength hence the high firmness as previously reported in tomatoes (Arthur, *et al*., 2015). Calcium can easily penetrate through the fruit cuticle cracks and epidermis (Conway, *et al*., 1992). The contact time when spraying may have affected the penetration of calcium negatively as compared to immersion which may have allowed more calcium in. Fruits sprayed with calcium chloride at maturity had significantly higher peel firmness than those that were sprayed 15 days later because calcium

is more available during early stages of fruit development (Karemera, *et al*., 2014, Penter, et al., 2000). As the concentration of calcium chloride increased from 0.5% to 1.5% peel firmness increased irrespective of the mode and timing of application (Mahajan, *et al*., 2011, Ngamchuachit, *et al*., 2014). Calcium binds, strengthens the cell wall and maintains cohesion between cells maintaining the membrane structure and integrity (Kazemi, *et al*., 2011, White *et al*., 2003). Calcium also inhibits the expression of enzymes and genes related to cell wall degradation (Gao, *et al*, 2020) thus delaying the softening process. Calcium treated fruits have been observed to maintain higher water insoluble protopectin and lower soluble pectin content (Lv, *et al*., 2020) hence, the high firmness. Calcium reduces the rate of fruit weight loss evolution of ethylene reducing the rate of softening of the fruit that arises from the ripening process (Zhang, *et al*., 2019; Hussain, *et al*., 2012). Fruit firmness decreased during the storage period due to ripening and senescence of fruits that leads to weakened fruit lamellae (Bagheri, *et al*., 2015).

As fruits ripen there is an accumulation of soluble solids. Starch hydrolysis into simple sugars led to an increase in total soluble solids during the storage period of fruits were stored in ambient conditions till a point of no more hydrolysis when the TSS levels start declining. TSS levels in calcium treated fruits started declining late in the storage period compared to control fruits that experienced the decline at day 4 of storage. This indicates that calcium treated fruits could be stored longer than those those that were not sprayed with calcium as they had accumulated TSS to maximum (Kazemi, *et al*., 2011). Calcium delays metabolic activities hence the gradual accumulation of soluble solids in calcium treated fruits. Highest TSS was registered in fruits immersed in calcium chloride probably because calcium chloride formed a coating on the fruits which delayed fruit senescence and other metabolic activities. This has been reported previously in mango (Karemera, *et al.*, 2014; Poojapant, *et al.*, 2014) and guava (Mahajan, *et al*., 2011) fruits. Spraying of calcium chloride at maturity was better in slowing soluble solids accumulation than 15 days later because calcium is more available during early stages of fruit development (Karemera, *et al*., 2014, Penter *et al*., 2000).

The delay of the ripening process in calcium treated fruits led to higher levels of TTA than control fruits. The decrease in titratable acidity during ripening is attributed to an increase in amylase enyme and pyruvate decarboxylation reaction (Dhillon, *et al*., 2013; Singh, *et al*., 2017). The decline in TTA during the storage period has been reported by Karemera, *et al*.,

(2014), Ngamchuachit, *et al*. (2014) and Islam, *et al*. (2013). Calcium chloride has been reported to be an ethylene synthesis inhibitor (Zhang, *et al*., 2019). Ethylene plays a role in ripening of mango fruits. The ripening process involves a number of processes like breakdown of acids and starch to sugars hence higher acidity in calcium chloride treated fruits.

Color development during ripening involves chlorophyll degradation and synthesis of anthocyanins and carotenoids among other pigments. Calcium could have retarded chlorophyll degradation and synthesis of the pigments. Fruits treated by immersion had probably more calcium penetration/uptake followed by those sprayed at maturity and 15 days later respectively hence the maintained color. The slow color changes exhibited by calcium treated fruits could be due to the suppressing effect of calcium on ethylene evolution (Ishaq, *et al*., 2009) which retarded ripening and changes in color. Untreated fruits and those that were sprayed 15 days after physiological development had less or no chlorophyll degradation and anthocyanins synthesis representing full ripening. Similar results have been reported in mango (Mounika, *et al*., 2017) and papaya (Eryani, *et al*., 2009) in which infiltration of fruits by calcium chloride delayed color development. Additionally, post-harvest application of calcium chloride delayed ripening of sapodilla (Poonsawat, *et al*., 2007), tomatoes and African eggplant (Chepngeno *et al*., 2016).

The increase in beta carotene content during the storage period could be attributed to the breakdown of chlorophyll and increase in carotenoids content by chlorophyllase enzyme during storage (Maina, *et al*., 2019). Calcium reduces the degradation of chlorophyll hence a gradual increase in beta carotenes on calcium treated fruits and more in fruits immersed in calcium than other treatments. Similar findings on beta carotene increase with storage have been reported in mango (Maina, *et al*., 2019), tomato (Chepngeno *et al*., 2016) and passion (Yumbya, *et al*., 2014) fruits. Higher beta carotene in calcium treated fruits have been reported by Jakhar, *et al*. (2016).

Fruits immersed in calcium chloride may have shriveled more than those sprayed because the more calcium salts in the solution may have caused dehydration of the skin hence shriveling which may be as a result of osmotic effects (Saftner, *et al*., 1998). Similar results on fruit skin shriveling due to application of calcium have been reported previously (Anjum, *et al*., 2004,

Mahmud, *et al*., 2015, Yuen, *et al*., 1993). Immersion of fruits in calcium chloride and spraying of fruits at maturity scored higher in pulp color and aroma than other treatments perhaps due to increased calcium content (Karemera, *et al*., 2014, Anjum, *et al*., 2004). Calcium application led to deteriorated mango flavor and taste probably due to reduced accumulation of soluble solids with the application of calcium as previously reported (Anjum, *et al*., 2004, Mahmud, *et al*., 2015, Ngamchuachit, *et al*., 2014). This has also been reported in peach (Hamzehzad, *et al*., 2010), apricot (Antunes *et al*., 2003) and jujube (Moradinezhad, *et al*., 2019). Additionally, the use of calcium chloride, a divalent cation, may have imparted bitterness and saltiness which results from residual calcium chloride on the fruit hence the unfavorable taste scores (Lovera, *et al*., 2014, Luna-Guzman, *et al*., 2000).

Calcium chloride deactivates the activity of enzymes involved in the conversion of starch to sugars, therefore reducing respiration hence a reduced rate of carbon dioxide evolution. Calcium has also been reported to reduce the activity of fruit softening enzymes (Pinzon-Gomez, *et al*., 2014). Similar results in a decreased production of carbon dioxide due to immersion of fruits in calcium chloride have been reported in lemon (Tsantili *et al.*, 2002), tomato (Chepngeno, *et al.*, 2016) and ethylene in apple (Shirzadeh, *et al*., 2011) fruits. The peak of calcium treated fruits came later in the storage period because calcium delays the onset of climacteric peak (Ben-Arie, *et al*., 1995). The inhibiting effect of calcium chloride on ethylene evolution increased as the calcium concentration increased in this study and this corroborates with findings by Madani, *et al.* (2016) in papaya and Zhang *et al*. (2019) in melon fruits.

Fruits sprayed/immersed in calcium chloride at 1.5% had a more delayed ripening period probably because there was more calcium available to the fruit than the rest of the fruits. Calcium can penetrate through the epidermis and cuticle of the fruit on the peel (Conway, *et al.*, 1992). Calcium delays the process of ripening by reducing the respiration rate and ethylene synthesis (Hussain, *et al*., 2012; Zhang et al., 2019). The delay of ripening by application of calcium has been reported previously (Gofure, *et al*., 1997; Sive, *et al.*, 1985). Fruit sprayed at maturity took longer to ripen than those sprayed 15 days later probably because calcium is more available during early stages of fruit development as earlier observed by Karemera, *et al*. (2014) in mango and Penter, *et al.* (2000) in avocado fruits .

The decrease in weight during the storage period could be attributed to the loss of water through evapo-transpiration, degradation and respiration processes. Therefore, control fruits had higher rates of respiration and transpiration than calcium treated fruits. Similar results of the decrease in weight due to storage of fruits in ambient conditions have been reported by Jakhar, *et al*., (2016). Calcium is known to maintain the cell membrane integrity, structure and functionality hence the reported minimum loss in weight for the fruits that were treated with calcium chloride. Calcium has also been reported to maintain fruit firmness, reduced respiration and a delay in fruit senescence (Karemera, *et al*., 2014). Calcium forms a network with the pectin of the fruit cell wall thus restricting water loss as reported by Genanew, *et al*., (2013). Similar results on the decreased fruit weight loss due to calcium treatment has been reported by Karemera, *et al.,* (2014); Mahajan, *et al*. (2011), Kazemi *et al*., (2011) and Kardum (2004). Similarly, Dhillon, *et al*., (2013) reported that post-harvest application of calcium chloride slowed the weight loss of mango fruits. Calcium applied at earlier stages has been reported to more effective than late applications as alluded to in this and other (Karemera, *et al*., 2014; Penter, *et al*., 2000) studies.

CHAPTER SIX: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

Calcium significantly increased fruit weight, length, retention percentage and number of fruits/tree. Calcium is involved in the formation of cell membrane and developments hence increase in the fruit physical attributes. Additionally, calcium increases the productivity of mango fruits because of its role in reduction of abscission thus the eventual yield increase. A better performance in yield attributes was obtained with early application of calcium at fruit set than late applications. Further, application of calcium led to an increase in the flesh calcium concentration and an apparent association of yield parameters with calcium content. This reinforces the fact that calcium is important for increased fruit yield as has been reported in a number of fruits.

There was a reported suppressed jelly seed incidence by the application of calcium where fruits sprayed at early stages of development had lower jelly seed incidence than those sprayed at later stages of fruit development. This reinforces the fact that calcium is involved in enhancing tissue stability and firmness hence maintaining cell intergrity.Further, fruits sprayed with calcium at fruit set had low jelly seed incidence because the fruits were actively taking up calcium. Calcium content was higher in the fruit endocarp, mesocarp and exocarp of fruits with less on no jelly seed occurrence as indicated by the inverse relationship between calcium content and jelly seed occurrence.

There was a general increase and then decline in the fruit TSS in all the fruits during the storage period. There were generally lower levels of TSS in fruits sprayed with calcium than calcium unsprayed fruits implying that calcium sprayed fruits could be stored longer than fruits with a lower TSS. Calcium chloride led to an improved peel color appearance but calcium nitrate and easy gro of higher rates led to a deteriorated peel color appearance. Calcium treated fruits had significantly higher TTA content than control due to a delay in the ripening of the fruits associated with calcium. Application of calcium led to a reduced loss in weight because calcium maintains the cell wall integrity hence a lowered loss in weight. In the cell wall, pectic acid and

calcium bind to generate calcium pectate that strengthens and retains the wall structure. Firmness of fresh produce is important as firm fruits are able to resist physical damage that may result from transportation or any form of handling.

The significant interaction between the rate of application, time and source of application as depicted in this study suggests that the effectiveness of the calcium applied will depend on a number of factors including the time of application and calcium formulation used besides the concentration of the calcium formulation used.

6.2 Conclusions

Application of calcium enhanced the yield of mango fruits through enhanced improvement of yield components. Application of calcium chloride, 2.0%, at fruit set had the most enhanced yield and yield components. Further, calcium application led to a suppressed jelly seed occurence with calcium chloride, 2.0% applied at fruit set reporting lowest jelly seed occurrence and an improved shelf life as indicated by the delay in the accumulation of soluble solids, increased color saturation and respiration and ethylene evolution and a sustained firmness during the storage period. Immersion of fruits in calcium chloride on the other hand led to improved fruit quality and shelf life through retained peel firmness, flesh colour and reduced total soluble solids accumulation.

6.4 Recommendations

1. Recommendations to farmers and extension agents
   a. Farmers may use 2.0% calcium chloride applied at fruit set on mango fruits to enhance yield.
   b. Calcium chloride (2.0%) applied at fruit may be used to alleviate jelly seed in Van Dyke mango fruits and hence reduce post-harvest losses from this physiological disorder.
   c. Calcium chloride (1.0%) applied to mango fruits by immersion may be used to enhance the shelf life of fruits.
2. Recommendations for further research

a) It would be necessary to carry out similar studies in other agro ecological zones to get zone specific information to guide farmers and other interested parties since the present study covered one agricultural zone.
b) A similar study incorporating soil and foliar based calcium sources should be conducted to establish the effect on calcium plant uptake and the cost benefit associated with the treatments.
c) Fruits treated by immersion in calcium chloride had an enhanced shelf life and quality. However, there was a reduced pulp flavor and taste of the fruits as the rates of calcium chloride increased. It would therefore be necessary to carry out further research on the effectiveness of calcium chloride by varying the duration of the immersion.

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