OPTIMISING TECHNIQUES FOR IMPROVING POST-HARVEST QUALITY OF ORANGE (*Citrus sinensis* (L.) Osbeck) AND MANGO (*Mangifera indica*, L.) FRUITS IN EASTERN ZONE OF TANZANIA

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EXTENDED ABSTRACT

The preliminary experiment was done by using Jaffa orange variety to assess the effects of different concentrations of hexanal, calcium chloride and smoke treatment on physico-chemical quality. Jaffa orange fruits were separately (i) dipped in hexanal at 0.01%, 0.02% and 0.04% volume/voume for five minutes (ii) dipped in calcium chloride 1%, 2% and 4% weight/volume for five minutes (iii) fruits were smoked by burning 0.5 kg, 1.0 kg and 1.5 kg of dry banana leaves (iv) Untreated fruits (control). The fruits were evaluated under two storage conditions; ambient (28 ± 2 °C) and reduced temperature (18 ± 2 °C) and the data were collected at the 4th, 8th and 12th day after fruit harvest. Collected data were analysed by using R - software. Mean separation was done by using Tukey Honestly Significant Difference at $p \leq 0.05$. Results of preliminary experiment showed that hexanal at 0.02% v/v and calcium chloride at 0.02% w/v and smoke treatment obtained by burning 1.0 kg of dry banana leaves were effective in maintaining physico-chemical quality of Jaffa orange. Then, hexanal 0.02% v/v, calcium chloride 2% w/v and smoke treatment obtained from burning 1.0 kg of dry banana leaves were selected and used in other objectives. The actual experiments were conducted for two consecutive seasons of 2016 and 2017 to assess the effects of hexanal, calcium chloride and smoke on physico-chemical, shelf life, nutritional quality and cost benefit analysis of two orange (Msasa and Jaffa) and two mango (Apple and Palmer) varieties. The study on post-harvest losses of these fruits along the supply chain was also conducted. Various physico-chemical parameters were assessed. Results showed that hexanal and calcium chloride significantly reduced physiological weight loss, maintained fruit firmness and increased total soluble solids of both mango and orange fruits relative to smoke treatment and the controls. Reduced temperature significantly lowered physiological weight loss over the ambient storage. Major sites of post-harvest losses were at harvest, transport, wholesale and retail stages of supply chain. Post-harvest treatments of fruits with hexanal and calcium chloride significantly increased the shelf life and reduced disease incidences relative to control and smoke treated fruits. Reduced temperature significantly increased shelf life of fruits over the ambient storage. Hexanal improved nutritional quality of the fruits followed by calcium chloride and the control. While vitamin C and total flavonoids were decreasing, total sugars and reducing sugar content increased with storage time. Further results showed that hexanal and cold storage conditions led to higher number of marketable fruits over other treatments. Smoke treatment had the lowest number of marketable fruits. Mango fruits treatment with hexanal and stored under ambient storage was the most viable post-harvest technique with positive net present value and cost benefit ratio greater than 1.0, thus, viable investments while the other post-harvest techniques had negative net present values and cost benefit ratio less than 1.0. Hexanal treatment is therefore recommended to farmers, transporters and traders for improved quality and shelf life of orange and mango fruits.

DECLARATION

I, **Baltazari Anna,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

To my parents, Baltazari Semetei Kaaya and Elieremisa Mathayo Sumari, who laid the foundation of my education.

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LIST OF ABBREVIATIONS AND SYMBOL

AMAGRO	Association of Mango Growers in Tanzania
ANOVA	Analysis of Variance
CIFSRF	Canadian International Food Security Research Fund
DAH	Days after Harvest
HSD	Honestly Significant Differences
IDRC	International Development and Research Centre
MNR	Marginal Net Return
PWL	Physiological Weight Loss
SD	Standard Deviation
SE	Standard Error
SUA	Sokoine University of Agriculture
TA	Titratable Acidity
TSS	Total soluble solids
URT	United Republic of Tanzania
USDA	United States Department of Agriculture

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Mango (*Mangifera indica,* L.) and orange (*Citrus sinensis* (L.) Osbeck) are among the major fruits produced and consumed in Tanzania. Fruits are highly perishable and if not handled with care during production, harvesting, transport and storage, they soon deteriorate leading to high post-harvest losses. Post-harvest loss refers to measurable quantitative and qualitative food loss in the post-harvest system (Kiaya, 2014).

Citrus are the most produced and consumed fruits in the world (El-Otmani *et al*., 2011) Orange is the most important citrus fruit tree in Tanzania due to the nutritive value and socioeconomic importance (Mwatawala *et al*., 2019). Major orange producers in Tanzania are Tanga, Coast and Morogoro regions that accont for 52%, 16% and 7% of the total national production respectively (URT, 2012). The most popular varieties produced in Tanzania are Hamlin, Delta, Washington navel, Matombo sweet, Nairobi, Zanzibar, Early Valencia (Msasa), Late Valencia, and Jaffa (Mwatawala *et al*., 2019). Tanzanian orange production in 2016 was 465 608 tonnes which was produced from the area of 39 893 ha (FAO, 2017). Production of sweet oranges in Tanzania is not optimal due to biotic and abiotic stresses, and amount harvested is also prone to high postharvest losses largely due to limited use of appropriate orange handling methods (Mwatawala *et al*., 2019).

Mango is an important tropical fruit globally. Mango fruits are rich in minerals, fibre, vitamins and is therefore commercialized throughout the world (Brecht *et al*., 2010). Mango production in Tanzania is dominated by traditional/local varieties which account for 99% while production of improved/exotic varieties account for 1% of the total production (MMA, 2008). The traditional varieties include Dodo, Bolibo, Muyuni, Viringe and Bonyoa which are mainly cultivated by small scale farmers. The improved varieties include Apple, Keitt, Kent, Alfonso and Palmer and are mostly grown by medium and large scale farmers (MMA, 2008). Tanzania produces mango with an annual yield of more than 490 434 mt per annum (MMA, 2017) from an area of 38 000 ha (FAO, 2017.

An average of one third of all the edible food produced for human consumption in the world is wasted, which amounts to 1.3 billion tons (Gustavasson *et al.*, 2011). Reduction in post-harvest losses of fruits and vegetables is a complementary means for increasing production and it may not be necessary to step up the production to cover growing demand (Sudheer and Indira, 2007). Costs of preventing post-harvest losses in general are less than costs of producing a similar additional amount of fruits and vegetables of the same quality (Sudheer and Indira, 2007).

1.2 Fruit Ripening and Fruit Quality

Fruit ripening is a physiological process that involves the acceleration of a variety of metabolic processes, most or all enzymatically regulated and catalysed. During fruit ripening starch is converted to sugars, chlorophyll is broken down and carotenoids synthesized, respiration rate and enzymatic activities accelerated leading to wall disassembling (Paliyath and Droillard, 1992). The ripening processes occur in conjunction with the initiation of membrane degradation by activation of the Phospholipase D, which drives the senescence process (Paliyath *et al.*, 2008).

Phospholipase D enzyme initiates a series of catabolic cascades that eventually lead to deterioration of membrane, which is part of the development of the organoleptic quality of fruits during ripening (Paliyath *et al.*, 2008). This leads to the generation of several neutral lipids, the accumulation of which results in the destabilization of the membrane. The Phospholipase D enzymes have very little effect once the membrane starts to deteriorate (Paliyath *et al.*, 2008).

Quality is defined as the degree of excellence or suitability of a product for a particular use (Abbott, 1999). Attributes of interest to consumer are visual appearance, texture/firmness, sensory, nutritional and food safety, which are primary criteria for making purchasing decisions (Kays, 1999). Consumers seek fruit that is easy to handle and peel, without seeds but with adequate size and juice content, balanced sugar to acid ratio, and attractive bright color (El-Otman *et al.*, 2011). Fruit quality is related to both internal variables (firmness, sugar content, acid content and internal defects) and external variables (shape, size, colour, external defects and damage) (Garcia-Ramos, 2005).

The constituents obtained by the human body from fruits and vegetables include water, carbohydrates, fats, proteins, fiber, minerals, organic acids, vitamins and antioxidants, (Florkowski *et al.*, 2009). Fruits are relatively low in calories and fat, they have no cholesterol, carbohydrates, fiber, vitamin C, carotene, some good source of vitamin B_6 with relatively low sodium and high in potassium.

The nutritional value of fruits and vegetables depends on their composition, which shows a wide range of variation among species, cultivar and maturity stage (Florkowski *et al.*, 2009). The accumulation and degradation of antioxidant compounds in fruits are influenced by both genetic and environmental factors. Genetic factors include; species and cultivars whereas environmental factors are radiation, cultural practices, maturity at harvest and storage conditions and processing (Florkowski *et al*., 2009; Mishra, 2002).

1.3 Handling Practices

Post-harvest food loss is a measurable qualitative and quantitative food loss along the supply chain, between harvest and consumption (Hodges *et al*., 2011). Post-harvest losses are highly experienced by smallholder farmers with relatively inappropriate crop handling, processing and storage technologies (Rugumamu, 2009). Gustavasson *et al*. (2011) reported the post-harvest losses of 30 to 40% in fruits and vegetables. Kusumaningrum *et al*. (2015) reported limited shelf life of tropical fruits as the main cause of post-harvest losses.

The primary factors causing post-harvest loss in fruits include mechanical, physiological, pathological and environmental factors (Kusumaningrum *et al.*, 2015). The limited shelf life of the fresh fruits is caused by their distinct properties, external conditions, microbial contamination, physiological disorders, mechanical damage and the level of post-harvest treatments; and sometimes a combination of several factors (Kasso and Bekele, 2018). Although it is difficult to control all the factors that affect the shelf life of fruits, minimizing their effect on shelf life is technically feasible (Kusumaningrum *et al.*, 2015).

1.4 Post-harvest Treatments

The post-harvest loss of fruits presents a challenge and is a drain of resources, especially in developing countries (Subramanian *et al*., 2014). Most of the post-harvest storage technologies are geographic region and crop specific and are often not adaptable or affordable to small-scale growers (Kumar, 2018). Post-harvest calcium treatments have been reported to retain fruit firmness in different horticultural produce such as apples, lemon and peaches and reduction in rotting incidences (Wang *et al*., 1993).

Farmers in developing countries have been using different local post-harvest handling treatments such as smoking to initiate ripening of fruits (Mebratie *et al*., 2015) and improve fruit quality. Techniques like smoking enhances mass fruit ripening where a large volume of fruits is needed (Saltveit, 1999). However, fruits treated with smoke do not attain uniform colour and flavour, quality impairments due to persistence of smoke odour on the produce, fruit softening and short market life (Jobling, 2010).

Post-harvest treatments with calcium chloride have been widely used as firming agent and preservative for both whole and fresh-cut fruits and vegetables (Florkowski *et al*., 2009; Luna-Guzman and Barrett, 2000; Saftner *et al*., 2003). Chloride salts are the source of chlorine commonly used in small-scale operations for post-harvest treatments of fruits (Bertzer *et al*., 2002) to extend their shelf life and to reduce incidences of fungal diseases.

The use of hexanal (Phospholipase D inhibition technique) is an emerging technique for reducing post-harvest losses of horticultural produce (Paliyath, 2011). Hexanal is the naturally occurring aldehyde compound produced by plant tissue upon wounding. Hexanal is a GRAS (generally regarded as safe) compound that is responsible for down regulating the expression of the Phospholipase D enzyme which initiates a series of catabolic reactions resulting in the degradation of the phospholipid bilayer (Paliyath *et al*., 2008; Waddell *et al*., 2010). Hexanal works by inhibiting the activities of Phospholipase D enzymes, produced during ripening and senescence of fruits. Phospholipase D enzymes initiate membrane degradation which results into fruits post-harvest deterioration and losses (Paliyath *et al*., 2008).

1.5 Problem Statement and Justification

Fruit traders normally buy fruits at farm gate but destined for local and international markets. In Tanzania and most developing countries, there are limited specialized post-harvest storage facilities, treatments and refrigerated trucks. Gebre-Mariam (1999) reported lack of post-harvest and marketing infrastructure (packaging, cold storage, prepackage and distribution), post-harvest treatment and washing facilities together. Production constraints are major problems leading to low productivity and considerable post-harvest loss of fruits. Post-harvest losses are barriers for international trade of tropical fruits that can lead to a reduction in fruit marketable yield and deterioration in fruit quality (Kusumaningrum *et al*., 2015).

Msogoya and Kimaro (2011) recorded the post-harvest losses of 48 to 60% in fresh mango. Post-harvest losses of citrus were estimated to be 40 to 50% in Nigeria (Ugoh *et al*., 2015). Post-harvest losses of 40% in banana were recorded in Ethiopia (Debela *et al*., 2011). These losses are observed at harvest, during packing, transportation, in wholesale and retail markets and during delays at different stages of handling (Kitinoja *et al*., 2010) including unseen delay at custom, traffic delay and trucks breakdown, high toll charges or delay in unloading places. These necessitate a need to extend the shelf life of fruits. Enhancement of the post-harvest shelf life is essential to ensure nutritional security of rural communities all over the world (Kumar, 2018). Reduction of post-harvest losses and quality deterioration are essential in increasing food availability from existing production (Kasso and Bekele, 2018).

Current post-harvest treatments such as smoke have been reported to affect quality of treated fruits (Mebratie *et al*., 2015). However, there is insufficient information on the effects of smoke treatments on internal and external quality parameters of mango and orange fruits under Tanzanian conditions. Therefore, there is a need to evaluate the effects of smoke treatment and document its suitability as post-harvest treatment for fruit quality improvement.

The use of hexanal as post-harvest treatment has been reported to enhance freshness and shelf life of fruits such as apple, sweet cherry, peaches, mango, tomatoes, guava, banana and strawberry (Paliyath *et al*., 2008). Application of hexanal in these fruits also significantly delayed ripening and senescence and extended fruit shelf life of fruits (Paliyath and Droillard, 1992). However, studies on hexanal application to improve post-harvest fruit qualities were limited to fruits such as mango, guava, plum, grapes, sweet cherries, papaya, tomatoes, apples, pears, peaches and strawberries (Paliyath, 2011; Paliyath *et al*., 2008). Moreover, the fruit quality characteristics tested on the mentioned fruits (Paliyath and Droillard, 1992) did not include physico-chemical characteristics which are important in fresh market and processing industry.

Furthermore, post-harvest hexanal application has been tested in limited geographies, and in fruit varieties from India and Canada (Paliyath *et al*., 2008). There is therefore no information from the African tropics and the major fruit varieties grown in Tanzania. Techniques used by Tanzanian farmers such as smoke treatment to improve post-harvest quality of fruits are not well evaluated and documented. Mishra (2002) reported that calcium chloride delayed ripening, reduced post-harvest decay and improved nutritional quality of fruits and vegetables. These results showed that calcium chloride retained firmness, increased vitamin C content and decreased storage rot in apple fruits. Lara *et al*. (2004) reported delayed fruit ripening, improved resistance to fungal attack and maintained structural integrity of strawberry cell walls after being dipped in 1% solution of calcium chloride. The hexanal and calcium chloride are considered food grade.

While researchers have identified many potentially useful post-harvest technologies for use in developing countries, there is lack of information regarding the costs and financial benefits of these post-harvest technologies, since costs are rarely documented during research studies (Kitinoja *et al*., 2010). Thus, this study aims at testing the effects of different techniques in reducing post-harvest losses and maintaining quality of Tanzanian mango and orange.

1.6 Objectives

1.6.1 Overall objective

To establish the best post-harvest techniques for improved shelf life of Tanzanian mango and orange fruits.

1.6.2 Specific objectives

1. To assess the performance of smoke, hexanal and calcium chloride for improving the physico-chemical quality of mango and orange fruits.
2. To assess post-harvest losses of mango and orange fruits at harvest, transportation and marketing.
3. To determine the nutritional qualities of mango and orange fruits during storage.
4. To determine cost-benefit analysis of hexanal, calcium chloride and smoking post-harvest techniques on orange and mango fruits.

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CHAPTER TWO

2.0 EFFECTIVENESS DIFFERENT DOSES OF SMOKE, HEXANAL, AND CALCIUM CHLORIDE ON IMPROVING POST-HARVEST QUALITY OF JAFFA ORANGE VARIETY UNDER DIFFERENT STORAGE DURATIONS AND STORAGE CONDITIONS

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ABSTRACT

Experiments were conducted at the Sokoine University of Agriculture, Tanzania to assess the effectiveness of hexanal, calcium chloride and smoke on the post-harvest quality of Jaffa orange variety under different storage conditions. A three-factor factorial experiment was used with six replications. The sources of variation were post-harvest techniques, storage duration and storage conditions. Post-harvest techniques included dipping fruits in hexanal solution at 0.01%, 0.02%, and 0.04% (volume/volume) for five minutes each, dipping fruits in and calcium chloride solution at 1%, 2%, and 4% (weight /volume) for five minutes each, and smoking fruits in 0.5 kg, 1.0 kg, and 1.5 kg of dried banana leaves, or control (no treatment). Two storage conditions tested were, ambient temperature 28 ± 2 °C) storage and cold or reduced temperatures (18 ± 2 °C) storage°onditions. Data were collected at three different storage durations (4, 8, and 12 days after harvest). Data calculated included physiological weight loss, fruit firmness, total soluble solids (TSS), and titratable acidity (TA), and the TSS/TA ratio. Analysis of Variance (ANOVA) was performed using R - software. Results indicate that hexanal and calcium chloride treatments significantly ($p < 0.001$) reduced orange physiological weight loss and maintained fruit firmness of both varieties compared to smoke treatment and untreated controls. Moreover, total soluble solids were significantly ($p < 0.001$) higher in hexanal and calcium chloride-treated oranges than the smoke treated fruits. Cold storage also significantly ($p < 0.001$) lowered physiological weight loss of hexanal and calcium chloride treated Jaffa oranges when compared to the smoke treated fruits and untreated controls. The total soluble solids of both varieties significantly increased ($p < 0.001$) with storage duration and temperature in the storage chamber. The titratable acidity decreased with storage duration irrespective of the post-harvest techniques and storage conditions used. Hexanal treatment at 0.02% and calcium chloride solution at 2% are recommended to maintain the quality of Jaffa oranges in Tanzania. Also smoke treatment with 1.0 kg is recommended for post-harvest management of orange fruits.

Keywords: Physiological weight loss, firmness, total soluble solids, titratable acidity (TA), sugar to acid ratio

2.1 Introduction

Orange is the most widely grown citrus fruit in Tanzania in comparing with other fruits in the country grown in Tanzania. Citrus fruits grown in Tanzania include orange, lime, lemon, grapefruits, mandarine, pomelo, kumpquat and blood orange. Among these citrus fruits, orange is the major citrus species produced in Tanzania. Msasa (early Valencia), Jaffa and Valencia (late Valencia) are the main orange fruits grown in Tanzania (Mwatawala *et al.,* 2019). The Jaffa variety is oval shaped and easily peeled because of its thick skin; and also have high juice content. Citrus fruits have a non-climacteric ripening behaviuor and should be harvested when the internal maturity has been achieved (Lado *et al*., 2014). Global production of citrus fruits in 2016 was 146 429 018 tonnes (FAO 2017). However, production of oranges in Tanzania is not optimal due to biotic and abiotic stresses. The major causes of post-harvest losses in developing countries include improper post-harvest practices, poor post-harvest management systems, and lack of supporting infrastructure for quality maintenance (Ahmad and Siddiqui, 2016).

Post-harvest loss is a refers to measurable quantitative and qualitative food loss in the postharvest system (Kiaya, 2014). Post-harvest loss of 40 to 50% of fresh horticultural produce in developing countries (Kusumaningrum *et al*., 2015; Ugoh *et al*. 2015; Ahmad and Siddiqui, 2016). Consumers decision to buy is influenced by fruit quality such as firmness, freshness, sugar content and acidity levels (Ahmad and Siddiqui, 2016; Martin-Diana *et al*., 2007).

Moreover, fruit harvest at an improper maturity stage, and storage time and conditions, especially temperature (Ahmad and Siddiqui, 2016), as well as post-harvest treatments cause significant post-harvest losses (Heather and Hallman, 2008). The physical quality factors of citrus fruits include fruit size, peel thickness, peel color, firmness, juice content, storability and shelf life (Levy and Boman, 1990). Chemical parameters include acidity, sugar, the sugar content, and minor constituents, such as bitter or aromatic compounds, which may influence fruit palatability. Organic acids present in citrus fruits, such as citric acid, malic acid, oxalic acid, succinic acid, and malonic acid are responsible for characteristic flavor of these fruits. Post-harvest management of horticultural produce is crucial for shelf life extension. Smoke treatment is commonly used by small scale farmers for degreening of orange fruit which usually remain green even after their ripen (Watada, 1986; Saltveit, 1999).

Calcium chloride is commonly used preservative and firming agent in the fruit and vegetable industry for whole and fresh-cut commodities (Martin-Diana *et al.*, 2007). Different concentration of calcium chloride has been used for treatment of perishable produce. Torress *et al*. (2009) used calcium chloride 6% for post-harvest treatment of atemoya fruits. Post-harvest dip of orange fruits in 4 - 6% concentration of calcium chloride reduced weight loss of treated orange fruit (Mishra, 2002). Post-harvest dip of apricot, peaches and pears in calcium chloride 2% maintained their textural quality (Barrett and Garcia, 2002).

Hexanal treatment is an emerging technique for reducing post-harvest losses of fresh horticultural produce (Paliyath *et al*. 2008; Paliyath, 2011) as it inhibits the activities of Phospholipase D enzymes, which are responsible for membrane degradation (Paliyath, 2011). Hexanal was reported to reduce weight losses in mango (*Mangifera indica* L.), extend the shelf life of sweet cherries (Sharma *et al.*, 2010), delay ripening of mango, and increase firmness and maintain total soluble solids in blueberry (Song *et al.*, 2010). There is lack of information on post-harvest dipping of fruits in hexanal formulations on quality of fresh fruits in tropical African countries Tanzania inclusive. Therefore, objective of this study was to assess the effectiveness of hexanal, calcium chloride and smoke treatment on post-harvest quality of Jaffa orange variety.

2.2 Materials and Methods

The Jaffa orange variety was harvested from Horticulture unit of Sokoine University of Agriculture in June 2016. Three post-harvest techniques, (i) dipping of fruits in hexanal solution, (ii) dipping of fruits in calcium chloride solution, and (iii) smoke treatment, were evaluated. Control groups consisted of untreated oranges that were neither dipped in hexanal solution nor calcium chloride solution, nor exposed to smoke, but were stored under ambient and cold conditions.

Post-harvest techniques included dipping fruits in hexanal solution at 0.01%, 0.02%, and 0.04% (volume/volume) for five minutes each, dipping fruits in and calcium chloride solution at 1%, 2%, and 4% (weight /volume) for five minutes each, and smoking fruits in 0.5 kg, 1.0 kg, and 1.5 kg of dried banana leaves, or control (no treatment). Fruits in three chambers (each with a volume of 12 m^3) were treated with different smoke that was obtained from burning 0.5 kg, 1.0 kg, and 1.5 kg of dried banana leaves. The smoke treatment was done three times at an interval of 12 hours. Before each subsequent smoke treatment, the chambers were ventilated for 30 minutes. The chambers were located six metres from the source of smoke to reduce heat transfer to the fruits.

There were two storage conditions: ambient storage (28 ± 2 °C) and cold storage (18 ± 2 °C). Data were collected on the 4th, 8th, and 12th day from the date of fruit harvest (DAH). Thirty fruits of each variety were exposed to every treatment and each treatment was replicated six times making a total of 360 fruits per treatment. Data collection was stopped on the 12th day from the date of harvest due to excessive shrinkage and drying of orange peels in some of fruit samples.

Data were collected on fruit weight, firmness, total soluble solids (TSS), and titratable acidity (TA). Physiological weight loss and the total soluble solids/titratable acidity (TSS/TA) ratio were calculated. The physiological weight loss was determined by randomly selecting five fruits from each treatment. These selected fruits were numbered and then weighed by using an electronic balance (BX 4200H, Shimadzu, Japan). The initial weight (W_1) of each fruit at harvest (day 0) and the new weight of the same fruit on the subsequent days (W_2) was recorded in grams and the per cent weight loss calculated using equation 1 below:

$$\text{Percentage weight loss (\%)} = 100 \times (W_1 - W_2)/W_1$$

Fruit firmness was determined by removing a small peel disc (approx. 2 mm^2) on the opposite side of the fruit cheek, and then fruit firmness was measured using a penetrometer (Wagner fruit test, FT 20 Model, Wagner Instruments, Italy). Total soluble solids content (°Brix) was measured using a hand-held digital refractometer (ATAGO, Japan) according to Nielsen (2010). Titratable acidity of the juice was determined by titration with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The titratable acidity (%) was estimated as per Ranganna (1999) and expressed as per cent anhydrous citric acid. The TSS/TA ratio was computed by dividing the TSS by the TA (%). The data were analysed using R software. Mean separation was done by Tukey's Honestly Significant Differences (HSD) at ($p \leq 0.05$).

2.3 Results

2.3.1 Physiological weight loss

The ANOVA results showed significant effects of post-harvest techniques ($p < 0.001$) and storage condition ($p < 0.001$) and storage duration ($p < 0.001$) on physiological weight loss of Jaffa fruits. The effects of interaction between post-harvest techniques and storage duration ($p = 0.012$), post-harvest techniques and storage conditions ($p < 0.001$); and the interaction between storage factor and storage condition ($p = 0.024$) on PWL of Jaffa orange variety were significant. The interaction between post-harvest techniques, storage duration and storage conditions on PWL of Jaffa ($p > 0.05$). The analysis of main means showed that the effects of post-harvest techniques on physiological weight loss of Jaffa differed significantly at 4 days after fruit harvest (DAH) ($p = 0.002$) and at 8 DAH ($p = 0.02$) (Fig. 2.1 and 2.2, respectively) but not at 12 DAH ($p > 0.05$).

Generally, physiological weight loss of Jaffa orange was lower in hexanal and calcium chloride treated fruits compared to both smoked and untreated control fruits. At 4 DAH, calcium chloride treated fruits at concentration of 1% had higher PWL than the concentration of 2% and 4% which had the lowest PWL. The hexanal treated fruits at all of its concentrations of 0.01%, 0.02% and 0.04% had the lowest PWL than other treated and untreated fruits at 4DAH. Also, at 4 DAH, fruits treated with 0.5 kg and 1.0 kg smoke had lower PWL than the fruits treated with 1.5 kg smoke. The PWL at 8 DAH of calcium chloride 1% treated fruits had higher PWL than calcium chloride 2% and 4% treated fruits. Also, at 8 DAH hexanal 0.01% treated fruits had higher PWL than calcium chloride 0.02% and 0.04% treated fruits. The fruit treated with 0.5 and 1.0 kg and had higher PWL than fruits with 1.5 kg smoke at 8DAH.

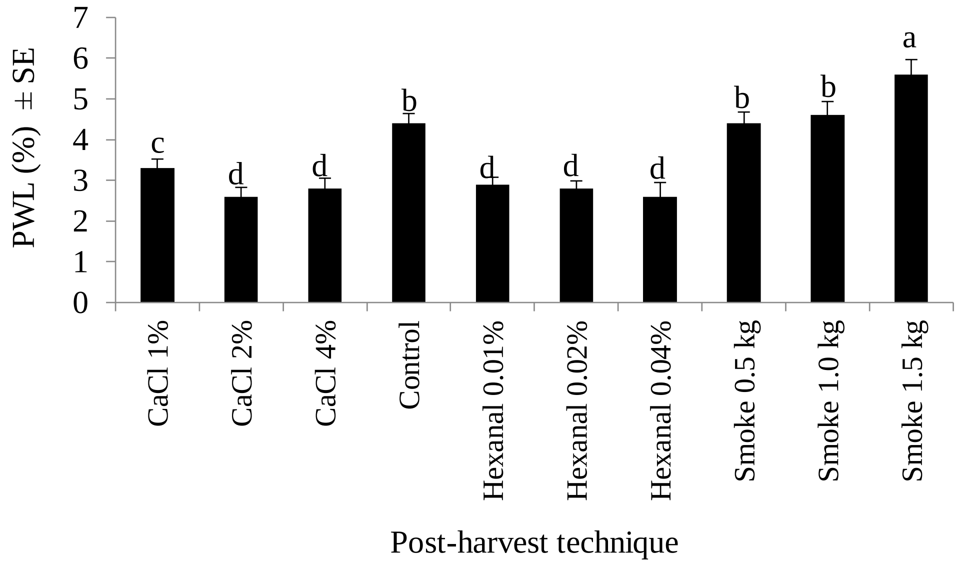

Figure 2.1: The effects of post-harvest techniques on physiological weight loss of Jaffa orange fruits at 4 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

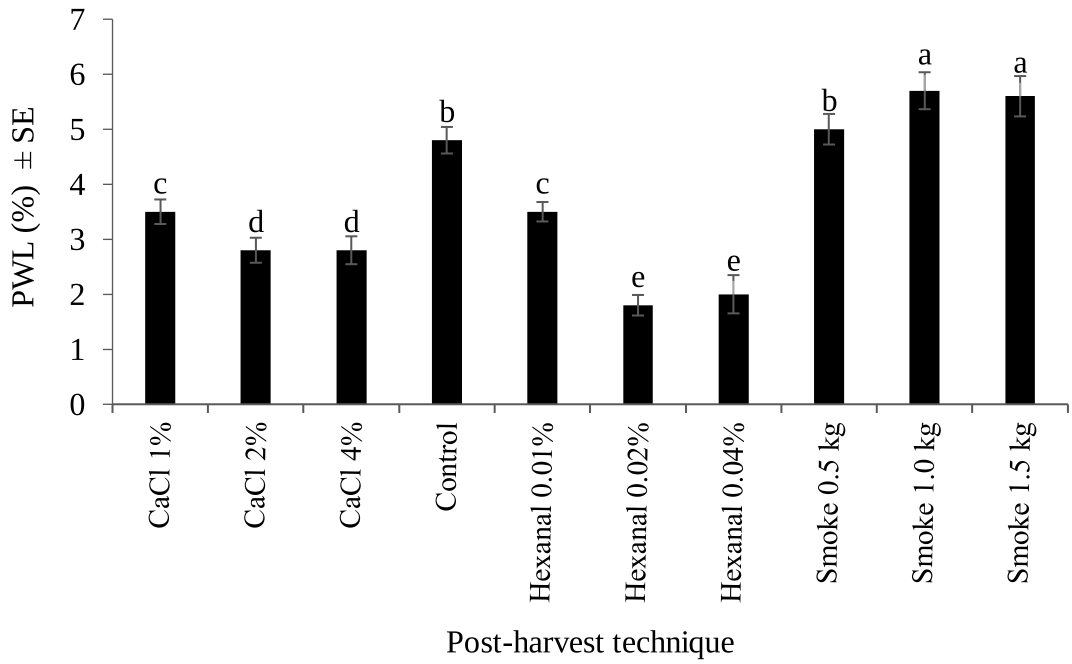

Figure 2.2: The effects of post-harvest techniques on physiological weight loss of Jaffa orange fruits at 8 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

2.3.2 Firmness

The ANOVA results showed that post-harvest techniques ($p < 0.001$) significantly increased firmness of Jaffa fruits. Firmness decreased with storage duration ($p < 0.001$) of Jaffa fruits. There were significant interactions between storage condition and storage duration ($p < 0.01$) as well as for post-harvest techniques by storage duration ($p < 0.001$) of Jaffa fruits. Further analysis of simple means showed that the effects of post-harvest techniques on firmness of Jaffa fruits differed significantly at 4 DAH ($p < 0.001$), 8 DAH ($p = 0.001$), and 12 DAH ($p < 0.001$) (Fig. 2.3 to 2.5, respectively) and it was increasing with increase in time._Firmness was highest in hexanal and calcium chloride treated Jaffa fruits compared to the smoked and untreated control. At 4 and 8DAH fruit firmness was highest was highest in calcium chloride 2% and 4% treated fruits while the calcium chloride 1% had the lowest firmness. The hexanal had the highest fruit firmness in all the three concentrations tested while the smoke treated fruits had lowest fruit firmness in all the concentrations tested at 4 and 8DAH. At 12 DAH, the calcium chloride 1% and 2% had lower fruit firmness than 4% calcium chloride treated fruits. Also, at 12DAH, the hexanal treated fruits with 0.01%, 0.02% and 0.04% had lower fruit firmness than hexanal treated fruits while the fruit treated with 0.5, 1.0 and 1.5 kg of smoke had the lowest fruit firmness compared with control and other fruits treated with other techniques. Generally, the fruit firmness was decreasing with increase in storage time regardless of post-harvest technique used (Fig. 2.3 to 2.5).

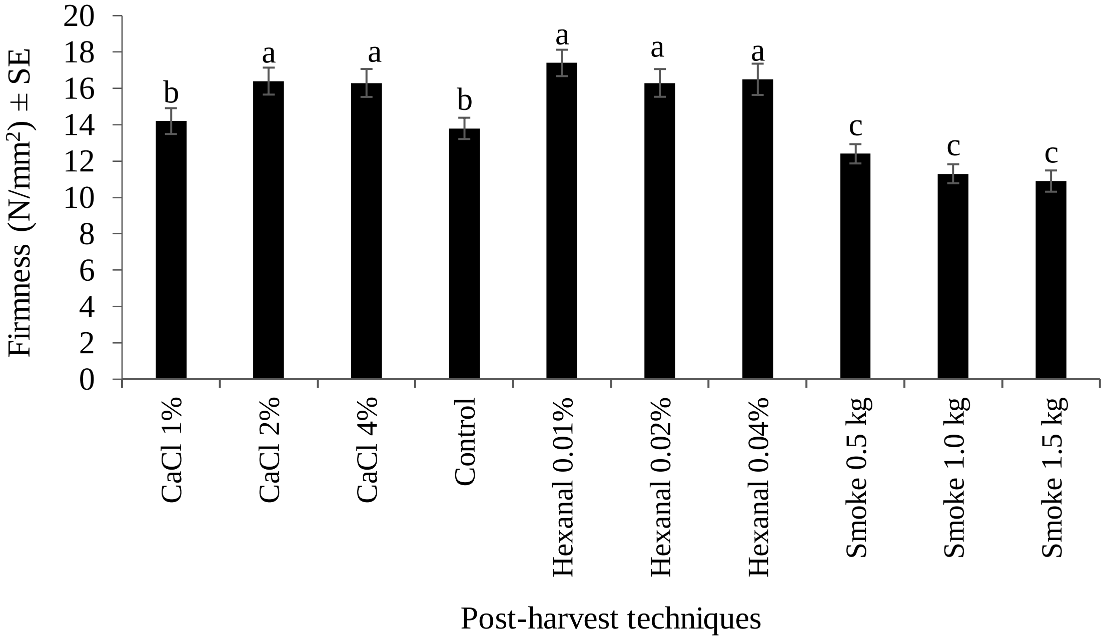

Figure 2.3: The effects of postharvest techniques on firmness of Jaffa orange fruits 4 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

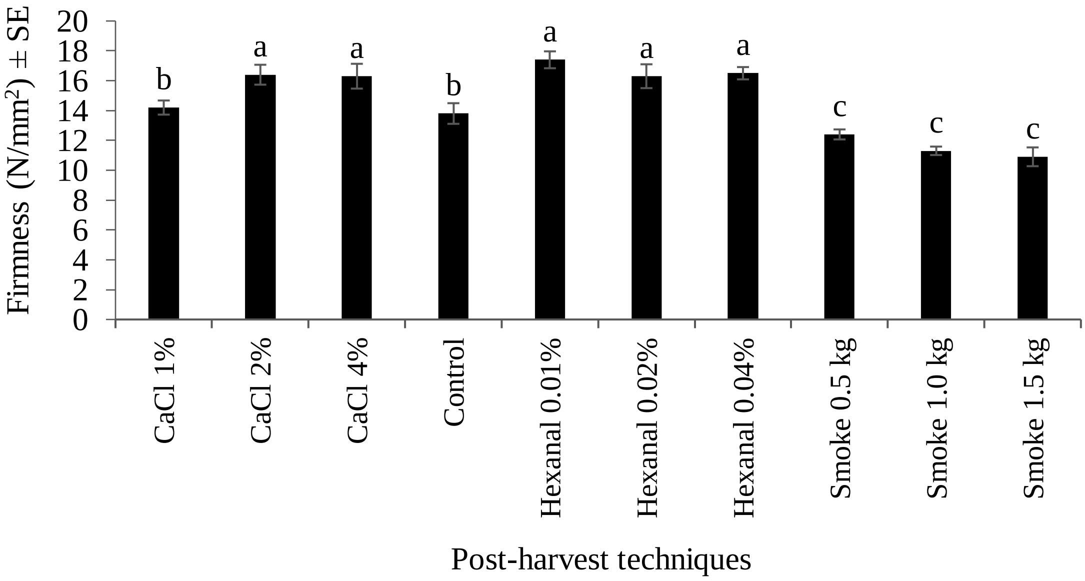

Figure 2.4: The effects of postharvest techniques on firmness of Jaffa orange fruits 8 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

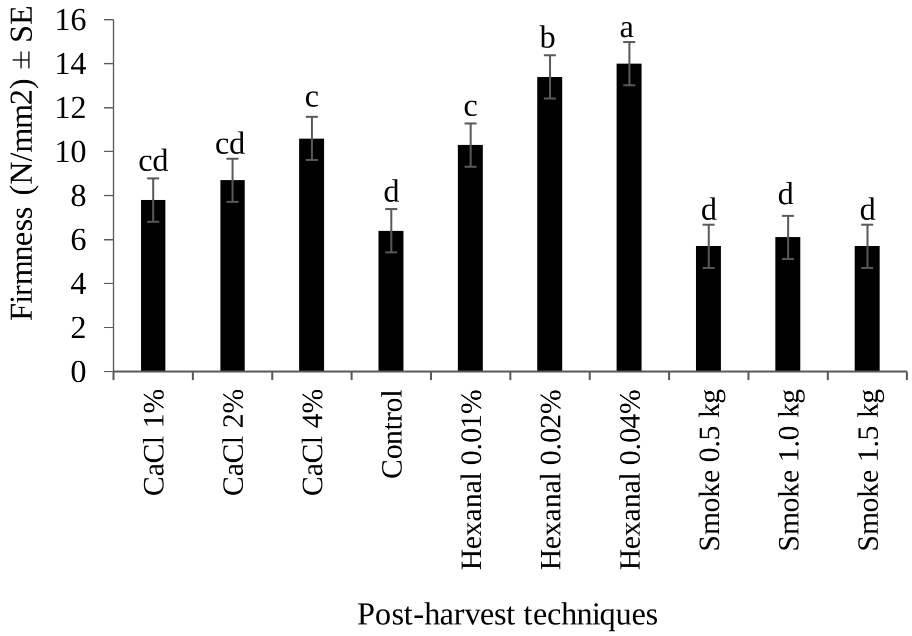

Figure 2.5: The effects of postharvest techniques on firmness of Jaffa orange fruits 12 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

2.3.3 Total Soluble Solids

The effects of post-harvest techniques ($p < 0.001$), storage condition ($p < 0.001$), storage duration ($p < 0.001$) and interaction between postharvest techniques and storage duration were significant on total soluble solids of Jaffa fruits. The effects of all other interactions had non-significant effects ($p > 0.05$) on total soluble solids of Jaffa orange variety. The ANOVA results for simple means showed that post-harvest techniques had significant effects on TSS of Jaffa orange fruits at 8 DAH ($p < 0.001$) and 12 DAH ($p < 0.001$) but not at 4 DAH ($p < 0.05$), on TSS (Fig. 2.6 and 2.7). At 8 DAH the TSS was highest in smoke treated and control fruits whereas it was lowest in hexanal and calcium chloride treated fruits. At 12 DAH, the TSS was highest in hexanal and calcium chloride treated fruits and was lowest in smoke treated and control fruits. At 8 DAH, smoke treated in all tested concentrations and untreated control fruits had the highest TSS followed by calcium chloride in all concentrations and hexanal treated fruits at 0.01%, but the hexanal treated fruits at 0.02% and 0.04% had the lowest TSS. At 12 DAH, hexanal and calcium chloride at all concentrations had the highest TSS while those treated with smoke and control fruits had the lowest TSS values.

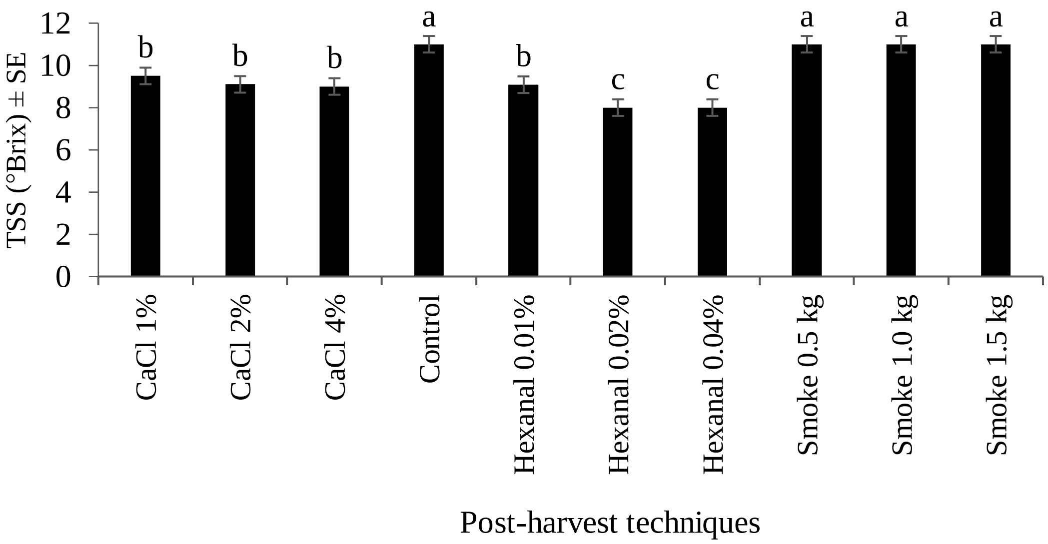

Figure 2.6: The effects of postharvest techniques on total soluble solids of Jaffa orange fruits at 8 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

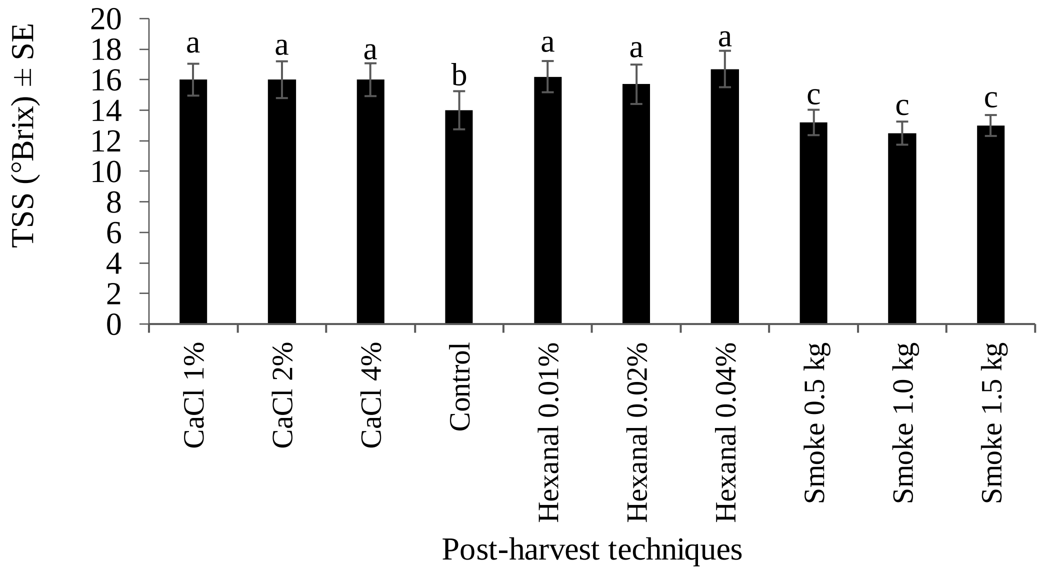

Figure 2.7: The effects of postharvest techniques on total soluble solids of Jaffa orange fruits 12 days after harvest

Note: Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

2.3.4 Titratable Acidity

The results showed that storage duration (p < 0.001), storage condition (p < 0.01) and interaction between storage condition and storage duration (p < 0.01) had significantly effects on titratable acidity of Jaffa fruits. Post-harvest techniques and all other interactions had non-significant effects on titratable acidity of Jaffa orange fruits (p > 0.05). The ANOVA results for simple means showed significant effects (p < 0.001) of storage time at 4 DAH (p = 0.037), 8 DAH (p = 0.035) and 12 DAH (p = 0.014) (Fig. 2.8). Titratable acidity was highest at 4 DAH and lowest at 12 DAH under both ambient and reduced storage conditions.

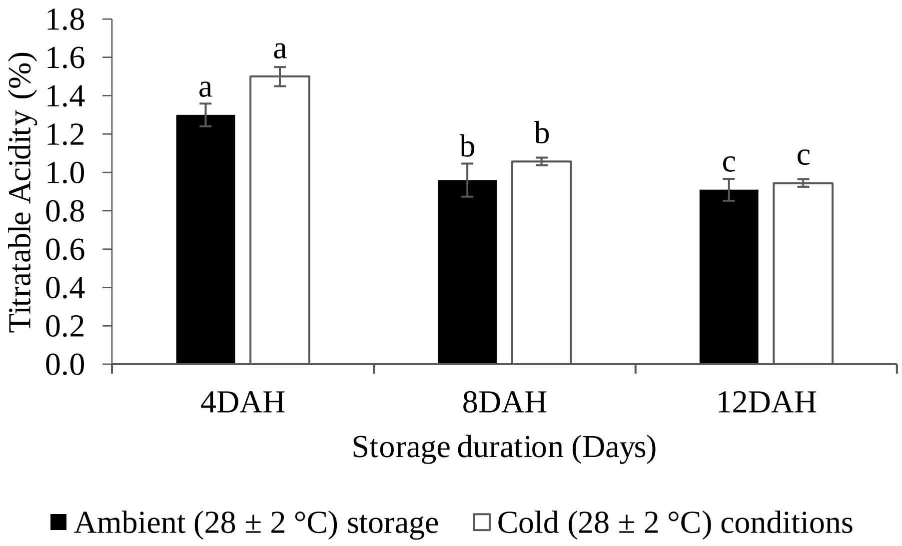

Figure 2.8: The effects of ambient and cold storage conditions on titratable acidity of Jaffa orange fruits at 4, 8 and 12 days after harvest

Note: means with the same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

2.3.5 Total Soluble Solids/Titratable Acidity Ratio

The ANOVA results showed significant effects of storage condition (p < 0.001), storage duration (p < 0.001) and interaction between storage duration and storage condition on TSS/TA ratio of Jaffa orange fruits. The effects of post-harvest techniques and other interaction had non-significant effects on TSS/TA of Jaffa orange fruits. The ANOVA of simple means showed that effects of storage duration on the TSS/TA ratio for fruits of Jaffa variety differ significantly at 4 DAH (p = 0.010) and at 12 DAH (p = 0.034) but not at 8 DAH (p > 0.05) (Fig. 2.9). The TSS/TA was lowest at 4 DAH and it was increasing with increase in storage time regardless of the storage conditions.

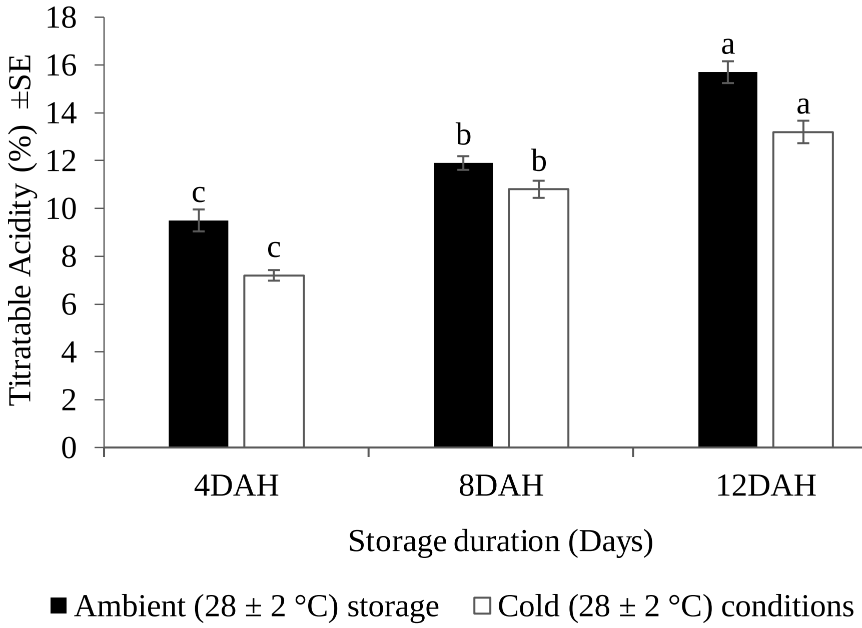

Figure2.9: The effects of ambient and cold storage conditions on TSS/TA ratio of Jaffa orange fruits at 4, 8 and 12 days after harvest

Note: Means with the same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

2.4 Discussion

The post-harvest techniques affected physiological weight loss of Jaffa oranges fruits. The smoke treated oranges had the highest physiological weight loss while hexanal had the lowest physiological weight loss. Fruits treated with smoke higher concentration of smoke shriveled and heightened the freshness loss earlier compared to the other treated and control fruits. Smoke treatment from burnt vegetation is one of the sources of exogenous ethylene gas. Karthika *et al*. (2015) reported that higher ethylene accelerated weight loss, ripening and fruit aging. The loss of fruit freshness is associated with rise in transpiration rate and an increased fruit wilting and shriveling (Paul and Pandey, 2016; Wardowski *et al*., 2006). Wardowski *et al*., (2006) have shown that respiration and transpiration rates are high immediately after fruit picking and decline during storage due to shriveling and drying of peel. Loss in weight is associated with moisture loss from the fruit surface during ripening and softening (Hutchinson *et al*., 2018). Hexanal-treated oranges had low physiological weight loss in all the concentration tested. El- Kayal *et al*. (2017) reported low weight loss in hexanal-treated raspberry compared to untreated controls. The hexanal and calcium chloride treated fruits had lower PWL than smoke and untreated control fruits.

Calcium chloride in all the concentrations improved the Physiological weight loss of Jaffa orange fruits. Calcium chloride has been reported to stabilize cellular membranes and consequently delay senescence of orange fruits. Akhtar *et al*. (2010) reported delayed senescence and reduced rates of respiration and transpiration in loquat (*Eriobotrya japonica, L.*) treated with calcium chloride. White and Broadley (2003) reported that exogenously applied calcium stabilizes the plant cell wall and protects it from cell wall degrading enzymes. Calcium chloride reduced the weight losses of treated carrots compared to untreated carrots (Mishra, 2002).

Physiological weight loss of Jaffa orange fruits increased with storage time regardless of postharvest technique, storage conditions and storage period. The fruits stored under ambient storage conditions had higher physiological weight loss than fruits stored under cold or reduced temperatures storage conditions. The study that was done by Singh and Reddy (2006) reported higher percent of cumulative weight loss in oranges stored under ambient than those in cold storage conditions. Increased temperatures are associated with increased rates of respiration, deterioration, and water loss in fresh produce. The low weight loss in fresh, hexanal and calcium chloride treated oranges translates into maintained quality, improved shelf life, and therefore, potentially expanded market window. Firmness of Jaffa orange fruits was increasing with storage duration regardless of the concentration used and post-harvest technique used. The fruits treated with hexanal was the most firm followed by those treated with calcium chloride. Similar results were reported by Sharma *et al.* (2010) in sweet cherries. Hexanal acts as a strong inhibitor of Phospholipase D action, and thus slows down ethylene stimulation of fruit ripening and softening processes (Karthika *et al*., 2015; Subramanian *et al*., 2014). Calcium chloride has been used as a firming agent for many fruits and vegetables (Mishra, 2002). Calcium chloride treated fruits had fruits with fresh appearance regardless of the concentration used. Calcium chloride accumulates in the cell walls leading to facilitation of the cross linking of the pectic polymers, which increases cell wall strength and cell cohesion (Akhtar *et al*., 2010). Calcium dips have been employed to improve firmness and extend the postharvest shelf life of a wide range of fruits and vegetables (Torres *et al*., 2010). The effectiveness of such treatments may be influenced by the combination of time and temperature. Calcium chloride retained the postharvest firmness of apple fruits (Mishra, 2002).

The smoke treated leads to increased fruit softness and senescence. Fruit firmness is important attribute for buyers' decisions. Bourne (1982) reported decreased firmness with increasing temperature in storage. The cold storage conditions led to firmer fruits than the ambient storage conditions. This could be due to reduced metabolic reactions in fruits stored at the reduced temperature. Wardowski *et al*. (2006) reported that citrus firmness undergoes changes during storage depending on storage conditions. The firmness of most fruits and vegetables showed decreased firmness with increasing temperatures (Bourne, 1982). The fruits stored under cold storage conditions were firmer than the fruits stored in ambient storage, regardless of the variety.

Hexanal and calcium chloride-treated fruits had lower values of total soluble solids than smoke-treated oranges at eight days after harvest due to delayed ripening. Hexanal slows down fruit ripening process due to inhibition of ethylene-induced ripening and softening (Karthika *et al.,* 2015; Subramanian *et al.,* 2014). The smoke treated fruits higher total soluble solids content was caused by accelerated breakdown of starch and ripening of the fruits by ethylene generated from smoke. Li *et al*. (2016) reported a slight effect of ethylene on internal fruit quality of non-climacteric fruit. Goldschmidt (1997) reported that citrus fruits reveal ripening-related symptoms in response to exogenous ethylene treatment. Similar to this study, Akhtar *et al*. (2010) reported higher values of total soluble solids content in calcium chloride treated fruits and the lowest values in the control fruits. On the other hand, Mayuoni *et al*. (2011) reported that ethylene had no effects on total soluble solids and acidic contents of citrus fruit juice.

The titratable acidity of Jaffa orange fruits was decreasing with increasing storage time. The quality of orange juice is influenced by physico-chemical parameters such as pH, total soluble solid content, and total titratable acidity. The physicochemical characteristics of juices considered in quality assessment include pH, titratable acidity (TA), total soluble solids (°Brix), ascorbic acid, total sugar, reducing sugar and °Brix (sugar)/acid ratio (Nonga *et al*., 2014). Citric acid is the dominant organic acid in citrus fruits (Etienne *et al*., 2013) and it determines the fruits' Organoleptic quality of citrus fruits are determined by the citric acid content in the fruit juice. The orange titratable acidity decreased significantly with storage duration, during ripening of the fruits. Starch conversion to sugar decrease fruit acidity which contributed to fruit sweetness. The fruit ripening is associated decreased acidity, reduced firmness and increased sugar content. As total soluble solids (TSS) content increases during ripening, this parameter is a very practical index of internal fruit quality and an accurate criterion for the decision of harvest in the field, especially where growers do not have other equipment available to objectively measure maturity (Lado *et al*., 2014).

The sugar to acid ratio (TSS/TA ratio) of Jaffa orange fruits increasing with fruit ripening in storage. TSS/TA is important quality indicator which determine the taste and texture of fruits (Wardowski *et al*., 2006; Ladaniya, 2008). TSS/acidity ratio has been used worldwide as the main commercial maturity indicator of citrus fruit internal quality (Lado *et al*., 2014). As the fruit ripens the acidity decreases and total soluble solids decreases so as the TSS/TA ratio. It can be inferred that longer storage duration positively influenced the TSS/TA ratio of fruits in the current study. Commercial maturity indices in citrus fruit are highly variable and dependent on citrus species and varieties, growing regions and destination markets, but, soluble solids, acidity and juice content are relevant parameters considered for harvest decision (Lado *et al*., 2014).

2.5 Conclusions and Recommendations

The current study showed that Jaffa orange fruits treated with hexanal at concentration of 0.02% and 0.04% reduced physiological weight loss, maintained firmness, and improved total soluble solids content and TSS/TA ratio of Jaffa oranges than Hexanal at concentration of 0.01% regardless of storage duration and conditions. Similarly, 2% and

4% calcium chloride treatment reduced physiological weight loss, maintained firmness, improved total soluble solids content and TSS/TA ratio, and of Jaffa oranges compared with calcium chloride at concentration of 1% in both storage conditions and duration. Conversely, 1.0 kg and 1.5 kg smoke treatment increased physiological weight loss and reduces fruit firmness under both ambient and cold storage durations compared to 0.5 kg smoke treatment. The cold/reduced temperatures storage condition reduced the physiological weight loss, and maintains fruit firmness and total soluble solids content better than the ambient storage condition. The cold storage at (18 ± 2 °C) delayed fruit ripening, reduced PWL, maintained the firmness and freshness, and also increased TSS and TSS/TA ratio of Jaffa orange fruits.

Based on the results of this study, hexanal formulation at the concentration of 0.02% and calcium chloride at 2% are recommended for post-harvest quality of fruits. The smoke treatment with 1.0 kg is also recommended for degreening of citrus fruits post-harvest. The reduced temperatures storage at (18 ± 2 °C) is recommended for post-harvest storage to maintain quality of fresh oranges in Tanzania.

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CHAPTER THREE

3.0 EFFECTS OF SMOKE, HEXANAL, AND CALCIUM CHLORIDE ON POST-HARVEST QUALITY OF ORANGES (*Citrus sinensis* (L.) Osbeck) UNDER DIFFERENT STORAGE DURATIONS AND CONDITIONS IN TANZANIA

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Abstract

Experiments were conducted to assess the effects of hexanal, calcium chloride, and smoke on the post-harvest quality of oranges under ambient (room) temperature (28 ± 2 ˚C) and reduced temperature storage (18 ± 2 ˚C) conditions on two varieties of orange (*Citrus sinensis* (L.) Osbeck) Msasa and Jaffa. Fruit were dipped hexanal (0.02% v/v) or calcium chloride (2% w/v) for five minutes each, or subjected to a smoking regime, simulating a popular traditional practice, by burning 1.0 kg of dried banana leaves, or left untreated (control). Various parameters including physiological weight loss, fruit firmness, total soluble solids (TSS), titratable acidity (TA) and the TSS/TA ratio were assessed to determine effects on post-harvest quality of fruit. Results indicated that hexanal and calcium chloride treatments significantly ($p < 0.001$) reduced physiological weight loss, maintained fruit firmness and significantly higher TSS in both varieties compared to smoke treatment and untreated controls. Reduced temperature storage also significantly ($p < 0.001$) lowered physiological weight loss of hexanal- and calcium chloride-treated oranges. Based on the results of this study, post-harvest dip treatments with hexanal or calcium chloride coupled with reduced temperature storage at 18 °C are recommended to maintain the quality of fresh oranges in Tanzania. On the contrary, the application of smoke is highly discouraged as it reduces the quality of oranges.

Keywords: Post-harvest treatments, post-harvest loss, shelf life, physiological weight loss, fruit firmness, total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio

3.1 Introduction

Post-harvest loss is a general term used to describe the fraction of produce that is rendered unfit for a particular use (Abbott, 1999). Post-harvest loss is a major constraint in the tropical fresh fruit industry (Kusumaningrum *et al.*, 2015). About 40% to 50% of fresh horticultural produce in developing countries is lost after harvest (Ahmed and Siddiqui, 2016; Ugoh *et al.*, 2015). Post-harvest losses are commonly characterized by fruit shrivelling, weight loss, softening, decay and changes in sugar content and acidity levels (Martin-Diana *et al.*, 2007; Ahmed and Siddiqui, 2016), which are major determinants of consumers' choices of fresh fruits. Post-harvest losses are thus barriers to both local and international trade of tropical fresh fruits (Kusumaningrum *et al.*, 2015). The major causes of post-harvest losses in developing countries include improper post-harvest practices, poor post-harvest management systems and lack of supporting infrastructure for quality maintenance (Ahmed and Siddiqui, 2016). Moreover, harvesting fruit at stages other than horticultural maturity, storage under inappropriate conditions (especially temperature), and use of improper post-harvest treatments results into significant post-harvest losses (Ahmed and Siddiqui, 2016; Heather and Hallman, 2008).

Several practices are used by farmers to reduce post-harvest losses and to maintain the quality of fresh fruits. Smoke treatment is a common post-harvest practice used by farmers in Tanzania to hasten fruit ripening for bulk purchase and prior to transportation (Saltveit, 1999). However, this technique results in increased fruit softening and reduced fruit shelf life (Watada, 1986). Storage temperature is an important factor that affects respiration, transpiration, senescence and other physiological processes in the fruit (Wani *et al*., 2014). Storage at low temperatures and high relative humidity is beneficial for maintenance of natural resistance of the peel to infection (Wardowski *et al*., 2006). Storage of horticultural products in reduced temperatures has been reported to be effective in delaying the physico-chemical changes related to quality loss in fruits (Wani *et al*., 2014).

Chlorine, sourced from chloride salts, is commonly used in small-scale, post-harvest treatments of fruits (Bertzer *et al*., 2002) to extend their shelf life and to reduce incidences of decay (Singh *et al*., 1993). Calcium chloride has been widely used as a preservative and firming agent in the fruit and vegetable industry for whole and fresh-cut commodities (Martin-Diana *et al*., 2007). For instance, calcium chloride maintained the quality of apples (*Malus domestica,* L.) (Chardonnet *et al*., 2003), increased the total soluble solids of fig (*Ficus carica,* L.) fruits (Irfan *et al*., 2013), reduced weight loss of loquart (*Eriobotrya japonica,* L.) (Akhtar *et al*., 2010), and also delayed ripening and senescence of strawberries (*Fragaria ananassa,* L.), blueberries (*Vaccinium corymbosum,* L.), apples (Martin-Diana *et al*., 2007; Mishra, 2002), and fig fruits (Irfan *et al*., 2013). Fruit treatment with a high concentration of calcium chloride, however, has been shown to lower fruit quality and increase susceptibility to fungal diseases (Chardonnet *et al.*, 2003).

Hexanal treatment is an emerging technique for reducing post-harvest losses of fresh horticultural produce (Paliyath *et al*., 2008; Paliyath, 2011) as it inhibits the activities of Phospholipase D enzymes, which are responsible for membrane degradation (Paliyath, 2011). Hexanal has been used to reduce post-harvest losses in sweet cherry (*Prunus avium,* L.) (Sharma *et al*., 2010) and tomato (*Solanum lycopersicum,* L.) (Tiwari and Paliyath, 2011). Hexanal was reported to reduce weight losses in mango (*Mangifera indica,* L.), extend the shelf life of sweet cherries (Sharma *et al*., 2010), delay ripening of mango and increase firmness and maintain total soluble solids in blueberry (Song *et al*., 2010). However, information is lacking on the effects of hexanal on post-harvest losses and quality maintenance of fresh citrus fruits. The objective of this study was to assess the effect of different post-harvest techniques on the reduction of post-harvest losses and quality maintenance of fresh oranges.

3.2 Materials and Methods

Fruits of the two most popular sweet orange varieties, Msasa and Jaffa, were harvested from Bwembera and Semngano villages in Muheza district, Tanga Region in Tanzania. Both varieties were harvested at standard commercial horticultural maturity. Three post-harvest techniques were applied: (i) dipping of fruits in Hexanal solution, (ii) dipping of fruits in calcium chloride solution and (iii) smoke treatment. Control groups consisted of untreated oranges of both varieties were included.

Fruits were completely immersed in hexanal solution at (0.02% volume/volume) for five minutes or in calcium chloride solutions of (2% weight /volume) for five minutes each, or subjected to smoke treatment generated by burning dried banana leaves, or were left untreated (control). For the smoke treatment, fruits in three chambers (each with a volume of 12 m^3) were treated with different smoke concentrations obtained from burning 1.0 kg of dried banana leaves. The smoke treatment was done three times at intervals of 12 hours. The chambers were ventilated for 30 minutes by opening between smoke treatments. The chambers were located six metres from the source of smoke to reduce heat transfer to the oranges. There were two storage conditions: ambient storage (28 ± 2 °C) and reduced temperature storage (18 ± 2 °C).

Data were collected on the 4th, 8th, and 12th day from the date of fruit harvest (DAH). Thirty fruits of each variety were used for each treatment, each of which was replicated six times making a total of 360 fruits per treatment. Data collection was stopped on the 12th day from the date of harvest due to the onset of post-harvest deterioration in some treatments. Data were collected on fruit weight, firmness, total soluble solids (TSS), and titratable acidity (TA). Physiological weight loss and the total soluble solids/titratable acidity (TSS/TA) ratio were calculated. The physiological weight loss was determined by randomly selecting five fruits from each treatment. The selected fruits were numbered and used for measurement of initial and final weights using an electronic balance (BX 4200H, Shimadzu, Japan) and percentage fruit weight loss was calculated. A small peel disc of approximately 2 mm^2) on the opposite side of the fruit cheek was removed, and then fruit firmness was measured using a penetrometer (Wagner fruit test, FT 20 Model, Wagner Instruments, Italy). Total soluble solids content (°Brix) was measured using a hand- held digital refractometer (ATAGO, Japan) according to Nielsen (2010). Titratable acidity of the juice was determined by titration with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The titratable acidity (%) was estimated as per Ranganna (1999) and expressed as per cent anhydrous citric acid. The TSS/TA ratio was computed by dividing the TSS by the TA (%). The data were analysed using R software, and where significant differences existed, using the *F*- statistic, and means were separated using Tukey's Honestly Significant Differences (HSD) ($p \leq 0.05$).

3.3 Results

3.3.1 Physiological Weight Loss

Physiological weight loss of fruits in both varieties tested was significantly lower in hexanal treatment in ambient conditions on all three days of observation. Significant low physiological weight loss was observed when the fruits were kept in reduced temperature conditions (Fig. 3.1 and Fig. 3.2). Overall, the physiological weight loss of oranges was lower in hexanal and calcium chloride-treated fruits compared to both smoked and untreated fruits of both varieties.

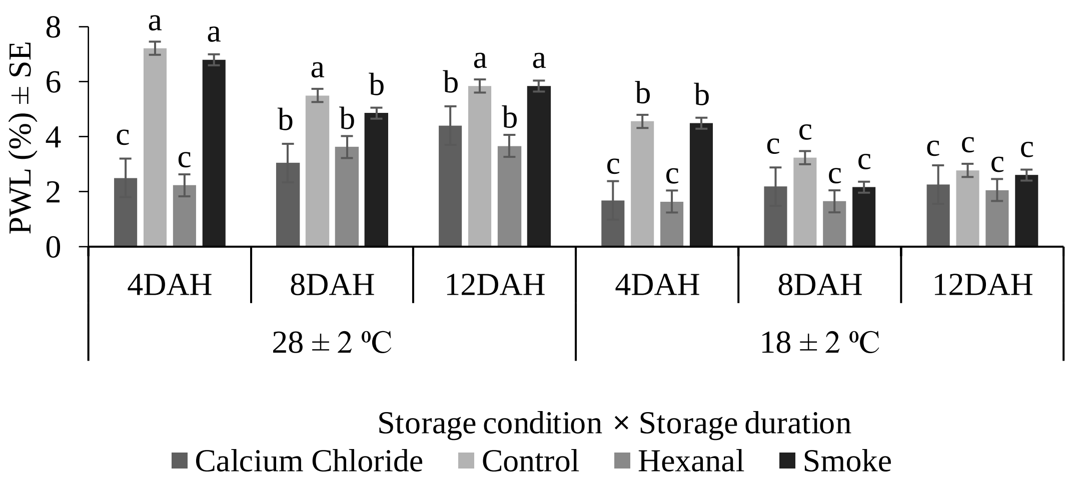

Figure 3.1: Physiological weight loss of Msasa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

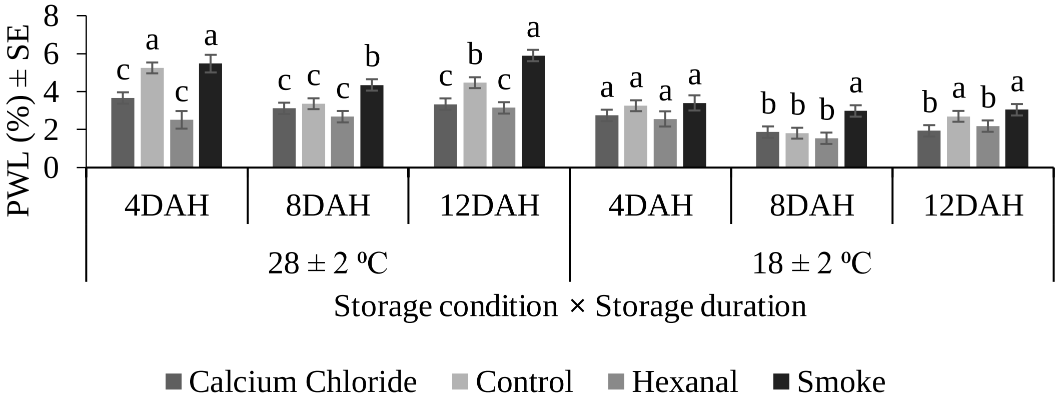

Figure 3.2: Physiological weight loss of Jaffa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

3.3.2 Fruit Firmness

Our results showed that fruits remained firm after hexanal and calcium chloride treatments compared to smoke-treated and control fruits of both cultivars. The firmness decreased, as expected, throughout the study period (Fig. 3.3 and 3.4). The highest firmness was 17.6 N/mm^2 for Msasa and 17.7 N/mm^2 for Jaffa when treated with hexanal under ambient storage conditions at 4 DAH.

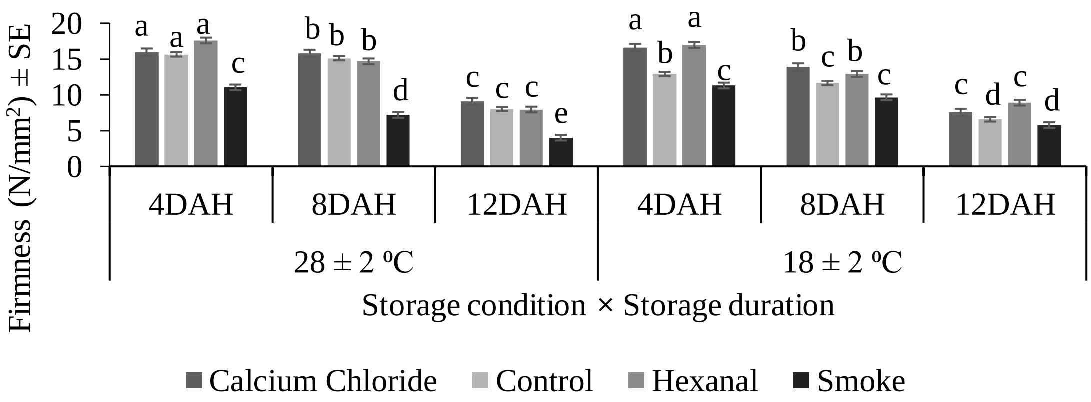

Figure 3.3: Firmness of Msasa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

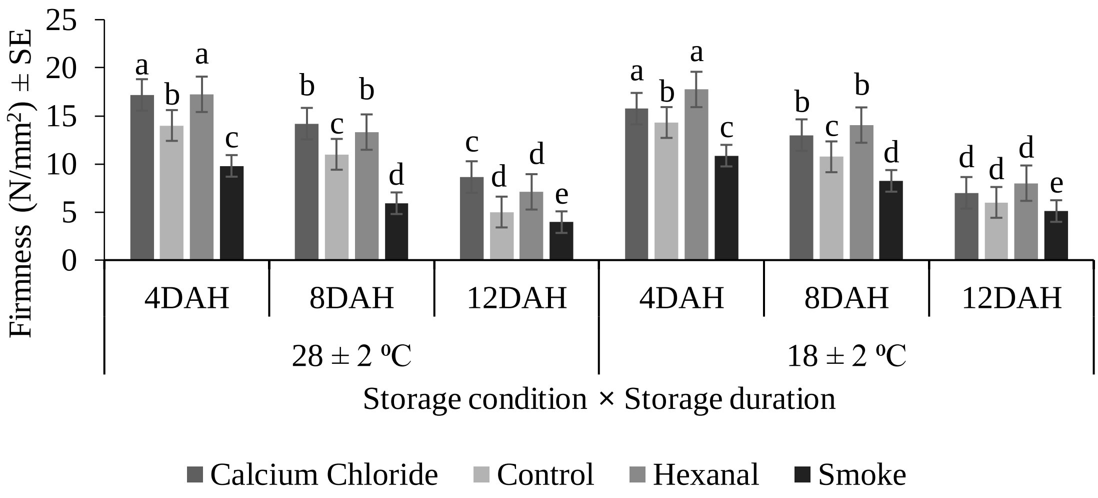

Figure 3.4: Firmness of Jaffa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

3.3.3 Total Soluble Solids

Total soluble solids increased with duration of treatment in all treatments, conditions and days after harvest. There were no significant differences in any of the factors tested in both varieties (Fig. 3.5 and 3.6). Since hexanal only delays membrane deterioration, this result is not surprising and follows the anticipated trend. Fruits treated with hexanal had the lowest value for total soluble solids in both varieties.

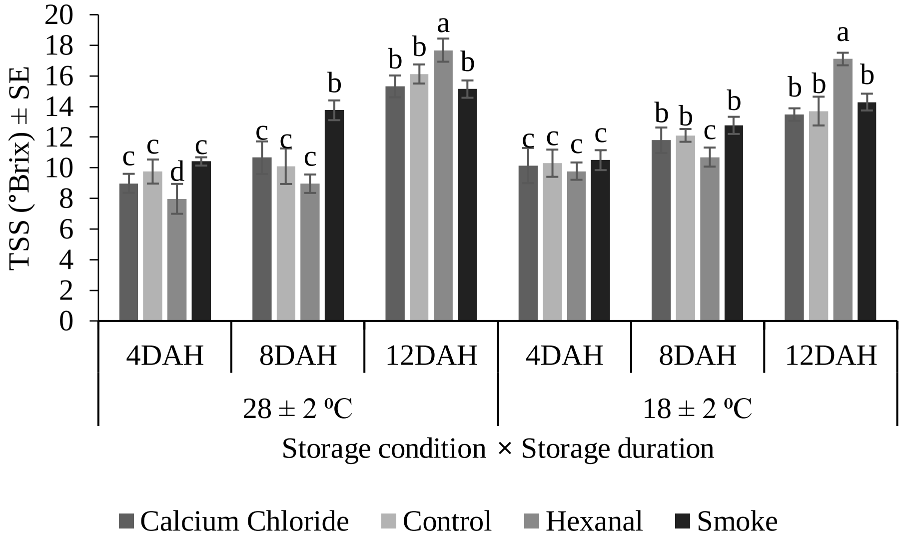

Figure 3.5: Total soluble solids of Msasa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

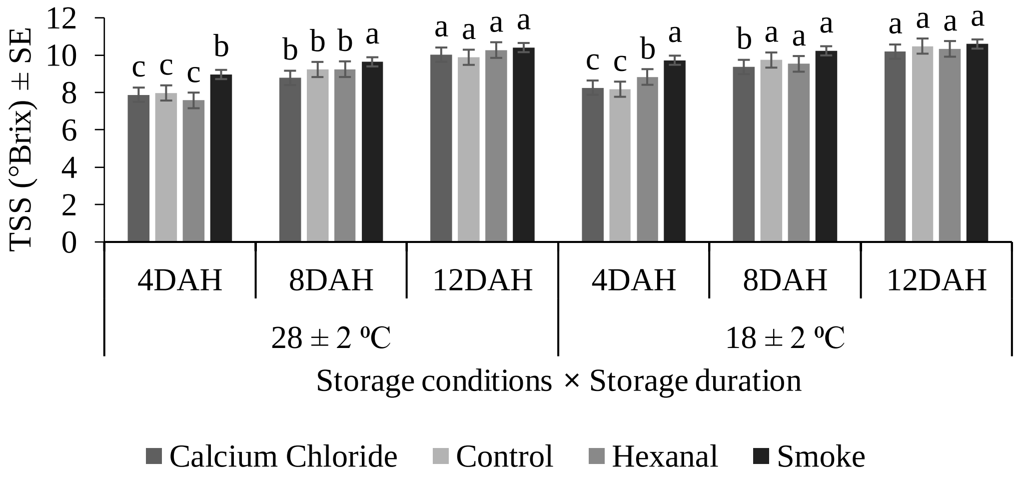

Figure **3.6: Total soluble solids of Jaffa orange variety under ambient and cold storage conditions**

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

3.3.4 Titratable Acidity

Titratable acidity decreased steadily over time in both varieties tested. The decrease was more pronounced in Msasa than Jaffa fruits stored at room temperature. For fruit stored under reduced temperature conditions the decrease was not as pronounced as in ambient conditions, although there were some anomalies in Msasa fruit, at 12 DAH, from hexanal and calcium chloride dip treatments (Fig. 3.7 and 3.8).

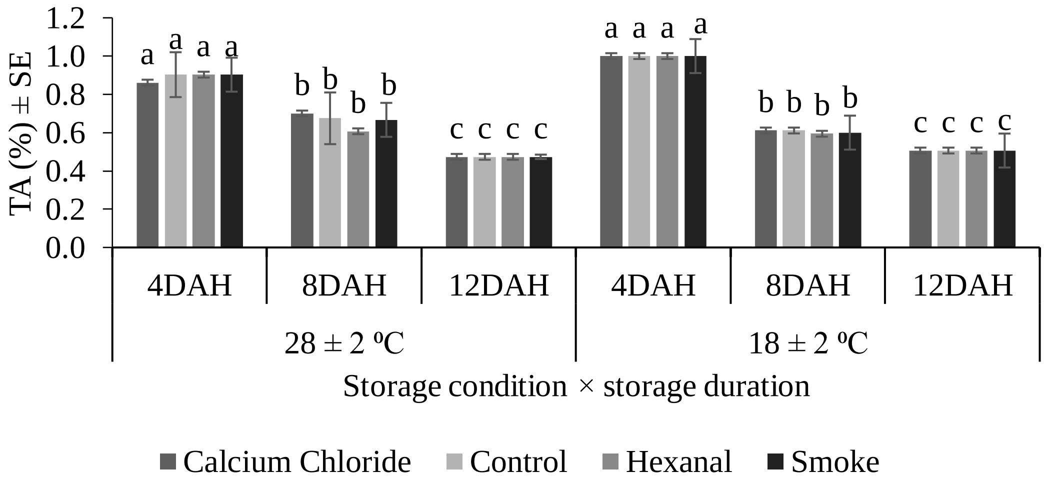

Figure 3.7: Titratable acidity of Msasa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

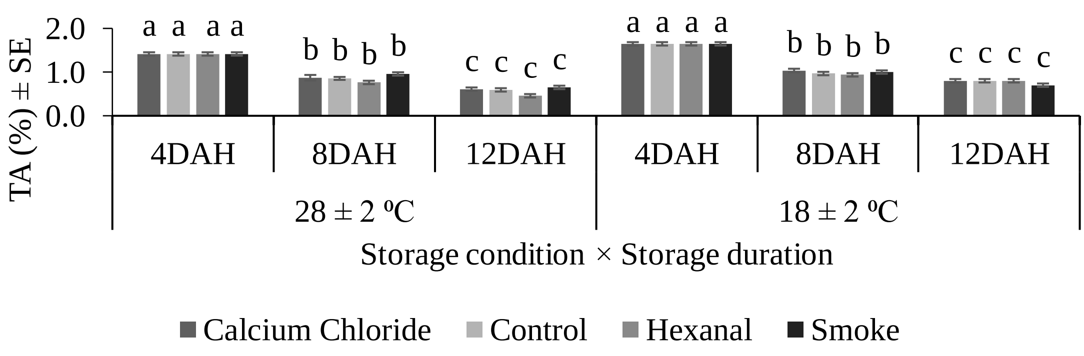

Figure 3.8: Titratable acidity of Jaffa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

3.3.5 Total Soluble Solids/Titratable Acidity Ratio

Results showed that TSS/TA increased significantly with storage duration in fruit of both varieties. However, post-harvest factor and storage condition did not alter the TSS/TA ratio significantly in either cultivar (Fig. 3.9 and 3.10). This is not surprising since we noticed opposite trends with TSS and TA as explained earlier. Overall, our results consistently showed that, treating the fruits with hexanal did slow down the post-harvest damages in physiological factors, thus helping oranges to keep longer in very ordinary conditions that are prevalent in Tanzania. Smoke treatment of oranges, a common practice in Africa, is not beneficial as this research has confirmed. This is the first report of the effects of hexanal in the citrus family, one of the top five fruit crops of the world.

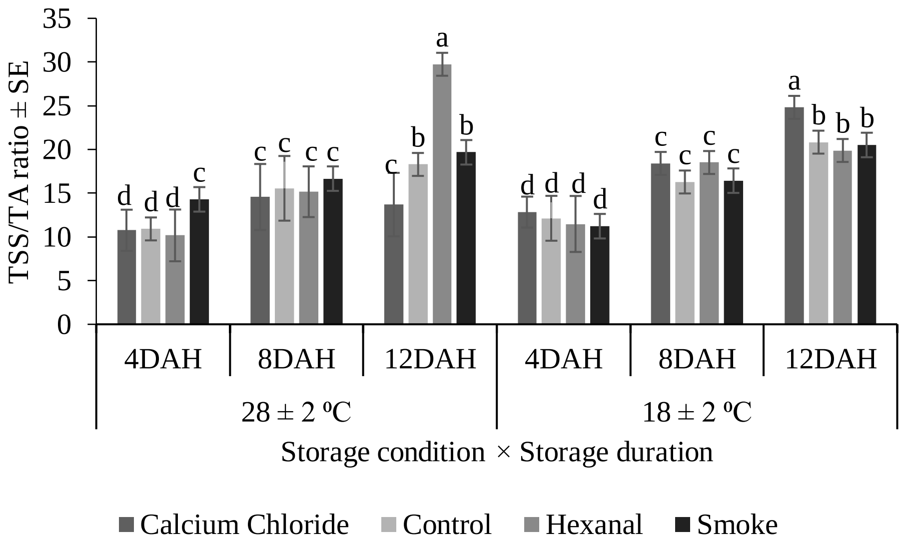

Figure 3.9: TSS/TA ratio of Msasa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

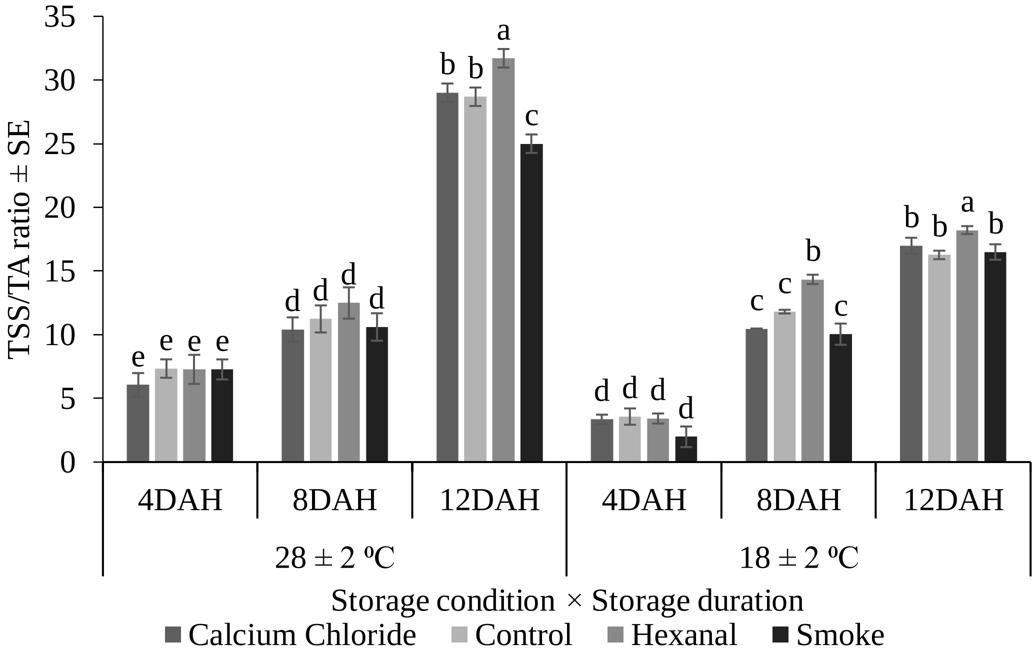

Figure 3.10: TSS/TA ratio of Jaffa orange variety under ambient and cold storage conditions

Note: Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

3.4 Discussion

3.4.1 Fruit physiological weight loss

Results showed that post-harvest techniques affected physiological weight loss of oranges. Further, the study found that smoke-treated oranges had the highest physiological weight loss. Fruits treated with smoke, shriveled and lost freshness earlier compared to fruits from the other treatments and the control. Higher smoke concentration aggravated the loss of fruit freshness compared to the other treatments and the control. Smoke treatment results in higher ethylene concentration in the storage room, which accelerates physiological weight loss, ripening and fruit aging (Karthika *et al*., 2015). Weight loss is an important factor in citrus deterioration during storage and it is essentially due to water loss by transpiration (Wardowski *et al*., 2006).

A previous study associated the loss of fruit freshness with the rise in transpiration rate and an increase in wilting and shriveling of stored fruits (Paul and Pandey, 2016). Wardowski *et al*. (2006) have shown that respiration and transpiration rates are high immediately after fruit picking and decline during storage due to shrivelling and drying of peel. Hexanal-treated oranges had low physiological weight loss regardless of the concentration. El Kayal *et al*. (2017) reported low weight loss in hexanal-treated raspberry compared to untreated controls. They found that there was delayed wilting in the fruit treated with calcium chloride and the fruit remained fresh for a longer time compared to untreated control fruit. Calcium chloride has been reported to stabilize cellular membranes and consequently delay senescence in horticultural produce Bertzer *et al*. (2002) and Akhtar *et al*. (2010) reported delayed senescence and reduced rates of respiration and transpiration in loquat (*Eriobotrya japonica,* L.) treated with calcium chloride. The low weight loss in fresh, hexanal-and calcium chloride-treated oranges translates into maintained quality, improved shelf life and therefore, potentially expanded market window.

Physiological weight loss increased during the storage period regardless of storage conditions and post-harvest treatment. Those under ambient (room) storage conditions experienced higher physiological weight loss than those under reduced temperature storage conditions. Singh and Reddy (2006) found that the percent cumulative weight loss in oranges during storage under ambient and refrigerated conditions for 17 days duration, increased with increasing storage period under both storage conditions. High temperatures are well known to result in increased rates of respiration, deterioration, and water loss in fresh produce, leading to reduced market, food, and nutritional values (Hailu and Derbew, 2015).

3.4.2 Fruit pulp firmness

Results showed that regardless of post-harvest techniques used, and the storage time at assessment, the firmest fruits were those treated with hexanal followed by those treated with calcium chloride. Similar results were reported by Sharma *et al.* (2010) in sweet cherries. Paliyath *et al*. (2008) also reported high firmness in fruits treated with hexanal formulations after harvest. Hexanal acts as a strong inhibitor of Phospholipase D action, and thus slows down ethylene stimulation of fruit ripening and softening processes (Karthika *et al.*, 2015). Calcium chloride treated fruits had higher firmness than untreated controls. Calcium chloride has been used as a firming agent for many fruits and vegetables (Mishra, 2002). Calcium chloride accumulates in the cell walls leading to facilitation of the cross linking of the pectic polymers, which increases cell wall strength and cell cohesion (Akhtar *et al*., 2010). The greater firmness in hexanal- and calcium chloride treated fruits may also be associated with fruit cells' turgidity, which maintains fruit freshness and increases fruit shelf life.

Results demonstrated that smoke treatment leads to increased fruit softness and senescence. Burning one kilogram of wood produces 2.245 g of ethylene (Todd and Good, 2003), which means that the effects of smoke are expected to be similar to those of ethylene (Porat *et al.*, 1999). Fruit firmness is one of the most important fruit quality parameters and thus the degree of fruit firmness has been used as an indicator of fruit quality. Further, firmness is one of the final indices that buyers use to make decisions as to whether to buy fruits or not (Batu, 2003). It is therefore important to extend fruit firmness so that shelf life and produce acceptance by buyers are improved, which will also result in reduced produce loss.

The reduced temperature storage conditions led to firmer fruits than the ambient storage conditions. This could be due to reduced metabolic reactions in fruits stored at the reduced temperature. Wardowski *et al*. (2006) reported that citrus firmness undergoes changes during storage depending on storage conditions, especially humidity. The firmness of most fruits and vegetables showed decreased firmness with increasing temperatures (Bourne, 1982). The fruits stored under reduced temperature conditions were firmer than the fruits stored in ambient storage, regardless of the variety.

3.4.3 Fruit juice total soluble solids

Hexanal and calcium chloride treated fruits had lower values of total soluble solids than smoke-treated oranges at eight days after harvest. This was due to delayed fruit ripening in the hexanal- and calcium chloride- treated fruits. It has been reported that hexanal slows down ethylene-induced fruit ripening and softening processes (Karthika *et al*., 2015). The higher total soluble solids content in smoke-treated fruits was due to the accelerated breakdown of starch, and ripening of the fruits caused by smoke. Goldschmidt (1997) reported that citrus fruits reveal ripening-related symptoms in response to exogenous ethylene treatment. On the contrary, Mayuoni *et al*. (2011) reported that ethylene had no effects on total soluble solids and acidic contents of citrus fruit juice. Like this study, Akhtar *et al*. (2010) also reported higher values of total soluble solids content in calcium chloride-treated fruits and the lowest values in the control group.

3.4.4 Fruit juice titratable acidity

The quality of orange juice is influenced by physico-chemical parameters such as pH, total soluble solid content, and total titratable acidity. Citric acid is the dominant organic acid in citrus fruits (Etienne *et al*., 2013) and it determines the fruits’ organoleptic quality. In our study, the oranges' titratable acidity decreased significantly with storage duration, but it was not affected by post-harvest treatments used. The titratable acidity was high at harvest and decreased with storage time, with higher values seen in ambient storage conditions than in reduced temperature storage conditions. During fruit ripening, starch is converted into sugar, which contributes to the sweetness of the fruits. The ripening of fruits is associated with softening, sweetening (or decreased bitterness) and colour change. The reduction in acidity is due to the conversion of the acids into sugars and their further use in the metabolic processes of the fruits. Faasema *et al*. (2011) reported a similar result of decreased acidity in citrus fruits during storage.

3.4.5 Fruit juice total soluble solids/titratable acidity ratio

The sugar to acid ratio (TSS/TA ratio) was influenced by storage conditions, and there was a higher TSS/TA ratio in ambient storage conditions than in reduced temperature storage conditions at the fourth day after fruit harvest. This could be due to decreased fruit acidity during ripening, and the reduced fruit metabolic activities in reduced temperature storage. The TSS/TA ratio is a key characteristic determining the taste and texture of fruit, and it contributes to characteristic fruit flavours (Wardowski *et al*., 2006). The TSS/TA ratio is a more reliable index of maturity than rind colour in sweet oranges especially in the humid, tropical regions (Ladaniya, 2008). Although the respiratory rates of mature citrus fruits are relatively low, extended post-harvest storage can result in internal quality changes (Echeverria and Ismail, 1987). It can be inferred that longer storage duration positively influenced the TSS/TA ratio of fruits in the current study.

3.5 Conclusion and Recommendations

The current study shows that hexanal treatment reduces physiological weight loss, and improves total soluble solids content and firmness in both Msasa and Jaffa oranges up to eight days of storage. Similarly, calcium chloride treatment reduces physiological weight loss, increases total soluble solids content, and increases firmness of oranges. Conversely, smoke treatment increases physiological weight loss and reduces fruit firmness under both ambient (room) and reduced temperature storage conditions with the latter giving better results. Based on the results of this study, treatments with either hexanal formulation or calcium chloride coupled with reduced temperature storage at (18 ± 2 °C) are recommended for the maintenance of quality of fresh oranges in Tanzania. On the contrary, smoke treatment is highly discouraged as it reduces the quality of oranges. Further studies are required on the cost-benefit analysis of hexanal and calcium chloride treatment of oranges. Research is also needed to evaluate the effect of hexanal and calcium chloride treatments on the quality maintenance of other tropical fruits in Tanzania.

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CHAPTER FOUR

4.0 EFFECTIVENESS OF SMOKE, HEXANAL AND CALCIUM CHLORIDE IN IMPROVING THE POST-HARVEST QUALITY OF MANGO (*Mangifera indica*, L.) IN TANZANIA

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Abstract

Experiments were conducted at the Sokoine University of Agriculture to assess the effects of hexanal, calcium chloride, and smoke on the post-harvest quality of mango under different storage conditions and storage durations. Two varieties of mango namely Palmer and Apple were used. A three factors factorial experiment was used for each variety and replicated six times. Post-harvest factor included dipping fruits in hexanal solution (0.02% v/v) for five minutes; dipping fruits in calcium chloride solution at (2% w/v) for five minutes; and smoke treatment obtained from burning 1.0 kg of dried banana leaves three times at 12 - hour intervals. The control group was not treated. The fruits were stored at ambient temperature (28 ± 2 °C) or cold (18 ± 2 °C) storage conditions. Data was collected at three different storage durations (at 4th, 8th, and 12th days after harvest). Data included physiological weight loss (PWL), fruit firmness, total soluble solids (TSS), titratable acidity (TA), and TSS/TA ratio. Analysis of variance (ANOVA) was performed using R statistical software. Results indicated that hexanal and calcium chloride techniques significantly ($p < 0.001$) reduced mango PWL and improved fruit firmness of both varieties compared to smoke treated and untreated fruits. Moreover, TSS were significantly ($p < 0.001$) higher in hexanal and calcium chloride treated mango than the smoke treated fruits. Cold storage also significantly ($p < 0.001$) lowered PWL of hexanal and calcium chloride treated Palmer and Apple mango fruits compared to the smoke treated fruits and untreated controls. The TSS of both varieties significantly increased ($p < 0.001$) with storage duration and storage temperature. The TA decreased with storage duration irrespective of the storage conditions used. Based on the results of this study, hexanal solutions and calcium chloride solution are recommended for use in mango fruit treatment. On the contrary, smoke treatment is discouraged as it reduces the quality of mango fruits. Further studies are required for determination of smoke composition and quantification of ethylene amount present in burnt vegetation.

Keywords: Shelf life, physiological weight loss, fruits firmness, total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio

4.1 Introduction

Post-harvest loss refers to measurable quantitative and qualitative food loss in the post-harvest system (Kiaya, 2014). The post-harvest losses and quality deterioration are among the contributing factors for the low availability of mango fruits in markets (Kasso and Bekele, 2018). Fruit losses and deterioration occur as a result of fruit damages and injuries, over-ripening and rotting as a consequence of overproduction and storage problems (Musasa *et al.*, 2013; Ezekiel *et al.* 2014; Strano *et al.*, 2017). Post-harvest losses of fruits are extremely high and are estimated to be 35 to 40% in the tropics and subtropics (Kumar and Bhatnagar, 2014). However, losses of 48 to 60% were recorded in fresh mango in Tanzania (Msogoya and Kimaro, 2011).

Reduction of post-harvest losses and quality deterioration are essential in increasing food availability from existing production (Kasso and Bekele, 2018). Various techniques are used by farmers in preparing their fruits for different market segments. Farmers in developing countries have been using different locally available post-harvest treatments such as smoke to hasten ripening of climacteric fruits such as dessert banana. Techniques like smoking enhances mass fruit ripening for transport where a large volume of fruits is needed (Saltveit, 1999). However, fruits treated with smoke do not attain uniform colour and flavour due to persistence of smoke odour on the product (Jobling, 2010; Mamiro *et al*., 2007).

Post-harvest treatment with calcium chloride has been widely used as firming agent and preservative for both whole and fresh-cut fruits and vegetables (Florkowski *et al.*, 2009; Bertzer *et al*., 2002; Mishra, 2002; Lara *et al*., 2004). The use of hexanal (Phospholipase D inhibition technique) is an emerging technique for reducing post-harvest losses of horticultural produce (Paliyath, 2011). Hexanal is a naturally occurring aldehyde compound produced by plant tissue upon wounding, that inhibits the activities of Phospholipase D enzymes. A Phospholipase D enzyme initiates membrane degradation during ripening and senescence of fruits which results into fruits deterioration (Paliyath *et al*., 2008).

Post-harvest fruit treatment using hexanal enhanced freshness and shelf life of various fruits (Paliyath *et al.*, 2008). Hexanal treatments delayed ripening and senescence of fruits thus extended fruit shelf life (Paliyath and Droillard, 1992; Paliyath, 2011; Paliyath *et al.*, 2008). However, there is insufficient information on the effect of hexanal application on physiological and chemical qualities and post-harvest losses of fruits such as mango in tropical Africa. Also, post-harvest techniques and practices used smallholder farmers and their effect on quality of fruits are not well evaluated and documented. The objective of this study was to assess the effects of different post-harvest techniques on the quality of mango fruits.

4.2 Materials and Methods

Two mango varieties, Apple and Palmer, were harvested from Lunyala village in Mwarusembe ward in the Mkuranga district, Coast region in eastern Tanzania. Harvesting was done during December 2016 and December 2017 mango seasons. Apple and Palmer are the commonly grown mango varieties in the study area, for both local and export markets. Three post-harvest techniques were used (i) dipping of fruits in hexanal solution, (ii) dipping of fruits in calcium chloride solution, (iii) smoke treatment. Untreated fruits were included as control. Fruits were stored under ambient and cold storage conditions.

Calcium chloride solution at (2% w/v) and hexanal solution at (0.02% v/v) were used. Fruits were dipped in either hexanal formulation or calcium chloride solutions. Smoke obtained from burning of 1.0 kg of dried banana leaves was pumped into a chamber with a volume of 12 m^3 at an interval of 12 hours for duration of 36 hours. Before a subsequent smoke treatment, the chamber was ventilated for 30 minutes by opening its window and doors. The chamber was located six meters from the source of smoke to reduce heat transfer to the mango fruits. There were two storage conditions: ambient storage (28 ± 2 °C) and cold storage (18 ± 2 °C). Data was collected on 4th, 8th, and 12th day from the date of fruit harvest (DAH). Thirty fruits of each variety were exposed to each treatment and each treatment was replicated six times making a total of 360 fruits per treatment.

Data was collected on fruit weight (PWL), firmness, total soluble solids (TSS), and titratable acidity (TA). Physiological weight loss and the total soluble solids/titratable acidity (TSS/TA) ratio were calculated. The physiological weight loss was determined by randomly selecting five fruits from each treatment. The selected fruits were numbered and used for measurement of initial and final weights using an electronic balance (BX 4200H, Shimadzu, Japan) and percentage fruit weight loss was calculated. A small peel disc (approx. 2 mm^2) on the opposite side of the fruit cheek was removed, and then fruit firmness was measured using a penetrometer (Wagner fruit test, FT 20 Model, Wagner Instruments, Italy). Total soluble solids content (°Brix) was measured using a hand-held digital refractometer (ATAGO, Japan) according to Nielsen (2010). Titratable acidity of the juice was determined by titration with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The titratable acidity (%) was estimated according to Ranganna (1999) and expressed as percent anhydrous citric acid. The TSS/TA ratio was computed by dividing the TSS by the TA (%). The data were analysed using R software and means were separated using Tukey's Honestly Significant Differences at ($p \leq 0.05$). Data for each variety was analysed separately.

4.3 Results

4.3.1 Physiological Weight Loss

The ANOVA results showed that post-harvest techniques and storage duration had significant ($p < 0.001$) effects on PWL of both Apple and Palmer mango varieties. Storage conditions had significant ($p = 0.024$) and ($p < 0.001$) effects on PWL of Apple and Palmer fruits respectively. All the interactions for both Apple and Palmer varieties had non-significant ($p > 0.05$) effects on PWL. Analysis of main means showed that post-harvest techniques had significant ($p < 0.001$) effects on physiological weight loss of both mango fruits varieties (Fig. 4.1). On overall, physiological weight loss of Apple mango was lowest in hexanal, followed by calcium chloride treated fruits while the untreated and smoke treated had the highest PWL. The lowest PWL in Apple variety was 3.57% recorded at hexanal treated fruits, which was lower by 3.55% compared to untreated fruits. The Palmer variety had the lowest physiological weight loss (3.98%) which was recorded at hexanal treated fruits, which was lower by 1.62% compared to untreated fruits.

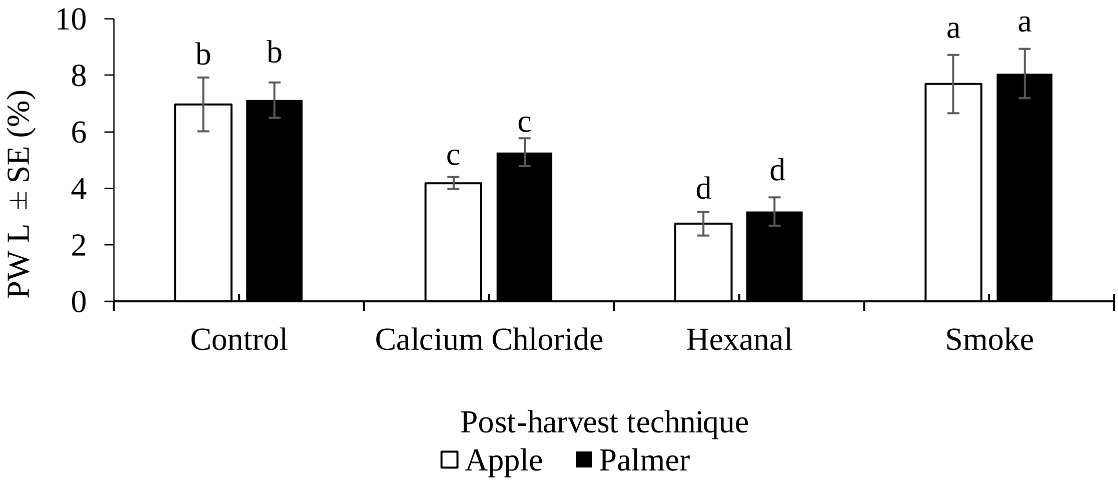

Figure 4.1: Effects of post-harvest techniques on physiological weight loss of Apple and Palmer mango variety

Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

4.3.2 Fruit Firmness

Firmness of both Apple and Palmer mango fruits were significantly affected by post-harvest techniques ($p < 0.001$), storage duration ($p < 0.001$) and storage conditions ($p < 0.001$). The post-harvest techniques × storage durations had significant ($p < 0.001$) and ($p = 0.017$) on fruit firmness of Apple and Palmer respectively. All other interactions had non-significant ($p > 0.05$) effects on fruit firmness. Analysis of simple means showed that post-harvest techniques had significant ($p < 0.001$) and ($p = 0.017$) effect on fruit firmness of both Apple and Palmer varieties at 4 DAH but not at 8 DAH and 12 DAH ($p > 0.05$) (Fig. 4.2). The hexanal treated fruits had the highest fruit firmness, followed by calcium chloride treated and untreated fruits while the smoke treated fruits had the softest fruits.

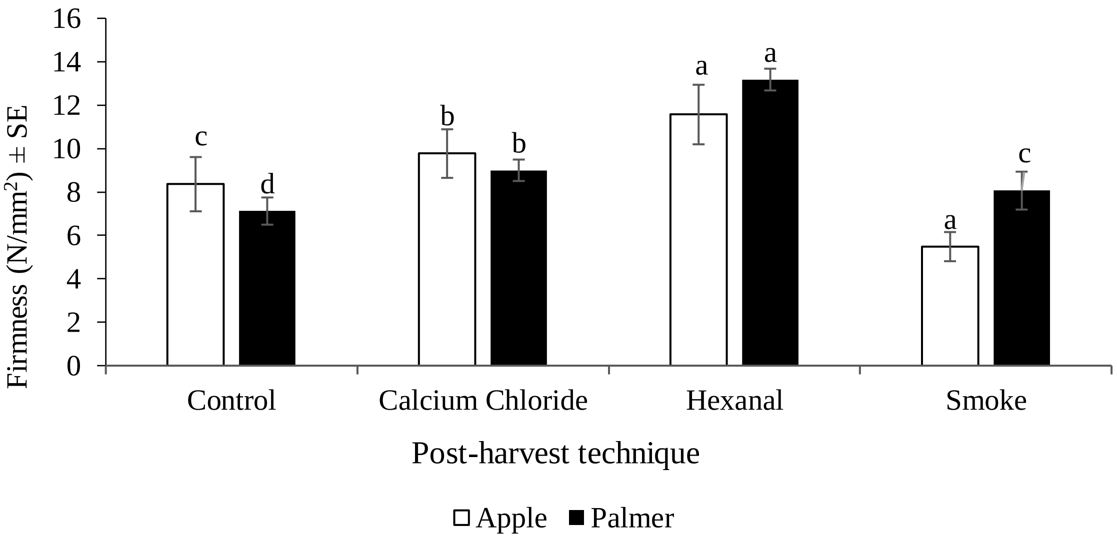

Figure 4.2: Effects of post-harvest techniques on firmness of Apple and Palmer mango variety

Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

4.3.3 Total Soluble Solids

Results showed significant effects of post-harvest techniques ($p < 0.001$) and storage duration ($p < 0.001$) on TSS of both Apple and Palmer mango fruits. The storage condition had significant ($p < 0.001$) effects on TSS of Apple variety but not on Palmer variety. All the interactions for both varieties had non-significant ($p > 0.05$) effects on TSS. Further analysis of main means showed that post-harvest techniques had significant ($p < 0.001$) effects on TSS of both Apple and Palmer mango fruits (Fig. 4.3). The highest total soluble solids value in Apple mango fruits was 21.43 °Brix recorded in fruits treated with hexanal which was higher by 4.3 °Brix compared to untreated fruits which had 17.13 °Brix. On the other hand, the highest total soluble solids value in Palmer fruits was 20.76 °Brix recorded fruits treated with hexanal which was higher by 2.76 °Brix compared to untreated fruits which had the TSS of 18.0 °Brix.

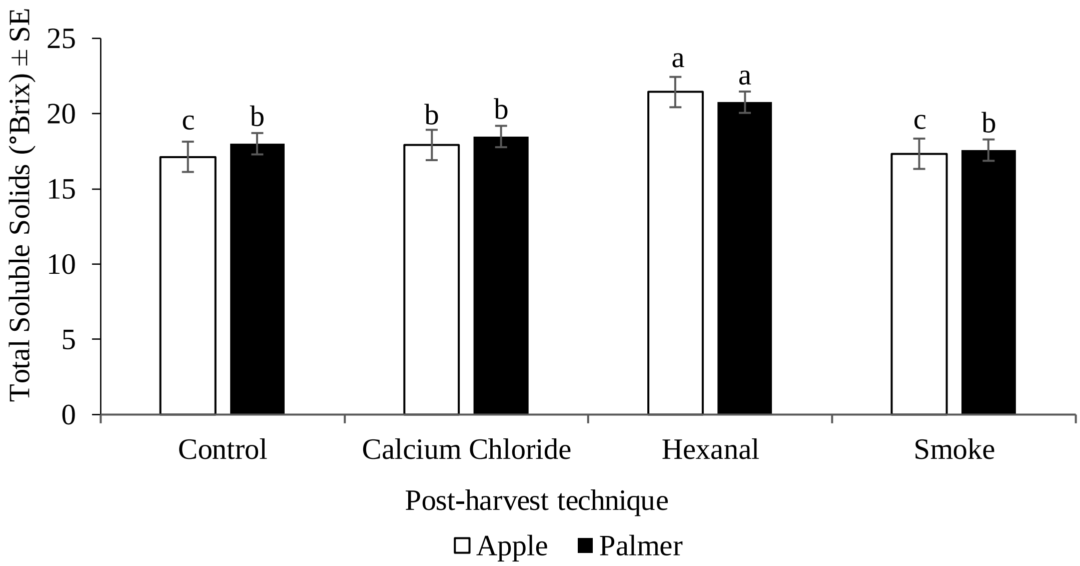

Figure 4.3: Effects of post-harvest techniques on total soluble solids of Apple and Palmer mango variety

Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

4.3.4 Titratable Acidity

Titratable Acidity (TA) of both Apple and Palmer fruits varieties were significantly affected by storage duration ($p < 0.001$). The effect of storage conditions, post-harvest techniques and all interactions had non-significant ($p > 0.05$) effects on TA of both fruit varieties. Analysis of main means showed that storage duration had significant ($p < 0.001$) effects on titratable acidity of the two mango varieties (Fig. 4.4). The titratable acidity of mango fruits was decreasing as the storage time was increasing. The fruits had the highest titratable acidity values of (2.02% and 1.44%) at 4 DAH while the lowest titratable acidity values (0.78% and 0.54%) were at 12 DAH for Apple and Palmer fruits respectively (Fig. 4.4).

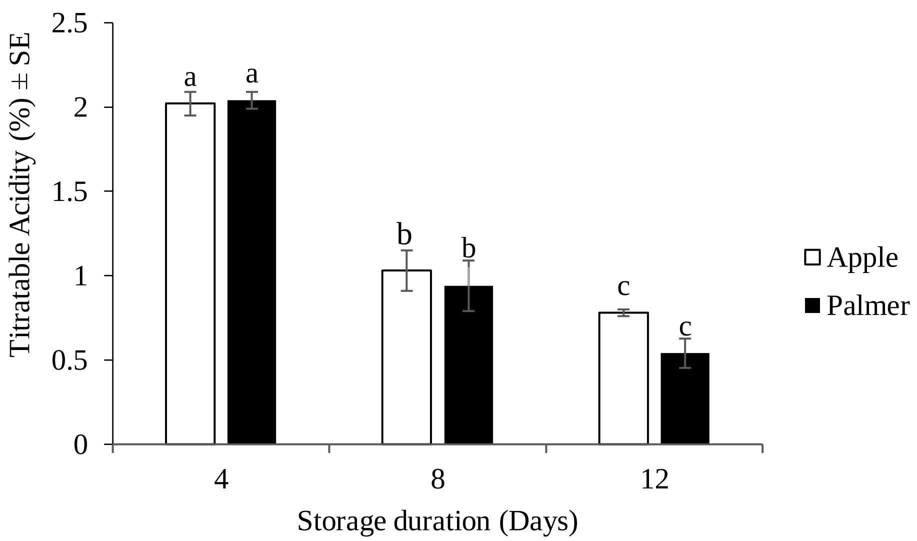

Figure 4.4: Effects of post-harvest techniques on titratable acidity of Apple and Palmer mango variety

Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

4.3.5 Total Soluble Solids/ Titratable Acidity (TSS/TA) ratio

ANOVA results showed that storage duration had significant ($p < 0.001$) effects on TSS/TA ratio of Apple and Palmer mango fruits. Effect of post-harvest techniques, storage conditions and all interactions had non-significant ($p > 0.05$) effects on TSS/TA of both mango fruits. Further analysis of main means showed that storage duration had significant ($p = 0.022$) effects on TSS/TA ratio of Apple and ($p < 0.001$) in Palmer mango fruits (Fig. 4.5). Generally, TSS/TA ratio of Apple mango fruits was increasing with increasing duration in storage. The TSS/TA ratio was low at 4 days after storage and highest at 12 days after storage.

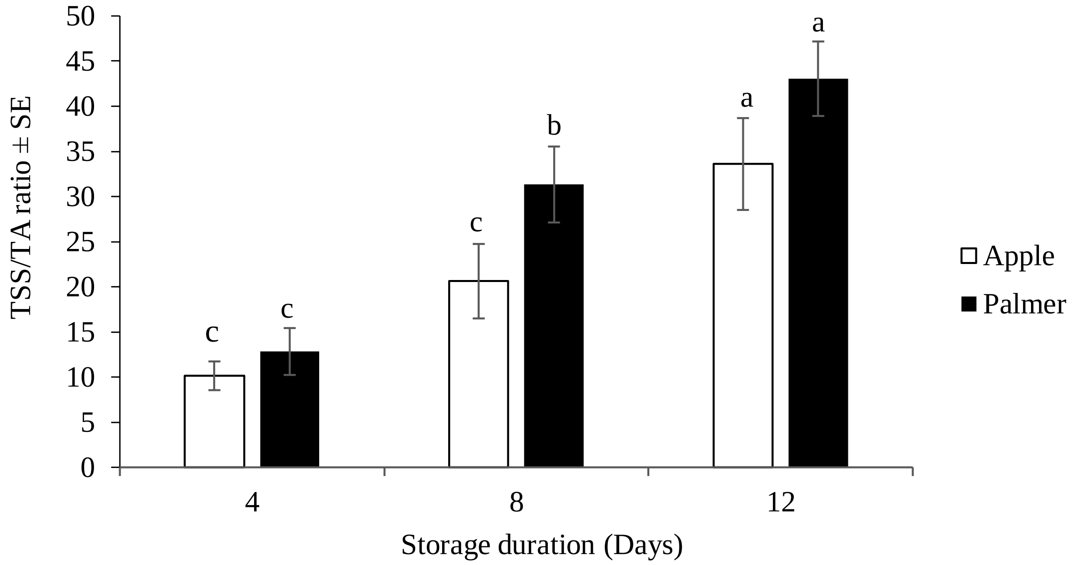

Figure 4.5: Effects of post-harvest techniques on TSS/TA ratio of Apple and Palmer mango variety

Means with same letters in the same variety are not significantly different at $p \leq 0.05$ (Tukey test)

4.4 Discussion

The post-harvest techniques affected physiological weight loss of mango fruits. Smoke treated mangoes had higher physiological weight loss than calcium chloride and hexanal treated fruits. The hexanal treated and calcium chloride treated fruits had lower physiological weight loss than untreated control and smoke treated fruits. Preethi *et al* (2017) reported reduced weight loss, maintained fruit firmness and improved sugar content in hexanal treated mago fruits. Smoke treated fruits lost their freshness earlier compared to the other tested techniques and the control. The high physiological weight loss in smoke treated fruits was associated with the high ethylene produced which accelerated fruits ripening, softening and deterioration. The fruits also lost a lot of water through metabolic activities like respiration. Respiration and transpiration are the two vital processes and are necessary to keep the tissue alive after harvesting of commodities (Patel *et al*., 2016; Ambuko *et al*., 2017).

Hexanal treated fruits had low physiological weight loss regardless of the concentration we used. The effect of hexanal and calcium chloride in reducing the physiological weight loss was significant in both treated Palmer and Apple mango varieties compared to untreated fruits. Physiological weight loss of harvested fruits is a major cause of quality and economic loss which limits shelf life (Preethi *et al.,* 2017). The calcium chloride treated fruits also had low physiological weight loss regardless of the concentration used. Calcium delayed senescence and rate of respiration and transpiration in mangoes, and thus reduced their physiological weight loss. Calcium binded polygalactonic acid to each other and made the membrane of tomato strong and rigid (Bhattarai and Gautam, 2006). Calcium chloride stabilized cellular membranes and consequently delayed the senescence in horticultural produce (Dhillon and Kaur, 2013; Akhtar *et al*., 2010).

The physiological weight loss increased with time regardless of the technique used. Carillo *et al*. (2000) reported increased trend of weight loss with the passage of storage time of Haden mango. hexanal and calcium chloride treatment resulted to significantly more fresh mango fruits with better quality and long shelf life compared to smoke and control under both ambient and cold storage conditions. High temperatures are well known to result in increased rates of respiration, deterioration, and water loss in fresh produce, leading to reduced market, food, and nutritional values (Gerbu *et al*., 2017). Shrivelled fruit skin gives bad appearance and mango fruits with smooth skin and no shrivelling fetch better price in the market (Anjum and Ali, 2004).

The hexanal treated fruits had the firmest fruits compared to calcium chloride, untreated and smoke treated fruits under both storage conditions and duration. The increased firmness in hexanal treated fruits might be due to inhibition of Phospholipase D enzyme, which is responsible for initiation of membrane degradation during fruit ripening and senescence. Jincy *et al. (*2017) reported slow ethylene stimulation of hexanal treated fruit during ripening and softening to be associated with inhibition of Phospholipase D enzymatic activities. Post-harvest use of hexanal was reported to increase firmness in sweet cherries, apple, peach, tomato and pear (Sharma *et al*., 2010; Paliyath *et al*., 2008).

Calcium chloride treated mango fruits had higher firmness than untreated controls. The higher firmness resulted from reduced rate of ripening, caused by low respiration rates and reduced ethylene production. Post-harvest calcium application maintains cell turgor, membrane integrity, tissue firmness and delays membrane lipid catabolism, extending storage life of fresh fruits (Manganaris *et al*., 2005). Akhtar *et al*. (2010) reported that accumulation of calcium chloride in the cell walls facilitated cross linking of the pectic polymers which increases cell wall strength and cell cohesion. The greater firmness in hexanal and calcium chloride treated fruits might also be associated with fruit cells' turgidity which maintains fruit freshness and increases fruit shelf life.

The smoke treated fruits were softer than untreated fruits. The reduced firmness in smoke treated fruits was caused by accelerated early ripening, which is associated with induction of ethylene produced by the burning vegetation during the smoking process. Fruit softening is due to breakdown of the cell wall and middle lamellae induced by pectinases and cellulases and the consequent loss of cell-wall integrity (Fischer and Bennet, 1991). Smoke from burnt vegetations are made up small particles, gases such as carbon monoxide, methane, ethane and propane (Todd and Good, 2003) as well as ethylene and water vapor, makes up the majority of smoke. The cold storage conditions led to firmer fruits than the ambient storage conditions. This could be due to reduced metabolic reactions in fruits stored at the reduced temperature. Low temperature decreases respiration rate and retards ripening and senescence (Fischer and Bennet, 1991). Fruits firmness is one of the attributes that determine customer's decisions to buy a particular fruit (Batu, 2003).

Hexanal and calcium chloride treated fruits had lower values of total soluble solids than smoke treated mango at eight days after harvest. This might be due to delayed fruit ripening in the hexanal and calcium chloride treated fruits after four and eight days of storage compared to untreated fruits. After twelve days of storage the hexanal treated fruit had the highest total soluble solids values than other treated and untreated fruits. This might be caused by delayed ripening in hexanal treated fruits due to inhibition of Phospholipase D enzymatic activities. The hexanal was reported to improve the total soluble solids of cherry, peach and pear fruits (Paliyath *et al*., 2008). Hexanal delayed fruit ripening and softening processes in horticultural produce (El Kayal *et al*., 2017; Karthika *et al.*, 2015).

After twelve days of storage, calcium chloride treated fruit had the TSS similar to untreated fruits. On contrary, Akhtar *et al*. (2010) reported higher values of total soluble solids content in calcium chloride treated fruits and the lowest values in the control group. On the other hand, the smoke treated fruits had the high TSS values at four and eight days of storage than untreated fruits. This might be due to the accelerated breakdown of starch, and ripening of the fruits caused by ethylene released by the burnt vegetation during the smoking treatments.

The hexanal treated fruits had the lowest titratable acidity compared to untreated control. The calcium chloride treated fruits and untreated fruits had similar values of TA while the smoke treated fruits had the highest values of TA. The titratable acidity affected by storage time of fruits, and it was decreasing with increasing time of storage. The decreased acidity during fruit ripening might be due to conversion of starch to simple sugars. During fruit ripening, acids in unripe fruits are broken down into the sweeter rather than sharp tastes (Medlicott and Thompson, 1985). Titratable acidity is directly related to the concentration of organic acids present in the fruit, which are an important parameter in maintaining the quality of fruits (Akhtar *et al*., 2010). In general, young fruits contain more acids that may decline during maturation and ripening due to their conversion to sugars during gluconeogenesis (Paliyath *et al*., 2008). The TA was not affected by storage conditions used in this study.

The TSS/TA ratio is the most reliable indicator of fruit maturity and taste which influence the consumer's purchase intention (Liu *et al*., 2016; Su *et al*., 2005). The TSS/TA was increasing with storage time, but not with storage conditions. The effects of cultivar, stage of maturity, post-harvest treatments and storage conditions on sugar and acid levels in mango have been studied extensively (Malundo *et al*., 2001; Tharanathan *et al*., 2006). The changes in TA and TSS values were reflected in the TSS/TA ratio, which increased with storage period among fruit harvests.

4.5 Conclusion and Recommendations

The results showed that hexanal treatment reduces physiological weight loss, and improves total soluble solids content and firmness in both Apple and Palmer mango fruits. Similarly, calcium chloride reduces physiological weight loss, increases total soluble solids content, and increases firmness of mango fruits. Conversely, smoke treatment increases physiological weight loss and reduces fruit firmness under both ambient and cold storage durations. The cold storage condition reduces the physiological weight loss, and maintains fruit firmness and total soluble solids content better than the ambient storage condition. Based on the results of this study, fruits treatment with either hexanal formulation or calcium chloride coupled with cold storage at (18 ± 2 °C) are recommended for the maintenance of quality of fresh mangoes in Tanzania. On the contrary, smoke treatment is highly discouraged as it reduces the quality of treated fruits. Further studies are required on the cost-benefit analysis of hexanal and calcium chloride treatment of mango fruits. Research is also needed to evaluate the effect of hexanal and calcium chloride techniques on the quality maintenance of other tropical fruits in Tanzania.

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CHAPTER FIVE

5.0 POST-HARVEST LOSS AND EFFECTS OF POST-HARVEST TECHNIQUES AND STORAGE CONDITIONS ON SHELF LIFE AND QUALITY OF ORANGE (*Citrus sinensis* (L.) Osbeck) FRUITS IN TANZANIA

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Abstract

Experiments were conducted at the Post-harvest Laboratory of the Sokoine University of Agriculture to assess the effects post-harvest techniques on the shelf life of oranges under different storage conditions. Post-harvest loss of oranges along the supply chain was also evaluated. Two varieties of oranges namely Msasa and Jaffa were used. A two factors factorial experiment was used for each variety, which was replicated six times. The sources of variation were post-harvest techniques and storage conditions. Post-harvest techniques included hexanal solution, calcium chloride solution, smoke treatments and the control which consisted of untreated fruits. The fruits were then stored in two different storage conditions: ambient temperature (28 ± 2 °C) and cold storage (18 ± 2 °C). The shelf life data were analysed by using R - software and where significant differences existed, the Tukey Honestly Significant Difference (HSD) ($p \leq 0.05$) was performed to separate the treatment means. Results showed that the major losses occurred at harvest and transportation stage and in the wholesale and retail markets of the supply chain. Furthermore, results indicated that post-harvest techniques of fruits with hexanal and calcium chloride significantly increased the fruits shelf life ($p < 0.001$) and reduced disease incidences ($p < 0.001$) compared with untreated control and smoke treated fruits. On the other hand, storage of fruits in cold condition significantly ($p < 0.001$) increased shelf life of the orange fruits compared to the ambient storage condition. Therefore, hexanal, calcium chloride and cold storage are recommended for extended shelf life, maintained fruit firmness and reduced disease incidence of green mold disease in orange fruits.

Keywords: Hexanal, calcium chloride, smoke, supply chain, firmness change, disease incidence

5.1 Introduction

Post-harvest loss is a fraction of a produce that is rendered unfit for a particular use; whereas the term quality implies the degree of excellence or suitability of a product for a particular use (Abbott, 1999). Orange (*Citrus sinensis* (L.) Osbeck) is a member of the Rutaceae family, along with other fruits such as mandarins, lemons, grapefruits and limes (Musasa *et al*., 2013). Global orange production for 2015/16 was 50.2 million tonnes with higher producers being Brazil, China and United States of America (USDA, 2015).

Tanzania is the largest citrus fruit producer in East Africa after Kenya and Uganda (Makorere, 2014). Orange is one of the most important fruit crops in Tanzania grown mostly produced in Tanga, Morogoro, Coast, Ruvuma and Mwanza regions. Major varieties grown include early Valencia (Msasa), Jaffa (Shamouti), Mediterranean Sweet (Nairobi), Late Valencia, Pineapple (Pamba), Washington Navel, Matombo Sweet and Zanzibar (MMA, 2008). The fruits produced in Tanga are both for domestic and export markets (Tu, 2008).

The supply of oranges in market is controlled by the merchant wholesalers who purchase the fruits from growers at a lower price and dispose off to different markets (Mahanta *et al*., 2014). Most of the harvested fruits are sold to wholesalers who transport and sell them to the retailers at distant markets (Tu, 2008). Fruits are liable to damage and deterioration during harvesting, transportation, marketing and storage, if not properly handled (Ilyas *et al*., 2007; Murthy *et al*., 2009).

Citrus industry in developing countries has been facing numerous post-harvest problems, leading to both high quantitative and qualitative losses (Malik *et al*., 2004). Orange production is constrained by pests, low soil fertility, management inefficiencies, climate variability, unreliable markets and fruit losses both in field and after harvest (Bhat *et al*., 2015; Tu, 2008; Bhandare *et al*., 2014). Post-harvest losses in horticultural crop production pose challenge in both developing and developed countries (Musasa *et al*., 2013). Post-harvest losses can occur at any stage in the supply chain hence there is a need to consider the whole supply chain to determine the losses (Musasa *et al*., 2013). However, information on post-harvest losses of orange is spotty and scanty, and the shortage is more severe in southern and eastern Africa, where past studies concentrated mainly on maize (Affognon *et al*., 2014).

Fruit traders normally buy fruits at farm gate but destined for local and international markets (Makorere, 2014). There are no specialized post-harvest storage facilities, post-harvest treatments or refrigerated trucks. Gebre-Mariam (1999) reported lack of post-harvest and marketing infrastructures such as packaging, cold storage, pre-package and distribution, post-harvest treatment and washing facilities together with production constraints as the major challenges leading to low productivity and considerable post-harvest loss of fruits. Thus, losses are observed at harvesting, during packing, transportation, in wholesale and retail markets, and during delays at different stages of handling (Kitinoja *et al*., 2010) which are caused by unseen delay at custom, traffic delay and trucks breakdown, high toll charges or delay in unloading. These challenges necessitate a need to extend the shelf of fruits.

5.2 Materials and Methods

Jaffa and Msasa varieties of orange fruits were harvested from Bwembera (05°13'59.9" S, 038°46'33.1"E, and 263 metres above sea level) and Semngano (05°14'14.8" S, 038°46'33.1"E, and 254 metres above sea level) villages in Muheza district, Tanga region in northern Tanzania. They were hand-picked from different trees and collected by using plastic woven bags (*viroba*) and pilled at selected points in the farm under shade. Then, marketable and unmarketable fruits were separated. The marketable quality of the fruits was subjectively assessed according to method by Mohammed *et al.* (1999) with some modifications. On each sampling time, marketability of the fruits was judged using a 1 to 9 rating scale, with 1 = unusable, 3 = unsalable (poor), 5 = fair, 7 = good, 9 = excellent; to evaluate the fruit quality. The mechanical damage, disease and insect freedom, softness, surface defects, and shrinkage were used as visual parameters for the rating. Fruits that received a rating of five and above were considered marketable, while those rated less than five were considered unmarketable.

5.2.1 Post-harvest losses evaluation

The marketable fruits were loaded in the open bodied truck and transported to Sokoine University of Agriculture, Morogoro (295 km away). On arrival, the transported fruits were sorted to remove all the unmarketable fruits and record was established on their respective cause of damage. The remaining marketable fruits were packed in the bamboo woven baskets cushioned with dry grass and allowed to stay under shade for three days to simulate the wholesale market conditions. On the third day after harvest, the fruits were evaluated and the number of unmarketable fruits with their respective cause of damage were recorded. The remained marketable fruits were counted and then repacked in bamboo baskets and allowed to stay under shade for six more days to simulate the retail market conditions in low demand season. Post-harvest losses (%) were evaluated according to method by Msogoya and Kimaro (2011) with some modifications. A total of 5000 fruits of each variety were assessed where all unmarketable fruits were removed with their respective cause of damage recorded. The causes of fruits damage were identified as either due to mechanical damage, microbial decay, softening or insect damage and their actual post-harvest losses (%) worked out. The experiment was conducted for the two consecutive orange main seasons in July 2016 and July 2017.

5.2.2 Shelf life, Change in fruit firmness and incidences of post-harvest disease

The effectiveness of different concentrations of calcium chloride, hexanal and smoke on shelf life, change in fruit firmness and incidences of postharvest diseases of Jaffa and Msasa orange varieties were studied. Fruits were dipped in calcium chloride solution (2%

w/v) and hexanal solution (0.002% v/v) for five minutes. Smoke was obtained by burning 1.0 kg of dried banana leaves which was pumped into a chamber with a volume of 12 m^3 at an interval of 12 hours for duration of 36 hours. Before a subsequent smoke treatment, ventilation of the chambers was done for 30 minutes by opening window and doors of the chamber. The chambers were located six meters from the source of smoke to reduce heat transfer to the oranges. Untreated fruits were included as control. The treated and untreated fruits were either stored under ambient (28 ±2 °C) or in cold (18 ± 2 °C) storage conditions.

From these treated and untreated fruits, the shelf life, change in fruit firmness and incidence of prevailing postharvest diseases were determined a follow: Shelf life was determined as the period (in days) through which the fruits remained marketable until 50% of the fruits was considered unmarketable. The fruits were assessed daily and when 50% of the fruits were rendered unmarketable, they were discarded and the number of days recorded. Fruit softening (firmness changes or change in firmness) was evaluated by using a penetrometer (Wagner fruit test FT 20 Model, Wagner Instruments, Italy). Thirty fruits of each variety were exposed to each treatment. Degree of fruit softness was computed by deducting the final firmness measured at 12 days after storage from the initial firmness (measured at time of harvest).

Fruits with decay symptoms were isolated and the causal agents of decay were identified to species level based on symptoms, colony cultures, and morphological characteristics with an aid of microscope and a compendium of post-harvest diseases (Whiteside *et al.*, 1993; Snowden, 2008). The incidence of post-harvest diseases was calculated as the percentage of diseased fruits out of the total number of fruits sampled in each treatment.

The incidence data were arcsine transformed before analysis. Thirty fruits of each variety were exposed to each treatment. The factorial experiment with six replications was used. Data was analysed by using R - software. Post Hoc was done by using Tukey Honestly Significant Difference (HSD) at ($p \leq 0.05$).

5.3 Results

5.3.1 Post-harvest loss at different stages of orange supply chain

Table 5.1 presents post-harvest losses (%) of Msasa and Jaffa orange varieties along their supply chains. Separate experiments were performed for each fruit variety and results are conveniently reported in within same sections. The post-harvest losses (%) of Msasa and Jaffa orange varieties along their supply chains are presented in Table 5.1. Total post-harvest loss for Msasa ranged from 39.60% to 40.19% while loss for Jaffa ranged from 45.77 to 52.42%. The average post-harvest loss of orange fruits was 44.35%. Lowest losses were recorded at harvest stage while highest losses were recorded at retail stage. Post-harvest losses of Msasa were generally lower than those of Jaffa. Chi square (χ^2) results showed that loss along the supply chain stage was significantly dependent on variety during 2016 ($\chi^2_{(1)}$ =10.83, p = 0.001) and 2017 ($\chi^2_{(1)}$ = 6.63, p = 0.01) season. The Jaffa variety showed higher post-harvest losses in both seasons.

Table 5.1: The post-harvest losses of Msasa and Jaffa orange varieties at different stages of supply chain in 2016 and 2017 seasons

Stage of supply chain	Post-harvest Loss (%) of Orange fruits			
	Msasa variety		Jaffa variety	
	2016	2017	2016	2017
Harvest stage	6.62b	3.88b	4.44b	6.14b
Transport stage	10.69ab	8.53b	16.48a	13.19ab
Wholesale stage	7.67b	7.03b	7.54b	10.38ab
Retail Stage	14.03a	20.75a	17.31a	22.71a
Avarage PHL per season	39.01	40.19	45.77	52.42
Avarage PHL per variety	39.60		49.10	
Average PHL for orange fruits	44. 35			

PHL means Post-harvest losses; Means with the same letters are not significantly different at $p \leq 0.05$ according to Tukey test.

5.3.2 Cause of post-harvest losses at different stages of orange supply chain

The various causes of post-harvest losses are presented in Tables 5.2. The main causes of losses include physical damage, insect pests, post-harvest diseases such as green mold diseases and other causes such as scars caused by bruises and tools in the field. The main causes of post-harvest losses of orange fruits were physical damage, insect pests and other causes such as scars caused by bruises and tools in the field. The losses of fruits at transport stage were mainly due to physical damage which occurred during loading, transport and unloading of fruits. The major causes of post-harvest losses of Msasa and jaffa orange varieties during wholesale market were green mold disease and physical damage due to fruit bruises. Post-harvest losses at retail stage was due to fruit flies damage and green mold infestations. Generally, Jaffa variety suffered higher losses at all stages than Msasa variety. Chi (χ^2) square results showed that loss caused by various factors was significantly dependent on orange variety at harvest ($\chi^2_{(1)}$ = 10.83, p = 0.001) and wholesale whole sale ($\chi^2_{(1)}$ = 6.47, p = 0.011) but not at transport ($\chi^2_{(1)}$ =3.43, p = 0.065), and retail stages ($\chi^2_{(1)}$ =, p = 0.745).

Table 5.2: Causes of post-harvest damage of Msasa orange at different stages of supply chain in season 1 and 2

	Msasa Variety							
Fruit damage feature	**Harvest stage (%)**		**Transport Stage (%)**		**Wholesale Stage (%)**		**Retail Stage (%)**	
Seasons	2016	2017	2016	2017	2016	2017	2016	2017
Green mould	0.0b	0.0b	0.0b	0.0b	96.6a	80.8a	100.0a	93.5a
Insects (Fruit fly maggots)	16.0b	6.2b	2.4b	1.8b	0.0b	0.0b	0.0b	6.5b
Others	6.9b	9.6b	0.00b	0.0b	0.0b	0.0b	0.0b	0.0b
Physical damage (crushing, bruises)	77.1a	84.2a	97.6a	98.2a	3.4b	19.2b	0.0b	0.0b
	Jaffa Variety							
Green mould	25.2ab	29.3ab	0.0b	0.0b	49.7a	69.5a	98.5a	99.4a
Insects (Fruit fly maggots)	32ab	15b	4.1b	1.3b	0.0b	3.1b	1.5b	0.6b
Others	6.8b	4.9b	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b
Physical damage (crushing, bruises)	36a	50.8a	95.9a	98.7a	50.3a	27.4b	0.0b	0.0b

Means with the same letters are not significantly different at $p \leq 0.05$ according to Tukey test.

5.3.3 Shelf life of orange fruits

ANOVA results showed significant effects of storage condition ($p < 0.001$), post-harvest techniques ($p < 0.001$) and post-harvest techniques × storage condition ($p = 0.002$) effects on shelf life of Msasa orange fruits. Analysis of simple means showed that post-harvest techniques had significant ($p < 0.001$) effects on shelf life of Msasa fruits in both ambient storage and cold storage conditions (Table 5.3).

Further results showed significant effects of storage condition ($p < 0.001$), post-harvest techniques ($p < 0.001$) and post-harvest techniques × storage duration ($p < 0.001$) on shelf life of Jaffa orange fruits. Analysis of simple means showed that post-harvest factors had significant (($p = 0.002$) and ($p < 0.001$)) effects on shelf life of Jaffa orange fruits under ambient and cold storage conditions respectively (Table 5.3).

The hexanal treated Msasa orange fruits had longer shelf life of 23 days and 19 days for cold and ambient storage conditions respectively compared to control fruits which had the shelf life of 15 and 13 days for cold and ambient storage respectively. The calcium chloride treated Msasa fruits had the shelf life of 18 and 21 days for cold and ambient storage respectively, when compared with untreated control fruits. The smoke treated Msasa fruits had the shelf life of 12 and 15 days for cold and ambient storage respectively (Table 5.3).

On the other hand, the hexanal treated Jaffa orange fruits had shelf life of 22 days and 18 days for cold and ambient storage conditions respectively compared to control fruits which had the shelf life of 15 and 13 days for cold and ambient storage respectively. The calcium chloride treated Jaffa fruits had the shelf life of 21 and 18 days for cold and ambient storage respectively when compared with control (Table 5.3). The smoke treated Jaffa fruits had the shelf life of 15 and 12 days for cold and ambient storage respectively. Generally, the hexanal treated fruits had the longest shelf life while smoke treated fruits had the shortest shelf life compared with untreated control fruits regardless of storage conditions and variety used.

Table 5.3: The effects of interaction between storage conditions and post-harvest techniques on shelf life of Msasa and Jaffa orange fruits

Post-harvest techniques	Shelf life (Days)			
	Msasa		Jaffa	
	Ambient Storage	Cold Storage	Ambient Storage	Cold Storage
Control	13 ± 0.17c	15 ± 0.13c	13 ± 0.35c	15 ± 0.01c
Calcium chloride	18 ± 0.17b	21 ± 0.17b	17 ± 0.34b	20 ± 0.48b
Hexanal	19 ± 0.45a	23 ± 0.22a	18 ± 0.08a	22 ± 0.42a
Smoke	12 ± 0.11c	15 ± 0.34c	12 ± 0.21c	14 ± 0.42c

Values presented are means ± standard error (SE). Means with the same letters are not significantly different at $p \leq 0.05$ according to Tukey test.

5.3.4 Changes in fruit firmness during storage

The Analysis of variance results showed that post-harvest techniques had significant ($p < 0.001$) effects on change in firmness of Msasa fruits. However, the effects of storage conditions and post-harvest techniques × storage condition were non-significant ($p > 0.05$). Analysis of main means showed that post-harvest techniques had significant ($p < 0.001$) effects on change in firmness of Msasa fruits (Fig. 5.1). The lowest change in firmness was recorded in hexanal treated Msasa fruits, followed by calcium chloride treated fruits while fruits treated with smoke had the highest change in firmness.

The analysis of variance results showed significant effects of post-harvest techniques ($p < 0.001$) storage condition ($p < 0.001$) and post-harvest technique × storage condition

(p < 0.001) effect on change in firmness of Jaffa fruits. The analysis of simple means showed significant effects of post-harvest techniques under both ambient and cold storage conditions (p < 0.01). Like in Msasa variety, hexanal treated Jaffa fruits had the lowest change in firmness, followed by calcium chloride treated fruits and untreated fruits regardless of the storage condition used. The smoke treated fruits had the highest change in firmness in both ambient and cold storage conditions (Table 5.4).

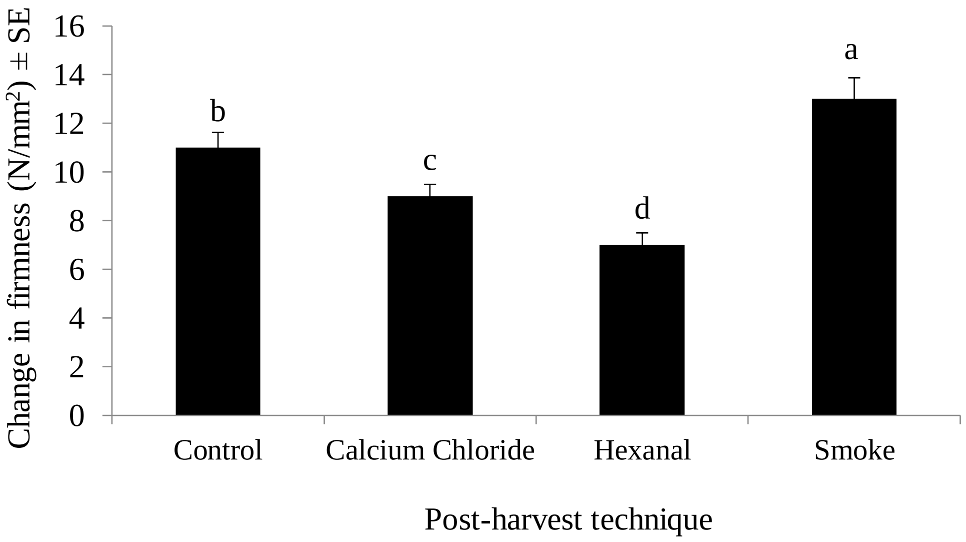

Figure 5.1: Effects of post-harvest techniques on change in firmness of Msasa orange variety

Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test).

The analysis of variance results showed significant effects of post-harvest techniques (p < 0.001) storage condition (p < 0.001) and post-harvest technique × storage condition (p < 0.001) effect on change in firmness of Jaffa fruits. The analysis of simple means showed significant effects of post-harvest techniques under both ambient and cold storage conditions (p < 0.01). Like in Msasa variety, hexanal treated Jaffa fruits had the lowest change in firmness, followed by calcium chloride treated fruits and untreated fruits regardless of the storage condition used. The smoke treated fruits had the highest change in firmness in both ambient and cold storage conditions (Table 5.4).

Table 5.4: The effects of post-harvest techniques under ambient and cold storage conditions on change in firmness of Jaffa fruits

Post-harvest Techniques	Change in Firmness (N/mm^2)	
	Ambient Storage	Cold Storage
Control	14.8 ± 0.79a	13.5 ± 0.47b
Calcium chloride	10.8 ± 0.69b	11.1 ± 0.43c
Hexanal	10.1 ± 0.71b	05.3 ± 0.96d
Smoke	15.4 ± 0.78a	14.5 ± 0.79a

Values presented are means ± SE; SE = standard error. Means with the same letters are not significantly different at $p \leq 0.05$ according to Tukey test.

5.3.5 Disease Incidences

The post-harvest diseases observed during post-harvest losses and shelf life evaluation under different post-harvest techniques and storage durations were identified to species level. The green mould disease was the dominant post-harvest diseases of orange fruits observed during the experiment. Based on observed symptoms on diseased fruits, colony morphology and microscopic features it was concluded to be caused by the *Penicillium digitatum* (Pers.) Sacc.

The ANOVA results showed significant effects of storage condition ($p < 0.001$), post-harvest techniques ($p < 0.001$) and storage condition × post-harvest technique ($p < 0.001$) on incidence green mould disease in Msasa variety fruits. Analysis of simple means showed that significant effects of post-harvest technique ($p < 0.001$) under both ambient and cold storage conditions (Table 5.5).

On the other hand, ANOVA results of Jaffa variety showed significant effects of post-harvest techniques ($p < 0.001$) and storage conditions × post-harvest techniques ($p < 0.046$) on incidence of green mould disease. Storage condition had non-significant ($p > 0.05$) effects on incidence of green mould disease of Jaffa orange fruits. Analysis of simple means of post-harvest technique of Jaffa variety also showed significant effects

(p < 0.001) of incidence of green mould disease under both ambient and cold storage conditions (Table 5.5).

The hexanal treated fruits had the lowest incidence of green mould disease followed by calcium chloride treated fruits, untreated control fruits while the smoke treated fruits had the highest disease incidences regardless of storage conditions. Fruits stored under ambient storage conditions had higher average disease incidence than cold stored fruits.

Table 5.5 Effects of post-harvest treatments on incidence of green mould diseases of Msasa and Jaffa fruits under ambient and cold storage conditions

Post-harvest techniques	**Disease Incidence (%)**			
	Msasa variety		**Jaffa variety**	
	Cold Storage	**Ambient storage**	**Ambient Storage**	**Cold Storage**
Control	9.44 ± 0.50ab	11.67 ± 0.93ab	15.00 ± 1.63ab	16.94 ± 0.96b
Calcium chloride	6.39 ± 0.62b	5.28 ± 1.12b	11.67 ± 1.20b	09.44 ± 2.52c
Hexanal	2.20 ± 0.75c	5.83 ± 0.95b	05.28 ± 0.87c	06.94 ± 1.12d
Smoke	13.89 ± 1.83a	12.78 ± 1.15a	21.11 ± 2.85a	19.44 ± 1.83a

Values presented are means ± SE; SE = standard error; Means with the same letters in the same column are not significantly different at $p \leq 0.05$ according to Tukey test.

5.4 Discussion

The average post-harvest losses of orange fruits varied with orange varieties and seasons. The Msasa variety had post-harvest losses of 39.60% which was lower than that of Jaffa variety (49.10%). Kitinoja *et al*. (2011) reported that post-harvest losses vary greatly among commodities, production areas and seasons. The post-harvest losses of Msasa are similar with those previously reported to be 30 to 40% (URT, 2006; Strano *et al.*, 2017). However, post-harvest losses of Jaffa variety were higher by 5 to 12% in 2016 and 2017 seasons respectively, from the range reported (URT, 2006; Strano *et al.*, 2017). In developed countries, post-harvest losses were reported to reach 10%, while in Philippines, post-harvest losses range from 15 to 35% (Ezekiel *et al*., 2014). Kabas (2011) and Murthy *et al.* (2009) reported fruit damages at different stages which resulted into direct losses. The higher post-harvest losses in Jaffa fruits might be due to their inherent characteristics. Jaffa variety has a thick spongy rind which makes it prone to mechanical damage, microbial spoilage, high transpiration rate and subsequently, short shelf life.

The major causes of post-harvest losses at different stages of orange supply chain were mechanical/physical damages, insect pests and post-harvest diseases mainly the green mould. Similar to these findings, similar causes of fruits losses were recorded along the orange supply chain (Kabas, 2011; Bhattarai *et al*., 2013; Musasa *et al*., 2013; Strano *et al*., 2017). These included fruit losses at harvest due to poor practices and facilities in harvesting, handling and storage, mechanical damages and bruises, fruit rot and insect pest infestations (Ezekiel *et al*., 2014). Fruit losses at transport was due to fruit bruises and physical crushing during loading and unloading of the fruits in the truck. Li and Thomas (2014) reported susceptibility of fresh fruits to mechanical damage during harvesting, packaging and transport, which resulted into substantial reduction in quality. The fruits losses at wholesale and retail stages were due to fruit rot caused by post-harvest diseases, fruit softening and shrivelling. Other studies have also reported that physical damage during handling and transport, physiological decay, and water loss, are causes of post-harvest losses of oranges making them unsuitable for consumption (Ezekiel *et al*., 2014; Strano *et al*., 2017).

Results from the current study revealed that both post-harvest techniques and storage duration significantly influenced the shelf life of the orange fruits. Hexanal treatment extended shelf life of both orange varieties compared to control and smoke treatments.

Previous studies reported that pre and post-harvest application of hexanal improved shelf life of several fruits and vegetables (Cheema *et al*., 2014; El Kayal *et al*., 2017; Paliyath *et al*., 2008; Sharma *et al*., 2010). Hexanal treated orange fruits had longer shelf life compared to fruits treated with smoke and the control (Al-Harthy, 2010). Of the two orange varieties, Msasa had relatively longer shelf life than Jaffa variety. On the other hand, storage condition of oranges significantly influenced the shelf life of the two varieties (Msasa and Jaffa). The current results showed that cold storage increased shelf life of both Msasa and Jaffa orange varieties compared to ambient storage. Similar to these findings, Baloch and Bibi (2012) reported that shelf life of mango fruit was longest for fruits stored at 20 °C and shortest for those stored at 40 °C concluding that reduced temperature extends shelf life of fruits.

Cold storage of fruits significantly improved shelf life of oranges compared to fruits under ambient storage. This might be due to delayed ripening due to reduced fruits metabolism under cold storage relative to those under ambient storage condition (Wang *et al*., 2017). Other researchers also reported that calcium treatment combined with cold storage significantly improved quality and shelf life of apricot fruits (Tucker *et al*., 2017). In addition, the current study showed significant interactions between post-harvest treatments and storage conditions on shelf life of both Msasa and Jaffa orange varieties. Generally, fruits stored in cold storage had longer shelf life relative to fruits stored under ambient storage conditions. Hexanal treated fruits had the longest shelf life followed by calcium chloride treated fruits while smoke treated fruits had the shortest shelf life regardless of storage conditions.

Firmness is one of the primary parameters used to evaluate the overall orange quality (Fekete, 1994). Reduced firmness of orange and other fruits indicates that the fruits are losing their fresh look, quality, and becomes less marketable (Sarig and Nahir, 1973). The current study showed that both the storage conditions and the post-harvest treatments tested significantly affected the firmness of the Jaffa orange variety for the two experimental seasons. However, the storage conditions had no significant effect on Msasa orange variety. It was further observed from the current study that the ambient stored fruits had the highest change in firmness (12.6 N/mm^2) than the cold stored (10.6 N/mm^2) Jaffa fruits. This means that the fruits stored in cold condition maintained their firmness and had small amount of reduced firmness relative to those stored in ambient condition. Previous study by Singh and Reddy (2006) reported similar trend when they assessed the post-harvest physico-mechanical properties of orange peel and fruit. The previous studies on kiwi fruit, orange and mango showed that the ambient storage had the softer fruits compared to those under cold storage (Tabatabaekoloor, 2014; Katsiferis *et al*.,2008; Qin *et al*., 2006). According to Ritenour *et al*. (1999) softening of different fruits is affected by storage period, storage temperature, ethylene levels and maturity of the fruit.

Post-harvest treatments of orange fruits had significant effect on firmness of both orange varieties. It was observed that hexanal and calcium chloride treatments on oranges maintained the fruit firmness where there was a reduced decline in firmness compared with the smoke treated and the control fruits. The higher value of change in firmness implies that there were wide differences between the initial fruit firmness at harvest and the final firmness at 12 days after fruits harvest. The higher the change in firmness the more the softer the fruit is. The smoke treated fruits showed higher change in firmness values and the softest fruits while the hexanal treated fruits had the lowest change in firmness and the firmest fruits, compared to untreated fruits and also with calcium chloride treated fruits.

It was observed that the green mould was the dominant disease which affected the orange fruits. It was found that the storage condition had significant effect on green mould disease incidence. Fruits stored in cold condition had low incidence of the disease relative to the fruits stored under ambient condition. Interestingly, treatment of fruits with hexanal and calcium chloride reduced the incidence of green mould in orange fruits compared with the untreated and smoked fruits. Hexanal was more effective in reducing incidence of diseases compared to the calcium chloride. The reduced incidence of green mould in hexanal and calcium chloride treated fruits suggests antifungal activity of the treatment agents (Hamilton-Kemp *et al*., 1992; Fallik *et al*., 1998). Other similar studies have shown that hexanal was effective in control of green mould (Archbold *et al*., 1999) and inhibited the growth of hyphae of *Penicillium expansum* and *Botrytis cinerea* (in vitro) and on apple slices (Song *et al*., 1996).

5.5 Conclusion and Recommendations

From this study, post-harvest losses were observed to occur at harvest, transport, whole sale and retail stage of supply chain. The evaluations of causes of post-harvest losses at different stages were due to physical damage, scars, insect pest infestations, and green mold diseases. Post-harvest treatment with hexanal led to fruits with longer shelf life compared to calcium chloride and untreated fruits while smoke treated fruits had the shortest shelf life under both ambient and cold storage conditions. Furthermore, storage of fruits in cold condition significantly increased fruit shelf life compared to ambient storage condition. The smoke treated fruits had the softest fruits while the hexanal treated fruits had the firmest fruits. Therefore, hexanal and cold storage are recommended to lengthen fruit shelf life, maintain fruit firmness and reduced post-harvest losses of orange fruits.

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CHAPTER SIX

6.0 EFFECTS OF POST-HARVEST TECHNIQUES AND STORAGE CONDITIONS ON SHELF LIFE OF MANGO (*Mangifera indica*, L.) IN TANZANIA

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Abstract

Experiments were conducted at the Post-harvest Laboratory of the Sokoine University of Agriculture in Morogoro, Tanzania to assess the effects post-harvest treatments on shelf life of mango fruits under different storage conditions. Post-harvest loss of Apple and Palmer mango fruit varieties along the supply chain were evaluated. A two factors factorial experiment was used for each variety, replicated six times. Sources of variation were post-harvest techniques and storage conditions. Post-harvest techniques included hexanal solution (0.02% v/v), calcium chloride solution (2% w/v), smoke treatment and control which comprised of untreated fruits. The fruits were then stored at two different storage conditions namely: ambient temperature (28 ± 2 °C) and cold or reduced temperatures storage (18 ± 2 °C). Shelf life, change in firmness and Disease incidence data were analysed by using R-software. Mean separation was done by using Tukey Honestly Significant Difference (HSD) at ($p \leq 0.05$). Results showed that the major sites of post-harvest losses were at harvest, transport, wholesale and retail stages of supply chain. Furthermore, post-harvest techniques of fruits with hexanal and calcium chloride significantly increased shelf life and reduced disease incidences compared to untreated control and smoke treated fruits. Cold storage significantly increased shelf life of mango fruits compared to ambient storage. Therefore, hexanal and cold storage are recommended to extend fruit shelf life, maintain fruit firmness and reduce disease incidences in mango fruits.

Key words: Post-harvest loss, supply chain, hexanal, calcium chloride, smoke, firmness change

6.1 Introduction

Mango (*Mangifera indica*, L.) is among the major fruits produced and consumed in Tanzania. The export potential and international trade of mango is limited due to several factors such as its perishable nature, disease (Singh *et al*., 2013) and insect pest infestations. Post-harvest loss refers to measurable quantitative and qualitative food loss (Kiaya, 2014). Post-harvest losses in developing countries are very high. Msogoya and Kimaro (2011) recorded losses of 48 to 60% in fresh mango. Reduction of post-harvest losses and quality deterioration are essential in increasing food availability from existing production (Kasso and Bekele, 2018).

Fruit traders normally buy fruits at farm gate but destined for local and international markets. There are no specialized post-harvest storage facilities, post-harvest treatments or refrigerated transport. Losses are observed at harvesting, during packing, transportation, in wholesale and retail markets, and during delays at different stages during handling (Kitinoja *et al*., 2010) which are caused by unseen delay at custom, traffic delay and trucks breakdown, high toll charges or delay in unloading places. These necessitates the need to extend the shelf life of fruits to prevent further losses.

Smoke treatment is commonly used by smallholder Tanzanian farmers for fruit ripening (Baltazari *et al*., 2018), but there is insufficient information on the effects of smoke treatments on internal and external quality parameters and shelf of mango fruits. Post-harvest fruit treatment using hexanal enhanced freshness and shelf life of fruits such as apple, sweet cherry, peaches, mango, guava, banana and strawberry (Paliyath *et al*., 2008). Hexanal treatments significantly delayed ripening and senescence of fruits and extended fruit shelf life (Paliyath and Droillard, 1992). Hexanal application had been reported to improve post-harvest fruit quality of guava, plum, grapes, sweet cherries, papaya, apples, pears, peaches, mango and strawberries (Paliyath *et al.*, 2008, Paliyath, 2011) grown in India and Canada. Furthermore, post-harvest hexanal application has been tested in limited geographies, and in fruit varieties from India and Canada (Paliyath *et al*., 2008). There is therefore no information from the African tropics and the major fruit varieties grown in Tanzania. Moreover, techniques used by Tanzanian farmers to improve post-harvest quality of fruits (e.g. smoke) are not well evaluated and documented.

Mishra (2002) reported that dipping fruits in 1% concentration of calcium chloride maintained firmness, reduced post-harvest decay and extended the shelf life of strawberries. Calcium chloride treatment also retained firmness, increased vitamin C content and decreased storage rot in apple fruits. Lara *et al*. (2004) reported delayed fruit ripening, improved resistance to fungal attack and maintained structural integrity of strawberry cell walls after being dipped in 1% solution of calcium chloride.

Fruit production is facing numerous post-harvest problems, leading to both high quantitative and qualitative losses (Malik *et al*., 2004; Musasa *et al*., 2013). Post-harvest losses in the horticultural production chain are a challenge in both developing and developed countries (Musasa *et al*., 2013). Fruits are liable to damage and deterioration during harvesting, transportation, marketing, storage and consumption, if not properly handled (Ilyas *et al*., 2007; Murthy *et al*., 2009).

6.2 Materials and Methods

6.2.1 Description of study area

Mango fruits were harvested from Lunyala village in Mwarusambe ward (7.1435^{o} S, 39.0542^{o} E and 58.30 metres above sea level) in Mkuranga district, Coast region in eastern Tanzania from December 2016 to December 2017.

6.2.2 Fruit sampling

Mango fruits were harvested by hand at their physiological maturity. Apple and Palmer, the commonly grown varieties in the study area were used. After harvest, the marketable and unmarketable fruits were separated. The marketable quality of the fruits were subjectively assessed according to method by Mohammed *et al.* (1999) with some modifications. On each sampling time, marketability of the fruits was judged using a 1 to 9 rating scale, with 1 = unusable, 3 = unsalable (poor), 5 = fair, 7 = good, 9 = excellent; to evaluate the fruit quality. The mechanical damage, disease and insect freedom, softness, surface defects, and shrinkage were used as visual parameters for the rating. The ratings were averaged and the fruits that received a rating of five and above were considered marketable, while those rated less than five were considered unmarketable.

6.2.3 Evaluation of post-harvest losses

Marketable fruits were loaded in the open bodied truck cushioned by dry grass and transported from the Coast Region to Sokoine University of Agriculture, Morogoro (234 km away). Upon arrival, the fruits were sorted to remove all the unmarketable fruits and counted to establish records on their respective cause of damage. The remaining marketable fruits were packed in bamboo crates cushioned with dry grass and allowed to stay under the shade for three days to simulate the wholesale market conditions. On the third day after harvest, the fruits were evaluated and the number of unmarketable fruits with their respective cause of damage were recorded. The same procedure was repeated, where the remaining marketable fruits were packed in bamboo crates cushioned with dry grass and allowed to stay in the shade for the six more days (making a total of nine days) to simulate the retail market conditions during low demand season. On the 9th day after harvest, the fruits were evaluated and the number of unmarketable fruits with their respective cause of damage was recorded.

Post-harvest losses were evaluated according to the method by Msogoya and Kimaro (2011) with some modification. The post-harvest loss at each stage was calculated as the percentage of fruits loss specific to a defined point along the supply chain. A total of 5 000 mango fruits of each variety were harvested, sorted and graded to remove all the unmarketable fruits with their respective cause of damage being recorded. The causes of fruits damage were identified and grouped as either due to mechanical/physical damage, microbial decay, softening or due to insect pest’s damage and their respective number were recoded. The percent loss for group of fruit damage was computed as the number of fruits in each group over total number of fruits assessed times 100. The mechanical injury was scored as the number of fruits with cuts, scrapes, and bruises (Brecht *et al*., 2010). The incidence of microbial decay was scored as the number of fruits with decay symptoms, and the causal agents of decay were identified based on symptoms according to Snowden (2008). Insect damage was scored upon the presence of larvae/maggots of fruit flies in the fruits according to Mwatawala *et al*. (2009). The experiments were repeated for 2 consecutive seasons of 2016 and 2017 mango seasons.

6.2.4 Shelf life assessment, change in fruit firmness and disease incidences

The effectiveness of calcium chloride, hexanal and smoke on shelf life, change in fruit firmness and incidences of post-harvest diseases of Apple and Palmer mango varieties were evaluated. Fruits were dipped in calcium chloride solution at (2% w/v) and hexanal solution at (0.02% v/v) for five minutes. Smoke was obtained by burning (1.0 kg) of dried banana leaves which was pumped into a chamber with a volume of 12 m^3 at an interval of 12 hours for duration of 36 hours. Before a subsequent smoke treatment, ventilation of the chambers was done for 30 minutes by opening window and doors of the chamber. The chambers were located six meters from the source of smoke to reduce heat transfer to the oranges. Untreated fruits were included as control. The treated and untreated fruits were either stored under ambient (28 ±2 °C) or in cold (18 ± 2 °C) storage conditions.

The shelf life is the length of time for which an item remains usable, edible or saleable. Shelf life was determined as the period (in days) through which the fruits remained marketable until 50% of the fruits was considered unmarketable. The fruits were assessed daily and when the half of the fruits were unmarketable, they were discarded and the time (number of days) recorded.

Fruit softening (change in firmness) was evaluated by measuring the fruit firmness at harvest and after storage for 12 days. A small peel disc (approx. 2 mm^2) on the opposite side of the fruit cheek was removed, and then fruit firmness was measured using a penetrometer (Wagner fruit test, FT 20 Model, Wagner Instruments, Italy) with 9 mm probe. Degree of fruit softness was computed by deducting the final firmness measured at 12 days after storage from the initial firmness (measured at time of harvest).

The incidence of microbial decay was scored as the number of fruits with decay symptoms, and the causal agents of decay were identified to species level based on their disease symptoms, colony cultures, and their macro and micro-morphology, with the aid of microscope and also using a compendium of fruit diseases (Snowden, 2008). The dominant disease was identified and then their incidence data recorded. The insect damage was scored upon the presence of larvae of fruit flies in the fruits.

Two-way factorial ANOVA with six replications was used to analyse data. The factors were three post-harvest techniques (hexanal, calcium chloride and smoke treatment) and two storage conditions namely ambient (28 ± 2 °C) and cold/reduced (18 ± 2 °C) temperatures) storage conditions. The disease incidence data were arcsine percent transformed before analysis. Then, data for shelf life, change in firmness and green mold disease incidence of each mango cultivars were separately analysed by using R software. Mean separation was performed using Tukey Honestly Significant Difference (HSD) at ($p \leq 0.05$).

6.3 Results

6.3.1 Post-harvest losses at different stages of mango supply chain

The two independent variety experiments for Apple and Palmer mango fruit conducted for two consecutive seasons of 2016 and 2017. The post-harvest losses were evaluated from untreated fruit while the effects of post-harvest techniques namely hexanal, calcium chloride, smoke treatments and control on fruit shelf life, loss of firmness and prevalence of post-harvest diseases were evaluated under ambient and cold storage conditions.

Post-harvest losses (%) of Apple and Palmer mango fruit varieties along the supply chain during 2016 and 2017 mango seasons are as shown on Table 6.1. The Apple mango variety had post-harvest losses of 49.02% and 44.11% in 2016 and 2017 seasons respectively, with the average of 46.57%. The Palmer mango variety resulted into 43.16 % post-harvest losses in 2016 and 41.55% in 2017 with an average post-harvest loss of 42.36%. The apple mango variety had higher post-harvest losses than Palmer variety. Chi square (χ^2) results showed that losses along the supply chain stage was significantly dependent on variety during 2016 ($\chi^2_{(1)} = 5.095$, $p = 0.024$) and 2017 season ($\chi^2_{(1)} = 9.55$, $p = 0.002$). The Apple variety showed higher post-harvest losses in both seasons.

Table 6.1: Post-harvest losses of Apple and Palmer mango varieties at different stages of supply chain in 2016 and 2017 mango seasons

Stage of supply chain	Post-harvest Loss (%)			
	Apple variety		Palmer variety	
	2016	2017	2016	2017
Harvest stage	3.44	2.90	5.42	2.96
Transport stage	18.89	8.49	8.48	8.72
Wholesale stage	7.69	7.77	9.08	6.86
Retail Stage	19.00	24.96	20.18	23.01
Avarage PHL per season	49.02	44.11	43.16	41.55
Average PHL per variety		46.57		42.36
Avarage PHL for mango fruits				44.47

Note: PHL means post-harvest loss

6.3.2 Cause of Losses at different stages of Mango supply chain

The main causes of post-harvest losses of in Apple and Palmer mango fruit during 2016 and 2017 seasons were as shown on Table 6.2. The Apple mango fruit had highest post-harvest losses at transport stage and the lowest losses at harvest stage. On the other hand, Palmer mango variety had the highest post-harvest losses at retail stage and lowest during harvesting. The post-harvest losses were caused by physical damage crashed and bruised fruit, infestation of insect such as fruit flies, over-ripening, post-harvest diseases and other causes such as scars due to scratches of fruit themselves and farm activities and tools. Chi square test results showed that losses along the supply chain stage was significantly dependent on variety at transport stage ($\chi^2_{(1)} = 6.038$, $p = 0.014$) and wholesale stage ($\chi^2_{(1)} = 4.96$, $p = 0.026$) but not at harvest ($\chi^2_{(1)} = 2.02$, $p = 0.155$) and retail stages ($\chi^2_{(1)} = 3.582$, $p = 0.058$).

Table 6.2: Causes of post-harvest damage of Apple and Palmer mango fruits at different stages of supply chain in 2016 and 2017 seasons

Fruit damage features	Post-harvest losses (%)							
	Harvest stage		Transport Stage		Wholesale Stage		Retail Stage	
	Apple	Palmer	Apple	Palmer	Apple	Palmer	Apple	Palmer
Physical damage	49.25	83.25	92.45	99.2	61.4	86.20	2.60	24.6
Insect pests	25.15	10.00	7.55	0.80	5.45	0.85	2.60	0.65
Anthracnose	0.00	0.00	0.00	0.00	6.4	5.6	46.75	33.25
Over-ripening	7.25	0.00	0.00	0.00	26.6	0.00	48.05	41.45
Others	18.34	6.70	0.00	0.00	0.00	0.00	0.00	0.00

6.3.3 Shelf life of mango fruits

The two ways ANOVA showed significant effects of post-harvest techniques ($p < 0.001$) and post-harvest techniques × storage duration ($p < 0.001$) on shelf life of Apple variety fruits. However, storage conditions had non-significant ($p > 0.05$) effects on shelf life of

Apple mango fruits. Further analysis of simple means showed that post-harvest techniques had significant ($p < 0.001$) effects on shelf life of Apple fruits under both ambient and cold storage conditions (Fig. 6.1).

Also, ANOVA results showed significant effects of post-harvest techniques ($p < 0.001$) on shelf life of Palmer mango variety. The storage condition, post-harvest techniques × storage duration had non-significant ($p > 0.05$) effects on shelf life of Palmer mango fruits. The analysis of variance for main means showed that the effects of post-harvest techniques on shelf life of Palmer fruits was significantly different ($p < 0.001$) (Fig. 6.2).

The hexanal treated mango fruits had the longest shelf life followed by calcium chloride while smoke treated fruits had the shortest shelf life compared to untreated control fruits regardless of storage conditions used (Fig. 6.1 and 6.2). Mango fruits stored under cold storage conditions has a longer shelf life compared to fruits stored under ambient storage conditions. The hexanal treated Apple mango fruits which were stored under cold storage conditions had the longest shelf life (22 days) while the smoke treated fruits that was stored under ambient storage conditions had the shortest shelf life (12 days) (Fig. 6.1). on the other hand, hexanal treatment extended the shelf life Palmer mango fruits from 12 days in untreated control to 20 days. Likewise, calcium chloride extended the shelf life Palmer mango fruits from 12 days in untreated control to 17 days. On the other hand, smoke treatment had a shelf life of 12 days similar to that of control fruits (Fig 6.2).

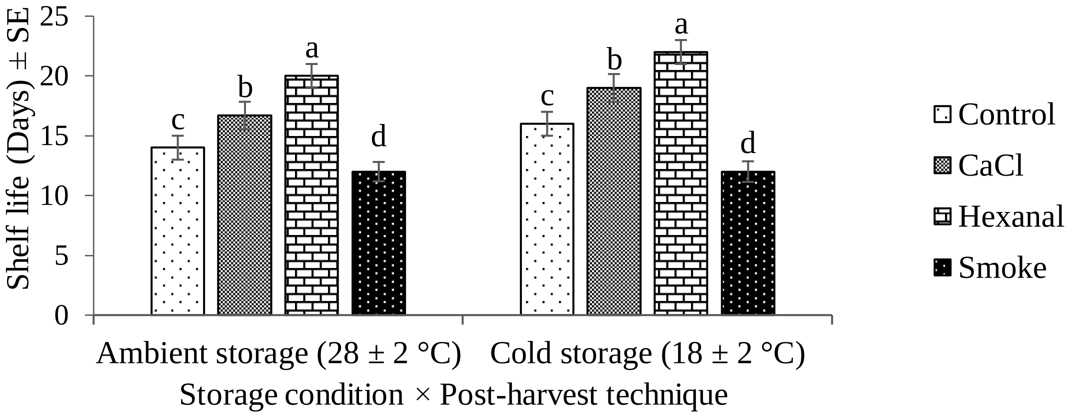

Figure 6.1: Effects of post-harvest techniques on shelf life of Apple mango variety under ambient and cold storage condition

Means with same letters in the same storage condition are not significantly different at $p \leq 0.05$ (Tukey test).

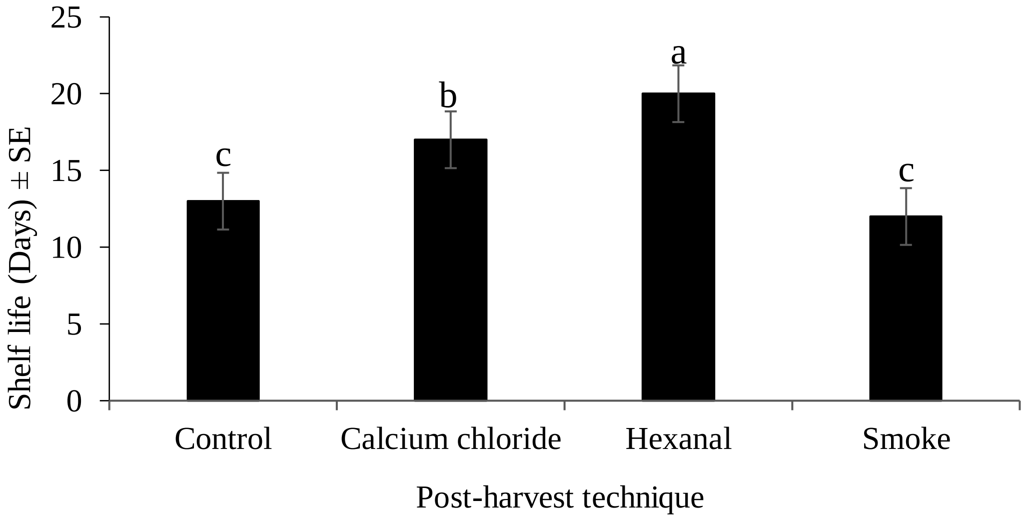

Figure 6.2: Effects of post-harvest techniques on shelf life of Palmer mango variety

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test).

6.3.4 Changes in fruit firmness

ANOVA results showed significant effects of storage conditions ($p < 0.001$) post-harvest techniques ($p < 0.001$) and storage condition × post-harvest techniques ($p < 0.001$) on change in firmness of Apple mango fruits. Analysis of simple means of post-harvest techniques had significant effects on changes of fruit firmness of Apple mango fruits in ambient ($p < 0.001$) and cold storage conditions ($p < 0.01$) (Fig. 6.3).

Post-harvest techniques had significant ($p < 0.001$) effect on changes in fruit firmness of Palmer mango variety. Storage conditions and post-harvest techniques × storage conditions had non-significant ($p > 0.05$) effect on change in firmness. Further analysis of main means of post-harvest techniques had significant ($p < 0.001$) effects on change in firmness of Palmer mango fruits (Fig. 6.4).

Fruits stored under ambient conditions had a higher change in firmness than those under cold storage condition. Hexanal treated fruits had the lowest change in firmness than the untreated fruits despite the storage condition used followed by calcium chloride and untreated fruits while the smoke treated fruits had the greatest change in firmness values under both storage conditions. Smoke treated fruits had a higher change in firmness than untreated control and other post-harvest techniques. The higher the change in fruit firmness the softer the fruits are.

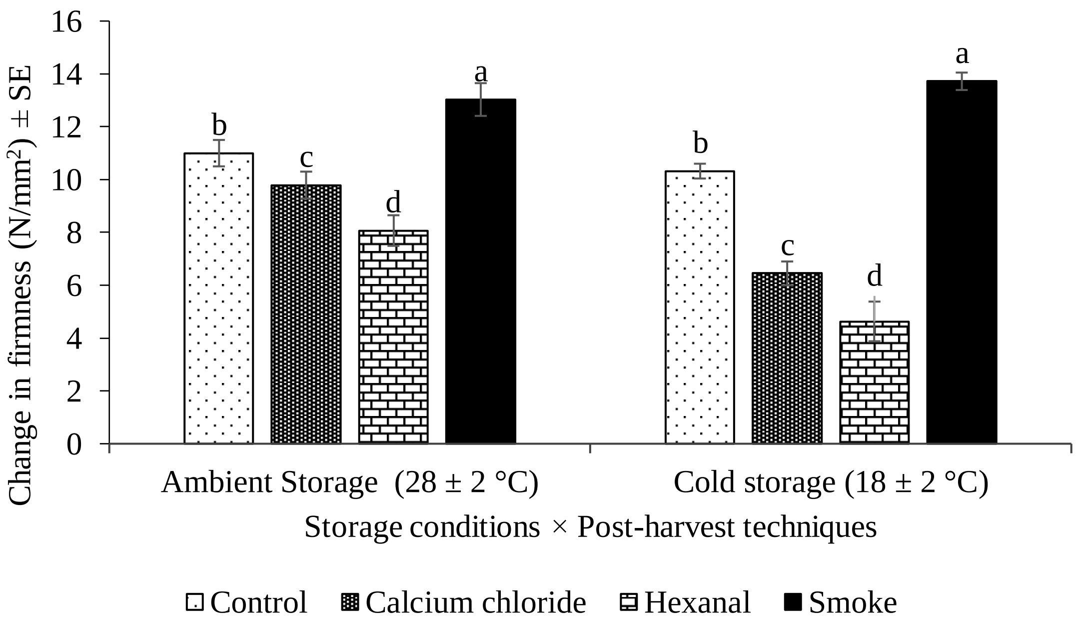

Figure 6.3: Effects of post-harvest techniques on change in firmness of Apple mango variety under ambient and cold storage conditions

Means with same letters in the same storage condition are not significantly different (Turkey test).

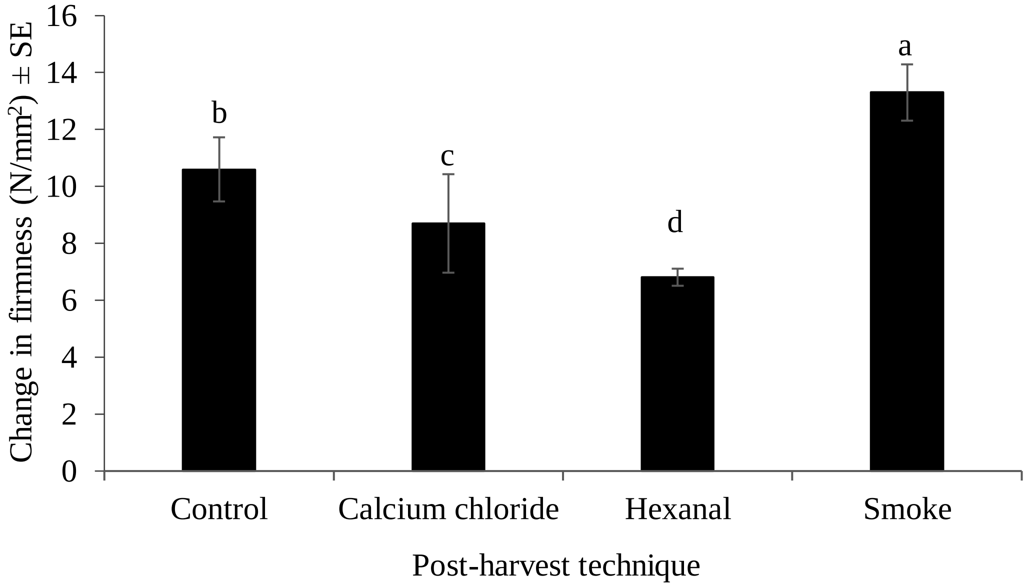

Figure 6.4: Effects of post-harvest techniques on change in firmness of palmer mango variety

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test).

6.3.5 Disease incidences

ANOVA results showed that effects of storage condition and post-harvest techniques had significant ($p < 0.001$) effect on the incidence of anthracnose disease of both Apple and Palmer mango fruits. However, effects of their interactions were not significant ($p > 0.05$). Further analysis of main means showed that post-harvest techniques also had significant ($p < 0.001$) effects on incidence of anthracnose disease on Apple and Palmer mango varieties (Fig. 6.5). Hexanal treated fruits had the lowest incidence of anthracnose disease, followed by calcium chloride while untreated fruits and smoke treated fruits had the highest disease incidences.

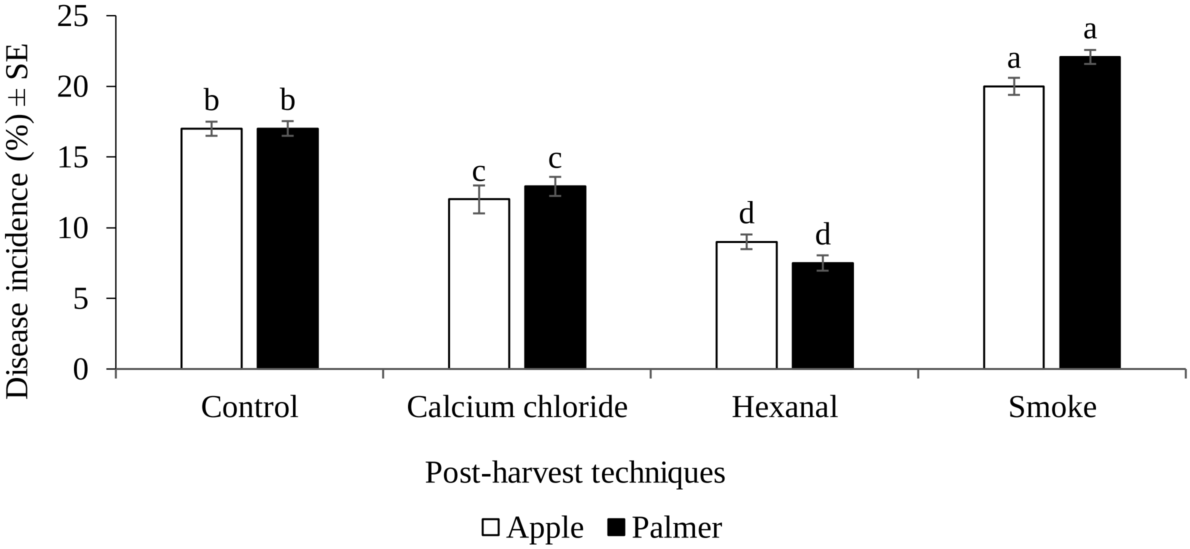

Figure 6.5: Effects of post-harvest techniques on disease incidence of Apple and Palmer mango varieties

Means with same letters for the same variety are not significantly different at $p \leq 0.05$ (Tukey test).

6.4 Discussion

Post-harvest losses incurred mango fruits were highest at retail stage followed by wholesale stage and transport stage while the lowest post-harvest losses were recorded at harvest. The total post-harvest losses of mango were 44.56%. Gebre-Mariam (1999) reported lack of post-harvest and marketing infrastructures such as packaging, cold storage, post-harvest treatments and washing facilities as the major problems leading to considerable post-harvest loss of fruits. Post-harvest losses observed at harvest were caused by mechanical damage such as bruises which was caused by mishandling during harvesting, insect pest infestations and healed scars caused by different field activities. The post-harvest damages are influenced by variety, storage temperature, and degree of maturity of the fruits. Blahovec (2001) and Sudheer and Indira (2007) reported that varietal differences and harvesting maturity as the main determinants of post-harvest fruit damages. Post-harvest losses experienced by smallholder farmers are relatively high mostly due to inappropriate crop handling, processing and storage technologies (Rugumamu, 2009). The high post-harvest losses during retail stage was mainly due to fruits softening, mechanical damage and infection by fungal diseases mainly anthracnose caused by *Colletotrichum gloeosporioides.*

Total post-harvest losses encountered al from harvesting to retailer were high in both Apple and Palmer varieties. Post-harvest losses vary greatly among commodities and production areas and seasons (Kitinoja *et al*., 2010). All the links from farmers to end user of the commodity constitute supply chain of the agricultural commodities (Negi and Anand, 2015). The causes of fruit losses at harvest were mechanical damages and bruises, fruit rot and insect pest infestations. The fruit damage at wholesale market was due to anthracnose diseases and physical injuries. The fruit damage at retail stage was caused by fruit rotting due to post-harvest diseases, fruit softening and shrivelling due to water loss. Kadawa and Kitagawa (1984) reported reduced fruit firmness and increased number of unmarketable fruits as the fruits loose water during storage.

The current study showed that hexanal extended shelf life of both mango varieties relative to smoke treated and untreated fruits. Similar results were observed by other researchers where hexanal extended shelf life of several fruits such as apple, banana, cherry, peach, strawberry and vegetables such as broccoli and tomato (Paliyath *et al*., 2008; El Kayal *et al.,* 2017). Fruits treated with calcium chloride had shelf life of 17 days compared with the 14 days of control. The current study also showed that calcium chloride extended shelf life of both mango varieties compared to the control and smoke treated fruits. Hexanal and calcium chloride extended shelf life of fruits through delayed aging, ripening and reduction of post-harvest decaying (Mishra, 2002).

Smoke treatments reduced fruit shelf life compared to the control. It is inferred that ethylene initiates the ripening of climacteric fruits, the internal ethylene concentration rises to saturation levels and additional application of exogenous ethylene has no further promotive effect on ripening (Saltveit, 1999; Porat *et al*., 1999). The reduced shelf life of mangoes was associated with presence of ethylene which enhances ripening fruits and softening of climacteric (Saltveit, 1999).

Fruit firmness has been long used as one of the primary parameters used to evaluate the overall fruits quality (Fekete, 1994). Thakur *et al.* (2017) pointed out that delaying in softening of fruit is the one of the objectives to extend the shelf life of fresh produces. Apple fruits stored under cold condition maintained their firmness better compared to those stored under ambient condition. According to Thakur *et al.* (2017) digestion of cell wall by enzymes was responsible for cell wall digestion, and this process was increased by the increase in storage temperature. Similar results were reported by Katsiferis *et al*. (2008) for orange, Tabatabaekoloor (2014) for kiwifruit, and by Hertog *et al.* (2004) for tomato. Generally, softening of different fruits is affected by storage period, storage temperature, ethylene levels and maturity of the fruit (Ritenour *et al*., 1999). Another related study was done to assess post-harvest physico-mechanical properties of orange peel and fruit and showed the same trend (Singh and Reddy, 2006).

There was also significant effect of post-harvest treatments on change in firmness of both Apple and Palmer mango varieties with similar trend smoke-treated fruits had the highest change in firmness compared to the untreated mango fruits. From this study, hexanal treatment led to fruits wit lowest change in firmness relative to other treatments including calcium chloride, smoke treated and the untreated fruits. Hexanal inhibits the activity of

Phospholipase D which is responsible for initiation of catabolic events that leads to the eventual deterioration of the membrane and therefore fruit softening (Thakur *et al.*, 2017; El Kayal *et al*., 2017). These findings confirm the argument that calcium chloride treatment is an effective way of controlling fruit ripening and quality by delaying ripening and maintaining firmness (El Kayal *et al*., 2017). Other study on effect of calcium chloride application on firmness and post-harvest retention of berry grape (*Vitis vinifera,* L.) cv. Askari indicated that calcium chloride retained fruit firmness over the control (Farahi and Goodarzi, 2008). However, the change in firmness for calcium chloride treated fruits was relatively higher than hexanal treated fruits indicating that haxanal was most effective in maintaining fruits firmness. Fruits treated with different levels of smoke had the highest firmness change indicating that smoke treatment was less effective in maintaining fruit firmness during storage.

Generally, hexanal treated fruits had the lowest change in firmness followed by calcium chloride followed by untreated control andsmoke treated fruits respectively. Interaction of storage conditions and post-harvest treatments significantly affected the firmness of Apple mango fruits but Palmer was not significant. Both the ambient and cold storage conditions with respect to post-harvest treatments had significant effects on change in firmness of Apple mango fruits variety. Sivakumar *et al*. (2005) reported that storage conditions and post-harvest treatments maintained the firmness of apple fruits. It was generally found that the ambient storage conditions had higher change in firmness values than cold storage conditions. Hexanal treated fruits had a low change in firmness than the untreated fruits despite the storage condition used.

The disease incidence was evaluated for mango varieties throughout the supply chain. It was observed that the Anthracnose disease was dominant during storage. It was also found that regardless of mango variety used, cold storage significantly delayed and reduced anthracnose disease relative to ambient storage. The assessment of disease incidence with regard to post-harvest treatments showed that mango fruits treated with hexanal had a lower disease incidence than the calcium chloride-treated, untreated and smoked-treated fruits. When, compared with the calcium chloride for disease incidence reduction, hexanal was the most effective in disease reduction as it had significantly low incidences for the two mango varieties. The reduced incidence of anthracnose is an indication that calcium chloride and hexanal have antifungal activity (Hamilton-Kemp *et al.*, 1992; Fallik *et al.*, 1998). Other similar studies have shown that hexanal was effective in control of fungal diseases such as green mould (Archbold *et al*., 1999) and inhibited in vitro the growth of hyphae of *Penicillium expansum* and *Botrytis cinerea* and on apple slices (Song, *et al*., 1996). Mango fruits treated with smoke had higher incidence of anthracnose disease than all other post-harvest treatments and the control. The smoke treated mango fruits ripens earlier than other treated and untreated fruits and therefore exposes the fruits to the risks of diseases.

6.6 Conclusion and Recommendations

From this study, post-harvest losses were observed to occur at harvest, transport, whole sale and retail stages of supply chain. The causes of post-harvest losses at different stages were due to physical damage, insect pests, over-ripening and post-harvest diseases such as anthracnose. The post-harvest treatment of fruits with hexanal resulted to fruits with longer shelf life than calcium chloride and untreated fruits while the smoke treated fruits had the shortest shelf life under both storage conditions. Hexanal and calcium chloride treated fruits maintained their firmness for a relatively longer time during storage compared to untreated control and smoke-treated fruits. Therefore, fruit treatment with hexanal (0.02% v/v) treatment and cold storage are recommended to extended fruit shelf life, maintained fruit firmness and reduced disease incidence in stored mango fruits.

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CHAPTER SEVEN

7.0 EFFECTS OF STORAGE CONDITIONS, STORAGE DURATION AND POST-HARVEST TECHNIQUES ON NUTRITIONAL CONTENT OF MSASA AND JAFFA ORANGE VARIETIES GROWN IN TANZANIA

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Abstract

Two orange varieties, Msasa and Jaffa were harvested from Bwembera and Semngano villages in the Muheza district, Tanga, during the 2016 and 2017 seasons. The aim of this study was to evaluate the effects of hexanal and calcium chloride on nutritional quality (vitamin C, total flavonoids, reducing sugars and total sugars) of orange fruits under different storage conditions and durations. These fruits were subjected to the post-harvest techniques namely; dipping of fruits in (i) hexanal (0.02% v/v) and (ii) calcium chloride (2% w/v) and the control group, which was untreated. Samples from each treatment were stored at ambient (28 ± 2 °C) and cold storage (18 ± 2 °C). Data was collected on the 0, 7th, 11th, and 15th days from the date of fruit harvest (DAH). Thirty fruits of each variety were exposed to each treatment and replicated six times making a total of 360 fruits per treatment. Chemical analysis was conducted to determine vitamin C content, total and reducing sugars as well as total flavonoids. Post-harvest techniques had significant effect on total flavonoids of Jaffa orange fruits, but not on Msasa fruits. Similarly, post-harvest techniques had significant effect on vitamin C of Jaffa variety but not for Msasa. The significant effect of post-harvest techniques on total sugar was observed in Msasa variety only. In all the significant results, hexanal had higher values of total flavonoids, vitamin C, and total sugars compared to calcium chloride treated and the controls. Storage condition had significant effect on reducing sugar of Msasa variety only. The storage durations showed significant effects on the vitamin C content of Jaffa fruits, total flavonoids, the total and reducing sugars of both fruit varieties. Vitamin C and total flavonoids decreased with increasing storage duration of fruits. Generally, hexanal exhibited better performance on improving the internal qualities of the orange fruit than calcium chloride and the control. The significant interactions of factors were observed on total sugar which was increasing with increasing storage duration, but higher in hexanal treated and cold stored fruits. Based on consumer acceptance test, the hexanal treated fruits were the most liked fruits followed by calcium chloride treated and untreated fruits based in the appearance, taste, aroma texture and overall acceptability. Therefore, hexanal fruit treatment is recommended for maintaining internal qualities of fruits.

Keywords: vitamin C, flavonoids, reducing sugar, total sugar

7.1 Introduction

The nutritional value of fruits and vegetables depends on their composition, which shows a wide range of variation depending on the species, cultivar and maturity stage (Florkowski *et al*., 2009). They contain many essential vitamins, minerals, fibre and phytochemicals such as phenolic compounds and caretonoids, many of which are antioxidants (Yahia and Berrera, 2009). They also contain flavonoids (hesperetin and naringenin predominantly as glycosides) and limonoids (Ladaniya, 2008; Florkowski *et* *al*., 2009; Boeing *et al*., 2012; Franke *et al*., 2005; Glade, 1999). Glucose, fructose and mannose are the major reducing sugar in sweet oranges (Ladaniya, 2008). Reducing sugars (primarily a mixture of fructose and glucose) are the main soluble carbohydrate of most fruits and account for 70% of seedless raisins (Johnson and Conforti, 2003). Various epidemiological studies have demonstrated a strong correlation between adequate consumption of fruits and vegetables with reduced risk of some major diseases such as cardiovascular, diabetes, hypertension, certain types of cancer and some of the degenerative diseases (Garcia-Salas *et al*., 2010).

The accumulation and degradation of antioxidant compounds in fruits are influenced by both genetic factors such as species and cultivars and environmental factors such as radiation, cultural practices, maturity at harvest and storage conditions and processing (Florkowski *et al*., 2009). Appearance, texture, colour, aroma, freshness and flavour are the important traits assessed by consumers in fruit selection. Consumers have preferences for different combinations of texture, taste, and flavour (Harker, 2001). The acceptance of any food depends on whether it responds to consumer needs and on the degree of satisfaction (Costell *et al*., 2010).

The goal of post-harvest research is to maintain safety and quality while minimizing losses of horticultural crops and their products between production and consumption (Kader, 2003; Kitinoja and Kader, 2002). Post-harvest losses and quality deterioration contribute to unavailability of nutrients in stored fruits. Nutritional quality parameters of fresh produce change with storage time, and quantification is necessary to determine shelf life (Barrett *et al*., 2010; Idah *et al*., 2010) and nutrient availability. Most fruits and vegetables are composed of 70 to 90% water and once separated from their source of nutrients undergo higher rates of respiration, resulting in moisture loss, quality and nutrient degradation, and potential microbial spoilage (Barett, 2007). The loss of nutritional quality during processing and storage of food commodities has become a major issue in the production chain (Rico *et al*., 2007). The aim of the current study was to determine the nutritional quality of Tanzanian orange fruits as influenced by different post-harvest techniques, storage time and storage conditions.

7.2 Materials and Methods

Msasa and Jaffa, the commonly grown orange fruits varieties were harvested from Bwembera and Semngano villages in the Muheza district, Tanga region in Tanzania from June, 2016 to July, 2017. They were harvested when fully mature and ripe. The results from two seasons were not significant, therefore the seasons were pooled together, and treated as replicates. A three factors factorial experiment was used for each variety and replicated six times. Thirty fruits of each variety were exposed to each treatment which was replicated six times to make a total of 360 fruits per treatment. The two varieties of oranges were sorted, cleaned and tested by two post-harvest techniques namely hexanal (0.02%) and in calcium chloride (2%) where they were dipped for 5 minutes in each solution, and they were compared to untreated control fruits. All the samples were stored under ambient (28 ± 2 °C) and cold (18 ± 2 °C) conditions. Data was collected on the 0, 4th, 7th, 11th and 15th days from the date of fruit treatment (DAT).

During sample collection, three fruits were randomly selected from each treatment. They were cut, squeezed, filtered to remove pulp and seeds and then centrifuged for 10 minutes. The supernatant was then used for measuring the nutritional parameters namely; vitamin C (Ascorbic acid), total flavonoids, reducing sugars and total sugars of orange fruits as described below. Vitamin C was determined by using 2, 6-dichlorophenol-indophenol titrimetric method following methods by Rajwana *et al*. (2010) and Hughes (1983). Total flavonoid was determined by aluminium chloride colorimetric assay following method by John *et al*. (2013). Total sugar was determined by Anthrone method as described by Cerning-Beroard (1975). Reducing sugar was estimated by Nelson-Somogy method (Marais *et al*., 1966). All parameters were measured in triplicates. Data was analysed using R software and where significant differences existed using the *F*-statistic and means were separated using Tukey's Honestly Significant Differences (HSD) ($p \leq 0.05$).

The consumer acceptance test was carried out in the DCSH - SUA by 80 untrained consumers who arrived in groups of 10, using a 5 - points Likert type scale (Albert and Tullis, 2013; Krabbe, 2017. (whereby; 1 = dislike extremely, 2 = dislike moderately, 3 = Neither like nor dislike/Uncertain, 4 = like moderately and 5 = like extremely). A Likert scale is an ordered scale from which respondents choose one option that best aligns with their view. The Msasa orange fruit samples were prepared and coded with 3-digit random number and served to the consumers or judges. The panel involved 80 individuals aged 21- 40 years among which 52.5 % were males and 47.5 were females. Water was provided for rinsing the mouth after assessing any sample. The consumer judges were instructed to rate the appearance of each fruit sample, for taste, aroma, texture and overall acceptability of each sample indicating their degree of liking or disliking by putting a number as provided in the hedonic scale according to their preference. Testing was complete in one session and each consumer evaluated all 3 samples. Chi square test statistic was used to assess the relationship between quality attributes and post-harvest treatments on sensory of fruits (Lawless and Heymann, 2010).

7.3 Results

7.3.1 Vitamin C (Ascorbic Acid)

The 3-way ANOVA results showed that storage durations had significant ($p < 0.001$) effect on vitamin C of Msasa orange fruits. Post-harvest techniques and storage conditions had non-significant ($p > 0.05$) effects on the vitamin C. On the other hand, all the interactions had non-significant effects ($p > 0.05$) on vitamin C. Further analysis of main means showed that storage duration had significant ($p < 0.001$) effects on vitamin C (Fig. 7.1) of Msasa variety. The fruits had high vitamin C content at harvest, and it was decreasing with increasing storage time from 7 days storage to 15 days storage.

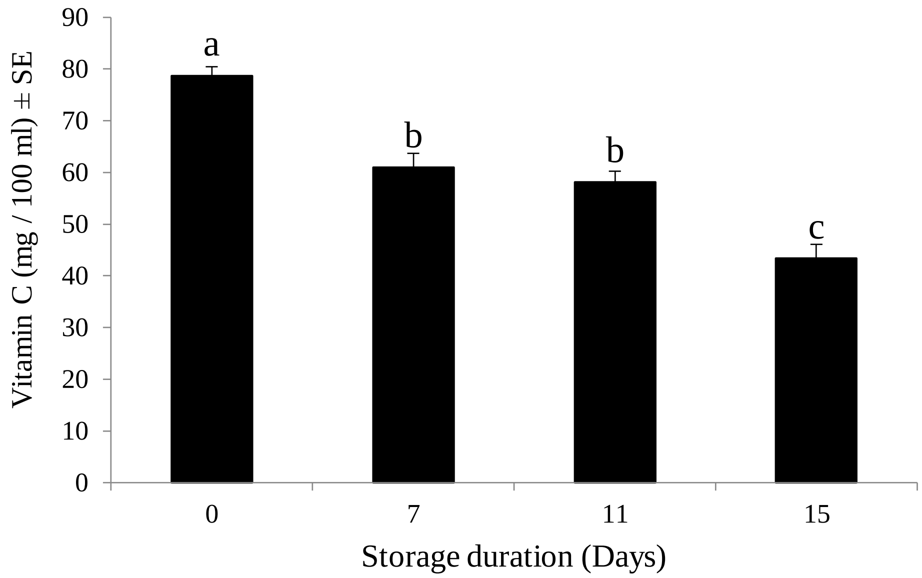

Figure 7.1: Effects of storage duration on vitamin C of Msasa orange fruits
Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

The ANOVA results showed significant effects of post-harvest techniques ($p < 0.001$), storage duration ($p < 0.001$) and post-harvest techniques × storage durations ($p < 0.01$) on vitamin C of Jaffa fruits variety. The storage conditions had non-significant ($p > 0.05$) effect on vitamin C of Jaffa fruits variety. Other remaining interactions had non-significant ($p > 0.05$) effects on vitamin C. Further analysis of simple means showed that post-harvest techniques had significant effects when the fruit were stored for 7 and 11 days. The effects of vitamin C were insignificant immediately after harvest and at 15 days in storage ($p > 0.05$). Fruits had higher vitamin C at harvest (before storage), but it decreased with storage duration from the 7th to 15th day storage. Hexanal treated fruits had the highest vitamin C content followed by calcium chloride treated fruits while the untreated fruits had the lowest vitamin C (Fig. 7.2).

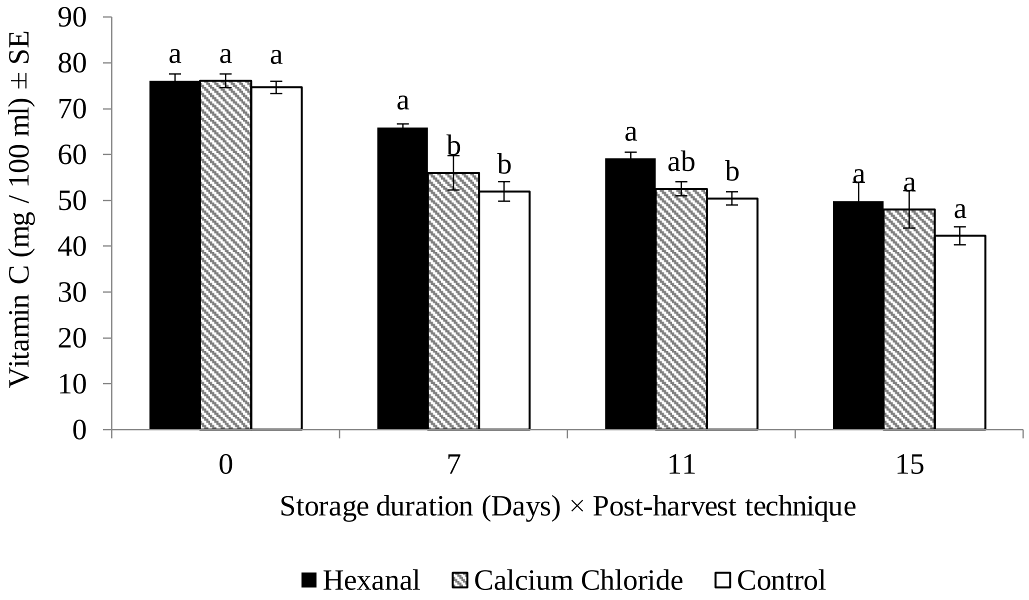

Figure 7.2: Effects of storage duration on vitamin C of Jaffa orange fruits

Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test).

7.3.2 Total flavonoids

Total flavonoids of Msasa fruits were significantly affected by post-harvest techniques ($p = 0.046$), storage duration ($p = 0.003$) and storage durations × post-harvest techniques ($p = 0.011$). Storage condition and all remaining interactions had non-significant effects ($p > 0.05$) on the total flavonoid of Msasa fruits. Post-harvest techniques had significant effects on total flavonoids of Msasa fruits stored for 7 days ($p = 0.027$), 11 days ($p = 0.01$) and 15 days ($p = 0.001$). The effects were insignificant immediately after treatment ($p > 0.05$). In fruits stored for 7, 11 and 15 days, hexanal had a high total flavonoid content compared to calcium chloride and untreated fruits (Fig. 7.3). The hexanal had the highest total flavonoids followed by calcium chloride treated fruits while the untreated control fruits had the lowest total flavonoid content (Fig. 7.3).

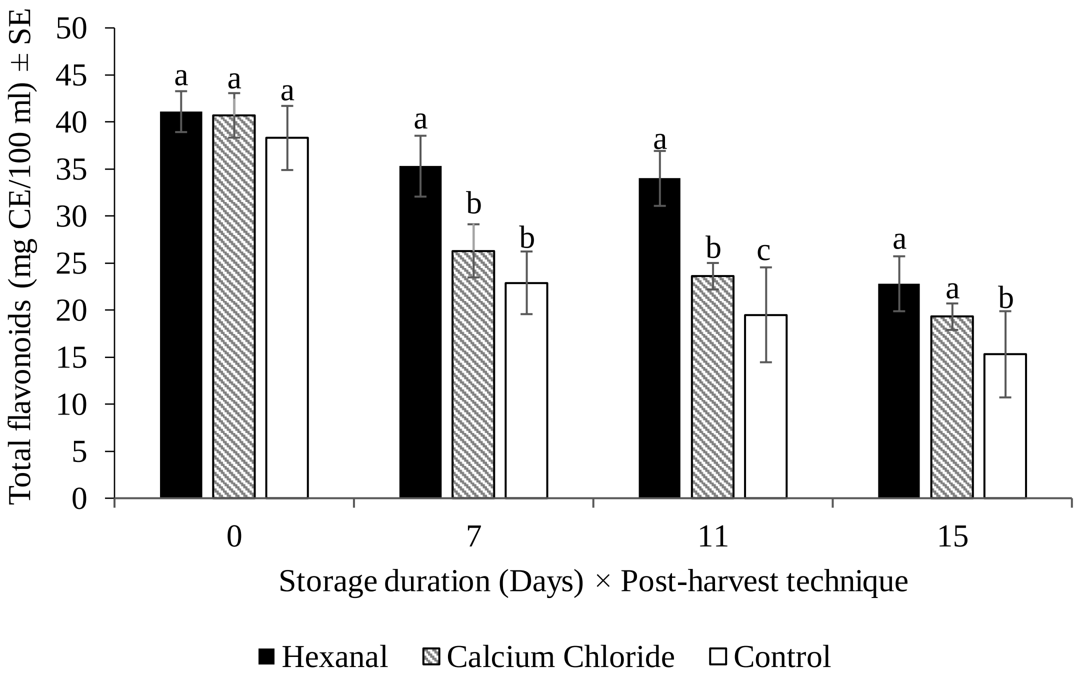

Figure 7.3: Effects of storage duration and post-harvest techniques on total flavonoids of Msasa orange fruits

Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test).

Post-harvest techniques ($p = 0.003$) and storage duration ($p < 0.001$) had significant effects on the total flavonoid content of Jaffa fruits. Storage conditions and all the interactions had non-significant ($p > 0.05$) effects. Analysis of main means showed that post-harvest techniques had significant ($p = 0.002$) effects on total flavonoid content of

Jaffa fruits (Fig. 7.4). Hexanal treated fruits had the highest content of total flavonoid content of Jaffa fruits followed by calcium chloride treated but the untreated control fruits had the lowest total flavonoid contents.

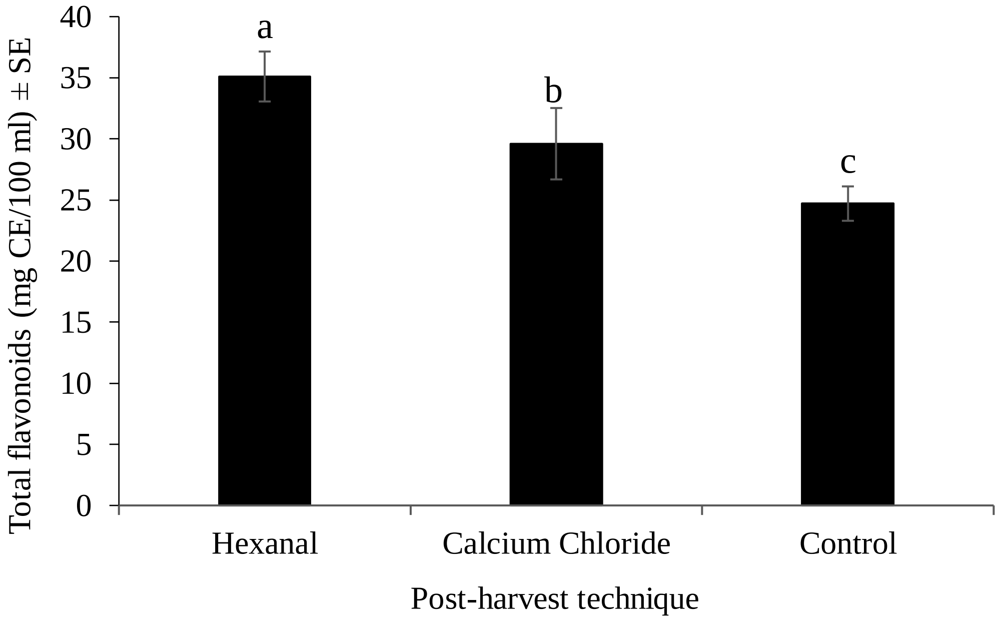

Figure 7.4: Effects of post-harvest techniques on total flavonoids of Jaffa orange fruits

Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

7.3.3 Total sugars

The ANOVA results showed that storage duration × post-harvest techniques had significant ($p < 0.001$) effect on total sugars of Msasa fruits variety whereas post-harvest techniques, storage duration, storage conditions and the remaining interactions had non-significant ($p > 0.05$) effects on total sugars. Further analysis of simple means showed that the post-harvest techniques had significant effects at 7 days ($p = 0.042$) and 15 days ($p = 0.003$) while the non-significant effects were observed after harvest and at 11 days in storage (Fig. 7.5). Hexanal treated Msasa fruits which were stored for 11 days had the highest total sugar content while the untreated control fruits had low total sugar content.

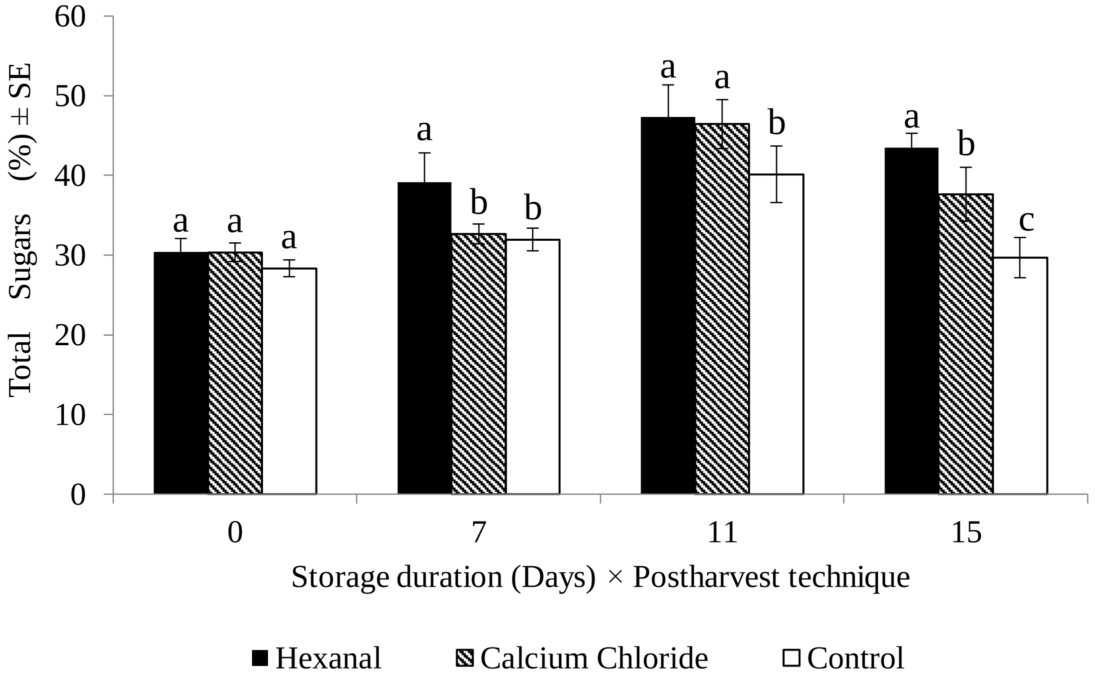

Figure 7.5: Effects of post-harvest techniques and storage duration on total sugars of Msasa orange fruits

Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test).

Results also showed that total sugars varied significantly with storage duration ($p < 0.001$) and post-harvest techniques × storage duration ($p < 0.001$) of Jaffa orange fruits. Both post-harvest techniques, storage condition and all remaining interactions had non-significant ($p > 0.05$) effects on total sugar of Jaffa variety. The further analysis of simple means showed that the post-harvest techniques had significant effects on total sugar at 7 days storage ($p = 0.025$), and 15 days storage ($p < 0.001$) but had non-significant ($p > 0.05$) effect at harvest (day 0) and 11 days storage (Fig. 7.6). At 7 days, high total sugar content was observed at hexanal treated fruits followed by calcium chloride while the untreated control fruits had low total sugar content. Total sugar of Jaffa fruits increased with storage time.

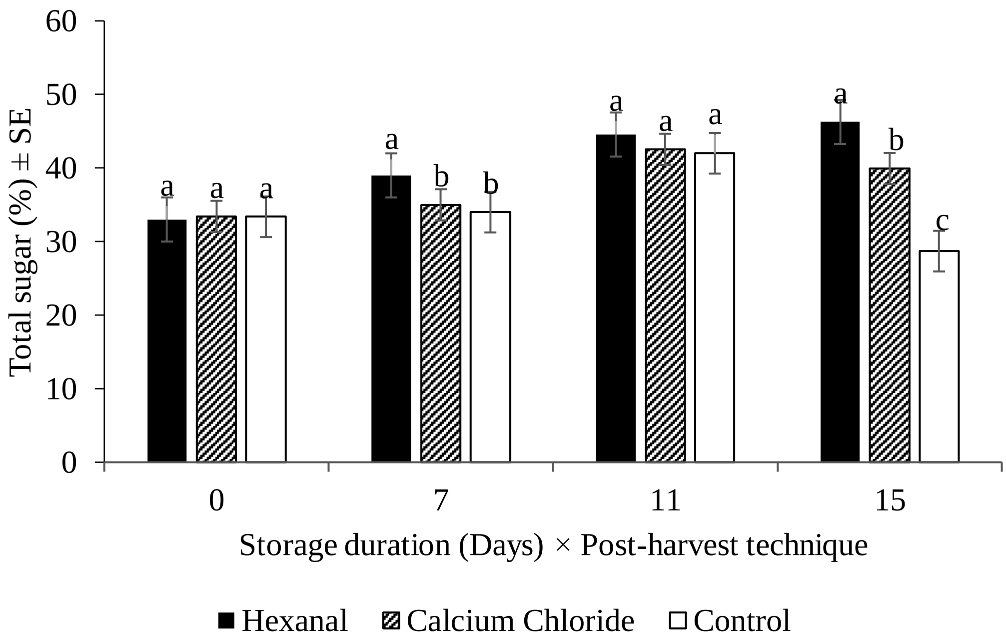

Figure 7.6: Effects of post-harvest techniques and storage duration on total sugars of Jaffa orange fruits

Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test).

7.3.4 Reducing sugars

Reducing sugar of Msasa fruits was significantly affected by storage duration ($p < 0.001$), storage condition ($p < 0.001$) and storage durations × storage conditions ($p < 0.001$). But, post-harvest techniques and the rest of interactions had non-significant effects ($p > 0.05$) on reducing sugar content. Storage conditions had significant effects after 7 days ($p = 0.017$) and 11 days ($p < 0.001$) after application (Fig. 7.7). On the other hand, storage conditions had non-significant ($p > 0.05$) effects on reducing sugar content of Msasa fruits immediately and 15 days post application. Generally, the reducing sugar of Msasa fruits was highest at 15 days of storage under ambient condition.

The 3 - way ANOVA results showed that storage duration had significant (p = 0.034) effect on the reducing sugars content of Jaffa fruits variety. The post-harvest techniques, storage condition and all the interactions had non-significant ($p > 0.05$) effects. Analysis of main means showed that the storage duration had significant ($p < 0.001$) effects on reducing sugar of Jaffa fruits (Fig. 7.8). Fruits had the lowest and similar reducing sugar content before storage. The reducing sugar content of Msasa fruits increased with storage duration. Fruits stored for 15 days had the highest reducing sugar content (Fig. 7.8).

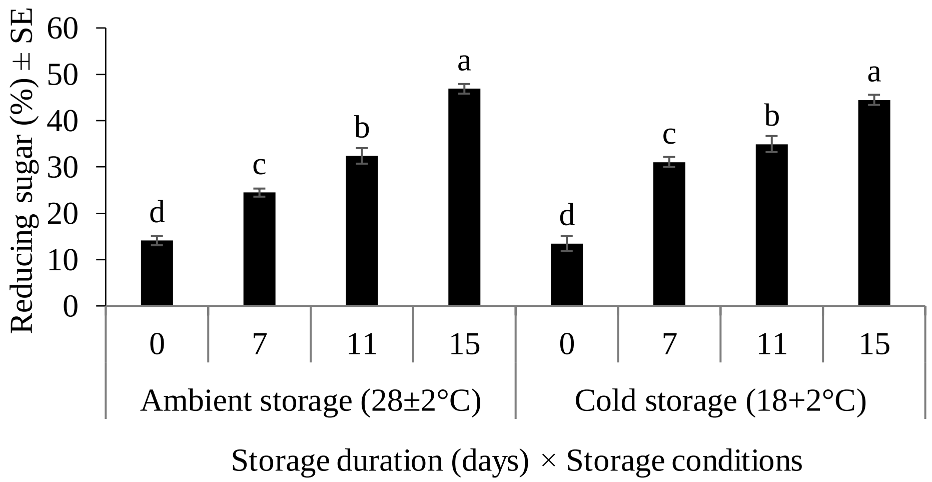

Figure 7.7: Effects of storage duration and storage conditions on reducing sugars of Msasa orange fruits

Means with the same letters are not significantly different at $p \leq 0.05$ (Tukey test)

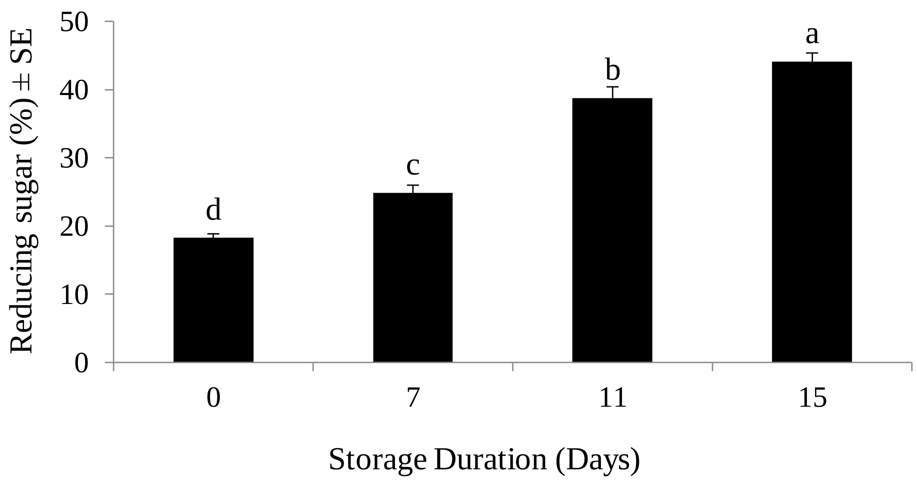

Figure 7.8: Effects of storage duration on reducing sugars of Jaffa orange fruits

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test).

7.3.5 Consumer Acceptance

The panellists' acceptance score for appearance, taste, aroma, texture and overall acceptance attributes are shown in Table 7.1. Chi square test results showed that appearance of fruits was significantly ($\chi^2 = 19.156$, $p < 0.001$) associated with post-harvest techniques (Table 7.1). The appearance of hexanal treated fruits was ranked the highest by the majority of panellists. We also found significant ($\chi^2 = 36.510$, $p < 0.001$) association between post-harvest techniques and taste of fruits (Table 3), in this case panellists score for hexanal treated fruits was the highest. Likewise, hexanal treated fruits had best aroma among all fruits. The association between aroma and post-harvest techniques was also significant ($\chi^2 = 29.764$, $p = 0.013$) (Table 3). Results further showed that texture of fruits was significantly ($\chi^2 = 147.905$, $p = 0.001$) associated with post-harvest techniques (Table 7.1). Calcium chloride treated fruits had the highest texture scores while untreated fruits scored the least. Finally, hexanal treated fruits were the most acceptable while untreated fruits were least accepted. The association between post-harvest techniques and overall acceptability of fruits was significant ($\chi^2 = 59.462$, $p < 0.001$) associated with (Table 7.1). According to panellists, appearance and tasted scored higher points in the ranking than aroma and texture.

Table 7.1: The Likert scores for Msasa orange fruits treated with Calcium Chloride, Hexanal and untreated control using 5-points Likert scale

Attributes	Post-harvest Techniques	Dislike Extremely (1)	Dislike Moderately (2)	Neither like nor dislike (3)	Like moderately (4)	Like extremely (5)
Appearance	Calcium Chloride	1	8	3	80	240
	Hexanal	2	4	6	48	340
	Control	14	24	27	88	100
Taste	Calcium Chloride	3	4	12	48	120
	Hexanal	1	6	12	96	165
	Control	3	4	9	120	5
Aroma	Calcium Chloride	1	2	12	108	5
	Hexanal	3	10	18	96	140
	Control	3	4	9	116	5
Texture	Calcium Chloride	2	6	12	40	105
	Hexanal	3	4	12	44	100
	Control	2	4	48	76	10
Overall acceptability	Calcium Chloride	3	6	21	24	130
	Hexanal	2	2	15	50	144
	Control	6	4	9	104	5

Note: The values in the brackets in each column represents respective value of the scale in that column.

7.4 Discussion

Post-harvest techniques employed in this study had an effect on the ascorbic acid content of orange fruits. Hexanal and calcium chloride treated fruits had a high content of ascorbic acid compared to untreated control fruits. The high ascorbic acid content in hexanal and calcium chloride is probably due to their ability to retain the ascorbic acid due to improved firmness. Calcium and its salts have been used to decrease softening of different varieties of minimally processed fruits (Soliva-Fortuny and Martin-Belloso, 2003). Turmanidze *et al*. (2017) reported that calcium chloride retained the level of ascorbic acid in the treated raspberry and strawberry fruits. The use of calcium chloride treatment in fruit tissue was associated with reductions in the respiration rate, ascorbic acid degradation and membrane lipid peroxidation which enhanced the total antioxidant capacity in the treated fruits (Turmanidze *et al*., 2017).

Vitamin C of orange fruits was highest at harvest (before storage) and it was decreasing with storage time. vitamin C decreased due to degradation which occur in fruits during storage as a result of reduction in their antioxidant potential. Ascorbic acid is the most sensitive vitamin to loss and changes to a less active form as the result of time and temperature in storage (Kramer, 1977). The degradation reactions of vitamin C are often responsible for significant quality changes that occur during the storage of foods (Touati *et al*., 2016). Smoot and Nagy (1980) reported that storage temperatures and storage time affects the percent of vitamin C content of orange fruits and orange juice. The degradation of vitamin C is delayed during the first few days during which the vitamin content actually increases as a result of continuing endogenous metabolism (Zee *et al*., 1991). Several studies reported the decreased stability of vitamin C with increase in storage temperature (Davey *et al*., 2000); Emese and Nagymate, 2008; Oyetade *et al*., 2012).

Post-harvest techniques had significant effects on total flavonoids. Hexanal and calcium chloride treated fruits had a high total flavonoid content compared to control fruits in both tested varieties. The hexanal treated fruits delayed ripening, maintained firmness and fresh appearance throughout storage time. El Kayal *et al*. (2017) reported delayed ripening in hexanal and calcium chloride treated raspberry fruits. A study by Sharma *et al*. (2010) revealed that hexanal maintained the post-harvest firmness of sweet cherry from 15 to 30 days. This study showed that the tested post-harvest techniques had significant effects on maintaining the total flavonoids of orange fruits stored for 4 days under ambient storage conditions only; while 8 days stored were significant in both storage conditions. Hexanal and calcium chloride treated fruits had higher content of total flavonoids than untreated fruits. The current study showed the decrease in total flavonoids with storage duration from day 0 to 15 day of storage. Saci *et al*. (2015) reported the decreased flavonoids with storage time.

Oranges treated with hexanal showed a high total sugar content compared calcium chloride and control fruits. Changes in sugars during fruit maturation usually depend on the fruit species and variety. Several fruits showed increasing glucose, fructose and sucrose levels with the more advanced stages of maturation (Mahmood *et al*., 2012). Total sugars increased with storage time, though it was highest on the 11th day of storage.

Storage duration had significant effect on the reducing sugars content of orange fruits of both varieties. Fruits stored for 11 days had a high reducing sugar compared to fruits stored for 7 and 15 days. The reducing sugar content was low before storage and it increased with storage time. Fructose and sucrose represented the major components of soluble sugars in cultivated fruits (Cordenunsi *et al.*, 2002). Our results were similar to those reported by Zhang and Ge (2016) who found that the sucrose content of watermelon increased substantially after 20 days after anthesis (DAA) and it was the main soluble sugar in mature fruit. The current study showed that storage condition had significant effect on reducing sugar where there were high values of reducing sugar in ambient storage relative to cold storage. The rising temperature during storage also accelerates hydrolysis of acids and polysaccharides into simple sugars (Nandal and Bhardwaj, 2014). Fructose and sucrose represented the major components of soluble sugars in cultivated fruits.

The consumer acceptance tested proved that hexanal treated fruits was the most liked fruits than the calcium chloride treated and untreated fruits. The acceptance of the food product usually indicates actual use of the product (Watts *et al.,* 1989). The primary consideration for selecting and eating a food commodity is the product's palatability or eating quality, and other quality parameters, such as nutrition and wholesomeness are secondary (Lawless and Heyman, 2010). The hedonic scale assumes consumer preferences exist on a continuum and that preferences can be categorized by responses based on like and dislike. The visual appearance of fresh fruit is one of the first quality determinants made by buyers (Mitcham *et al.,* 2003). Flavour, nutritional quality and appearance are recommended for increased consumption and healthier diets for consumers (Kader, 2003). Sensory inputs interact to drive overall impressions, for example ratings of flavour may be driven by appearance and texture inputs, as well as by pure flavour inputs (Moskowitz and Krieger, 1995).

7.5 Conclusion and Recommendations

From this study, it was found that post-harvest techniques had significant effect on total flavonoids, vitamin C and total sugar. Hexanal had higher values of total flavonoids, vitamin C, and total sugars compared to calcium chloride treated and the untreated fruits. Storage condition had significant effect on reducing sugar of Msasa variety only. Storage durations showed significant effect on the vitamin C content of Jaffa fruits, total flavonoids, the total and reducing sugars of both Msasa and Jaffa fruits. Vitamin C and total flavonoids decreased with increasing storage duration of fruits. Total sugars in Msasa variety increased from 0 day to 11th day of storage and then decreased where the fruits were stored to 15th day. Reducing sugar was observed to increase with increasing storage duration of fruits. It was generally noted that hexanal improved the internal qualities of the orange fruit relative to calcium chloride and the control. The significant interactions of factors were also observed on total sugar which increased with increased storage duration, but higher in hexanal treated cold stored fruits. Hexanal and cold storage are two important factors for maintaining internal qualities of fruits and therefore can be used in post-harvest handling of fruits to maintain the internal fruit qualities. Therefore, it is recommended that hexanal can be used for maintaining internal qualities of orange fruits.

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CHAPTER EIGHT

8.0 EFFECTS OF STORAGE DURATION, STORAGE CONDITIONS AND POST-HARVEST TECHNIQUES ON NUTRITIONAL QUALITY OF APPLE AND PALMER MANGO VARIETIES GROWN IN TANZANIA

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Abstract

Two mango varieties, Apple and Palmer were harvested from Mwalusembe village in Mkuranga District, Coastal Region, during 2016 and 2017 mango seasons. Fruits were subjected to post-harvest techniques namely; dipping of fruits in (i) hexanal (0.02% v/v) and (ii) calcium chloride (2% w/v) and the control group, which was untreated. Samples from each treatment were stored at ambient (28 ± 2 °C) and cold storage (18 ± 2 °C). Data was collected on the 0, 7th, 11th, and 15th days from the date of fruit harvest (DAH). Thirty fruits of each variety were exposed to each treatment and replicated six times making a total of 360 fruits per treatment. Chemical analysis was conducted to determine vitamin C content, total and reducing sugars as well as total flavonoids. Results showed that hexanal treated fruits maintained high vitamin C, total flavonoids, total and reducing sugar contents followed by calcium chloride treated fruits while the untreated control fruits had the lowest values for all parameters, irrespective of the storage conditions. Vitamin C and total flavonoids of Apple and Palmer mango fruits decreased with storage time, whereas total and reducing sugar contents increased with storage time. Based on this study it can be concluded that hexanal and calcium chloride treated fruits when stored under cold storage conditions, can maintain vitamin C, total flavonoids, total sugar and reducing sugar contents of mango fruits.

Keywords: vitamin C, flavonoids, reducing sugar, total sugar, hexanal, calcium chloride, phytochemicals

8.1 Introduction

Mango (*Mangifera indica*, L.) is commonly cultivated in many tropical and subtropical regions and distributed worldwide (Ara *et al*., 2014). Mango is an important tropical fruit commercialized and consumed worldwide, offering an excellent source of fibre, bioactive compounds including antioxidants such as provitamin A carotenoids, vitamin C (ascorbic acid) and phenolic compounds (Guiamba, 2016; Yahia and Berrera, 2009; Gonzalez-Aguilar *et al*., 2010). An antioxidant can be defined as any substance which significantly delays or prevents oxidation of oxidizable substrate when present at low concentration compared to that of an oxidizable substrate (Ravimannan and Nisansala, 2017). Antioxidants chemically bind and neutralize the tissue-damaging effects of substances in the environment known as free radicals (El-Ishaq and Obirinakem, 2015). Antioxidant components of plants include vitamins A, C, and E, anthocyanin, beta-carotene, catechins, elligic acid, lycopene and selenium (Ravimannan and Nisansala, 2017; Kesarkar *et al*., 2009). Mango is extremely important in human nutrition as a source of nutrients and non-nutritive food constituents as well as for the reduction in disease risks (Boeing *et al*., 2012). Epidemiological studies have demonstrated a strong correlation between adequate consumption of fruits and vegetables with reduced risk of some major non-communicable diseases such as cardiovascular, diabetes, hypertension, certain types of cancer and some of the degenerative diseases (Garcia-Salas *et al*., 2010).

The nutritional value of fruits such as mangoes depends on their composition, which greatly differs depending on the species, cultivar and maturity stage of the specific crop (Florkowski *et al*., 2009). Fruits are highly perishable, and the post-harvest losses from harvesting to consumption stage are approximated to be 25 to 40 percent (Medina and Garcia, 2002). To reduce these losses, different techniques may be used to extend shelf life and maintain nutritional quality of matured harvested fruits. Storage duration reduces nutritional qualities of fresh produce hence necessitate their quantification (Barrett *et al*., 2010; Idah *et al*., 2010). Storage temperature is another important factor which affects quality of fruits. Low temperature reduces the metabolism rate of fruits which is crucial in extending the storage life (Rees *et al*., 2012). Calcium chloride has been widely used as a preservative and firming agent in the fruit and vegetable industry for whole and fresh-cut commodities (Martin-Diana *et al*., 2007). Calcium chloride also improved stored quality of various tropical fruits (Mishra, 2002).

Hexanal inhibits the activities of Phospholipase D enzymes which are responsible for membrane degradation (Paliyath *et al*., 2008; Paliyath, 2011) during fruit ripening. Hexanal was reported to improve the physico-chemical qualities of mango, sweet cherry (*Prunus avium,* L.) and tomato (*Solanum lycopersicum,* Mill.) (Sharma *et al*., 2010; Tiwari and Paliyath, 2011). However, information is lacking on the effects of hexanal on nutritional quality maintenance of fresh mango fruits. Therefore, the current study was carried out to evaluate the effects of hexanal and calcium chloride on nutritional quality (vitamin C, total flavonoids, reducing sugars and total sugars) of mango fruits under different storage conditions and duration.

8.2 Materials and Methods

Apple and Palmer, the two commonly grown mango fruit varieties were harvested from Mwalusembe ward in Mkuranga district, Coast region in Tanzania in 2016 and 2017 mango seasons. Mango fruits were harvested at their physiological maturity (but not ripe) and transported to the Post-harvest Laboratory of Sokoine University of Agriculture, Morogoro. The results from two seasons were statistically not significant, therefore the seasons were pooled together, and treated as replicates. A three factors factorial experiment was used for each variety and replicated six times. The three factors were storage conditions, storage durations and post-harvest techniques. At the laboratory, the fruits were sorted, cleaned and tested against hexanal and calcium chloride as follows:

Fruits were dipped in hexanal solution (0.02% v/v) for five minutes. Also, fruits were dipped in calcium chloride solution (2% w/v) for five minutes. Non-treated samples were included as control. All samples (treated and untreated) were stored under ambient (28 ± 2 °C) and cold/reduced (18 ± 2 °C) temperatures conditions. Thirty fruits were used for each treatment. Data was collected before storage (on day 0), and then at 7th, 11th, and 15th days of storage. During each collection, three fruits were taken at random from each treatment.

8.2.1 Vitamin C determination

The vitamin C was determined by using 2, 6-dichlorophenol-indophenol titrimetric method followed methods by Rajwana *et al*. (2010) and Hughes (1983) with few modifications. Five grams (g) of fruit pulp was weighed and grinded in the blender with 50 ml of 4% oxalic acid as extractant. The juice then filtered, and the filtrate made up to 100 ml with distilled water. Five milliliters of filtrate was taken out and put in the conical flask, then 10 ml of 4% oxalic acid was added and titrated against 2, 6-dichlorophenolindophol till light pink end point which persisted for 10 to 15 seconds. The amount of 2, 6-dichlorophenolindophenol consumed is equivalent to amount of ascorbic acid in the sample. Standard ascorbic acid solution was prepared by adding 1 ml of 0.1% ascorbic acid and 1.5 ml of 0.4% oxalic acid. For the preparation of dye, 42 mg of baking soda ($NaHCO_3$) and 52 mg of 2,6-dichlorophenolindophenol were measured and put in a 200 ml volumetric flask and volume was made up to the mark by adding distilled water. The amount of vitamin C present in the sample was then calculated from as:

$$\text{Vitamin C} = \frac{R1 \times V \times 100}{R \times T \times W1}$$

Where:

R1 = volume of dye used in titration of aliquot

R = volume of dye used in titration of standard ascorbic acid solution

W1 = weight of sample used

V = volume of aliquot made by addition of 0.4% oxalic acid

T = volume of aliquot used for titration

8.2.2 Total flavonoid determination

Total flavonoid content was measured by the aluminium chloride ($AlCl_3$) colorimetric assay as described by John *et al*. (2013). Five grams of mango pulp was dissolved in 100 ml of 80% methanol in the flask. An aliquot (1 ml) of extracts and standard solutions of quercetin (20, 40, 60, 80 and 100µg/ml) was added to 10 ml volumetric flask containing 4 ml of distilled water. To the flask was added 0.30 ml of 5% Sodium nitrite ($NaNO_2$)

followed by 0.3 ml 10% $AlCl_3$ 5 minutes later. Five minutes later, 2 ml of 1 M Sodium hydroxide (NaOH) was added and the volume was made up to 10 ml with distilled water. The solution was mixed and absorbance was measured against the blank at 510 nm in the spectrophotometer. The amount of total flavonoid present in the sample was calculated from the graph and it was expressed as mg quercetin equivalents (QE)/100 mg.

8.2.3 Total sugar determination

Total sugar was determined by Anthrone method by Cerning-Beroard (1975). Mango pulp of 100 mg was put in a test tube containing 2.5 N HCl. Sample was hydrolysed by keeping it in a boiling water bath for 3 hours and then cooled to room temperature. Sample was neutralized with solid sodium carbonate until effervescence ceased. Then, volume was made up to 100 ml with distilled water and then centrifuged. The supernatant was collected and 1 ml aliquot was taken for analysis. The standards were prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard. The volume was made up to 2 ml in all the tubes including the sample tubes by adding distilled water. Four milliliters of Anthrone reagent was added and then heated in a boiling water bath for 8 minutes. The boiled mixture was cooled rapidly and absorbance was read at 630 nm in the spectrophotometer. From the graph, the amount of total sugar present in the sample tube was calculated as:

$$\text{Total sugar (mg/100 g of mango)} = \left(\frac{\text{Quantity of sugar obtained}}{\text{Weight of sample}}\right) \times 100$$

8.2.4 Reducing sugar determination

Reducing sugar was estimated by Nelson-Somogy method (Marais *et al*., 1966). Two grams of the mango pulp sample was weighed and the sugar extracted twice with 5 ml hot

80% ethanol. Extract was filtered by using 2 layers cheese cloth, and the supernatant was collected and evaporated by keeping it on a water bath at 80 °C. Ten milliliters water was added to dissolve the sugars. An aliquot of 0.1 ml was pipetted out to separate test tubes. The standard glucose solution was pipetted out of into a series of test tubes (0.2, 0.4, 0.6, 0.8 and 1 ml). Volume in both sample and standard tubes was made up to 2 ml with distilled water. Two milliliters distilled water was pipette out in a separate tube and set as blank. One milliliter of alkaline copper tartrate reagent was added to each tube. The tubes were placed in boiling water for 10 minutes, cooled and then 1 ml of arsenomolybolic acid reagent was added. The volume in each tube was made up to 10 ml with distilled water. The absorbance was read at 620 nm after 10 minutes. The amount of reducing sugars present in the sample was calculated from the graph.

Absorbance corresponds to 0.1 ml of test = x mg of glucose

$$\%\text{ of reducing sugars } = \left((\frac{x}{0.1} \times 10 \text{ mg of glucose} \times 100 \right)$$

All the parameters were measured in triplicates. Data was analysed using R software. Mean separation was done by using Tukey's Honestly Significant Differences at $p \leq 0.05$.

8.3 Results

8.3.1 Vitamin C (Ascorbic Acid)

The analysis of variance results showed that storage duration had significant ($p < 0.001$) effects on vitamin C of both Apple and Palmer mango fruits. The storage condition had significant ($p = 0.010$) effects on vitamin C of Apple mango fruits only. The post-harvest techniques and all the interactions of Apple and Palmer mango fruits had non- significant ($p > 0.05$) effects on vitamin C. Further analysis of main means showed that storage duration had significant ($p < 0.001$) effects on vitamin C of the two mango varieties

(Fig. 8.1 and Fig. 8.2). The vitamin C of mango fruits was higher at harvest but, it decreased with storage duration from the 7th to 15th days of storage.

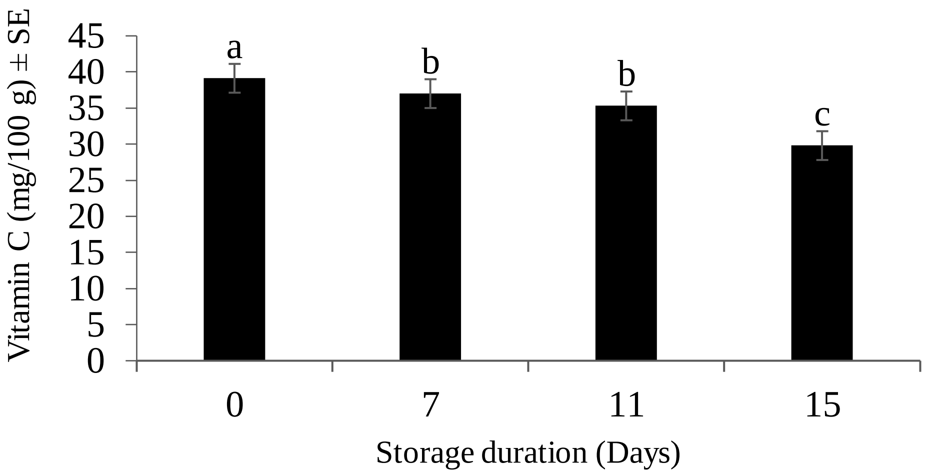

Figure 8.1: Effects of storage duration on vitamin C of Apple mango fruits

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

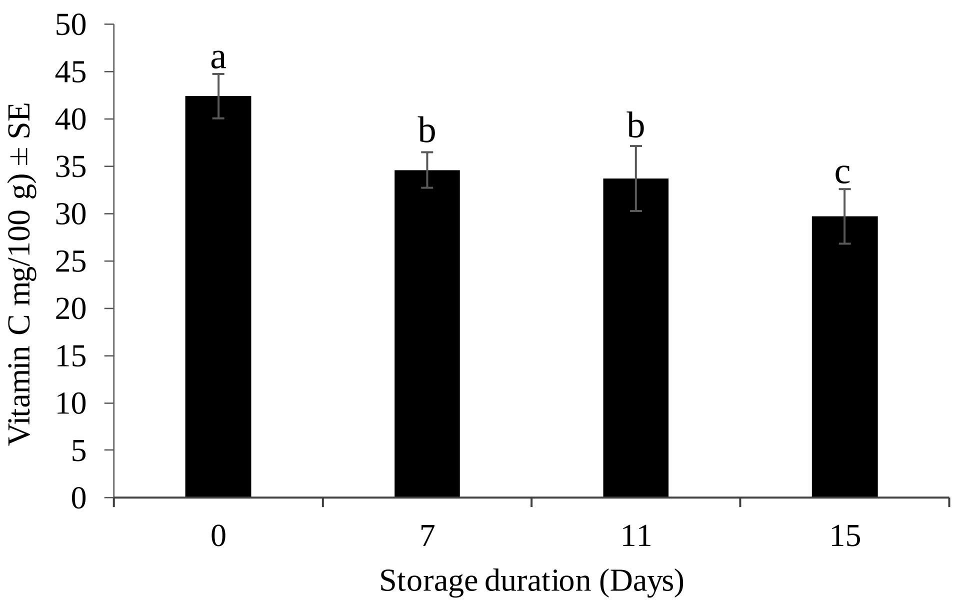

Figure 8.2: Effects of storage duration on vitamin C of Palmer mango fruits

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

8.3.2 Total flavonoids

Results showed significant effects of storage duration ($p < 0.001$), storage condition ($p = 0.002$) and post-harvest technique ($p = 0.024$) on total flavonoids of Apple mango fruits. All two way and three-way interactions were not significant ($p > 0.05$). Further analysis of main means showed that storage duration had significant effects ($p = 0.04$) on total flavonoids of Apple mango fruits. The total flavonoids were higher at fruit harvest and it decreased with storage time (Fig. 8.3). The total flavonoids of Apple mango fruits decreased with increasing storage time.

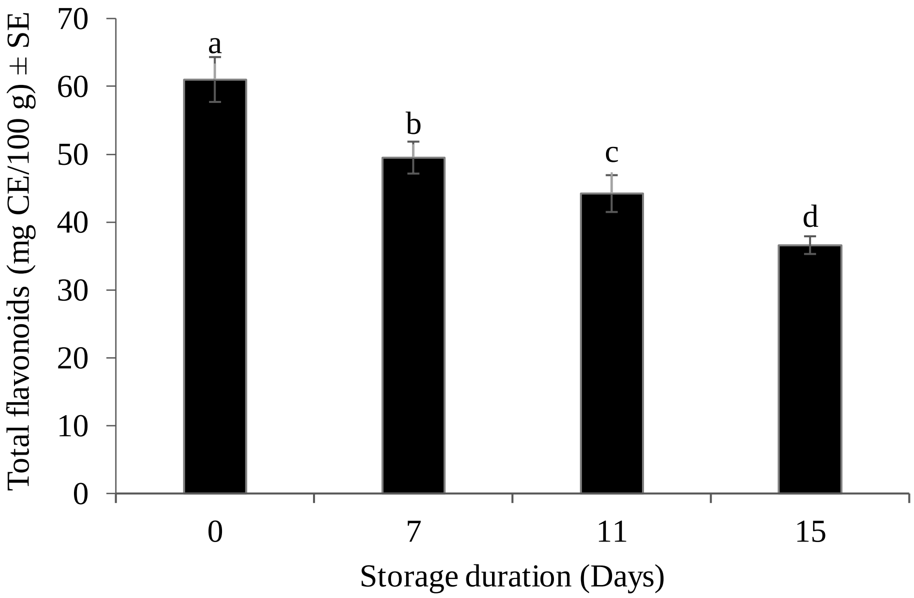

Figure 8.3: Effects of storage duration on total flavonoids of Apple mango fruits
Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

The total flavonoids of Palmer mango fruits were significantly affected by storage duration ($p < 0.001$). The interaction between post-harvest techniques and storage conditions had significant ($p = 0.015$) effects on total flavonoids. However, post-harvest techniques, storage condition and all other interactions had non-significant ($p > 0.05$) effects on total flavonoids. Further analysis of main means showed that storage duration had significant effect ($p = 0.03$) on total flavonoids of Palmer mango fruits. The total flavonoids of Palmer mango variety were highest at harvest and it decreased with increase in storage time (Fig. 8.4). Fruits stored for 15 days had the lowest total flavonoids.

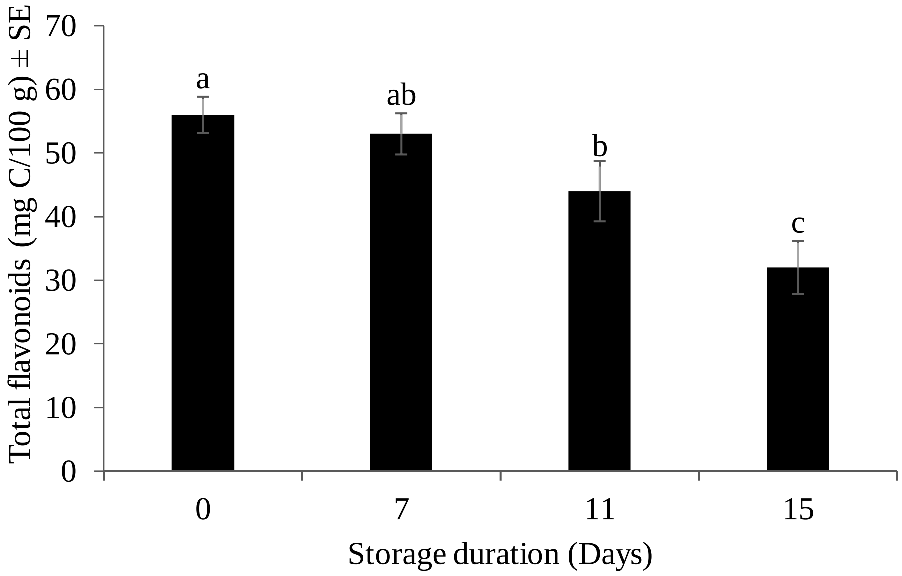

Figure 8.4: Effects of storage duration on total flavonoids of Palmer mango fruits
Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

8.3.3 Total sugars

Results showed that storage duration had significant ($p < 0.001$) effects on total sugars of Apple mango fruits. On the other hand, post-harvest techniques, storage condition and all the interactions conditions had non-significant ($p > 0.05$) effects on total sugars. The analysis of main means showed that storage duration had significant ($p < 0.01$) effects on total sugars (Fig. 8.5). The total sugar content of Apple mango fruits was highest in fruits stored for 15 days followed by 11 days and 7 days. Generally, total sugar content of Apple fruits before storage (day 0) was the lowest and it increased with storage duration (Fig. 8.5).

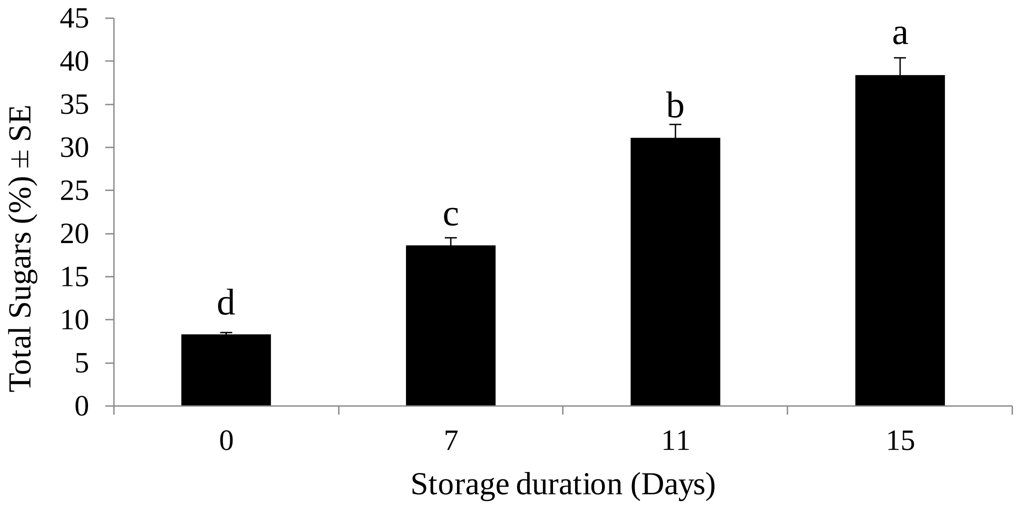

Figure 8.5: Effects of storage duration on total sugars of Apple mango fruits

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

It was found that Palmer showed significant effects of storage duration ($p < 0.001$), storage condition ($p = 0.003$), post-harvest techniques ($p = 0.003$), and storage duration × storage conditions ($p < 0.01$) on total sugar of Palmer mango fruits. All the remained interactions had non-significant ($p > 0.05$) effects on total sugar of Palmer mango fruits. The analysis of main means showed that post-harvest techniques had significant ($p < 0.001$) effects on total sugar of Palmer mango fruits (Fig. 8.6). The hexanal treated fruits had the highest total sugar compared to calcium chloride and untreated control fruits.

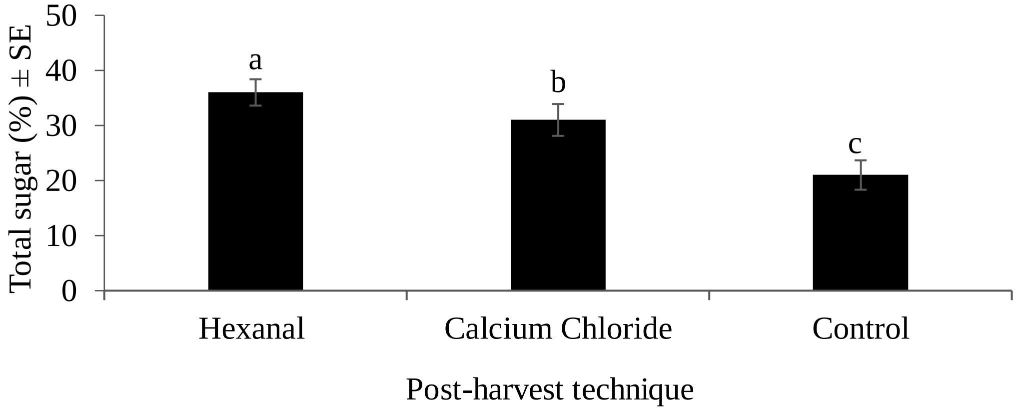

Figure 8.6: Effects of storage duration on total sugar of Palmer mango fruits under ambient and cold storage conditions

Means with same letters are not significantly different at $p \leq 0.05$ (Tukey test)

8.3.4 Reducing sugars

Reducing sugar of Apple mango fruits were significantly affected by storage duration ($p < 0.001$), storage condition ($p < 0.018$), post-harvest techniques ($p = 0.04$) and post-harvest techniques × storage condition ($p = 0.001$). All other interactions had non-significant ($p > 0.05$) effects on reducing sugar. The simple means showed that post-harvest techniques had significant effects of ($p < 0.01$) and ($p = 0.025$) on reducing sugar of Apple mango fruits stored under cold and ambient storage conditions respectively (Fig. 8.7). The hexanal treated mango fruits had the highest content of reducing sugar followed by calcium chloride treated fruits while untreated control fruits had the lowest reducing sugar content regardless of storage conditions (Fig 8.7). The fruits stored under ambient storage conditions had higher reducing sugar content compared to the cold stored fruits.

Palmer mango fruits showed significant effects of storage duration ($p < 0.001$), storage condition ($p < 0.001$), post-harvest techniques ($p < 0.001$), post-harvest techniques × storage duration ($p < 0.001$), and storage duration × storage condition ($p < 0.001$) on reducing sugar. The remained interactions had non-significant ($p > 0.05$) effects on reducing sugar. Further analysis of simple means of post-harvest techniques had significant effects on reducing sugars of Palmer variety at 11th ($p = 0.015$) and 15th ($p < 0.001$) days after fruit harvest (Fig. 8.8). post-harvest techniques had non-significant ($p > 0.05$) effects on reducing sugar of Palmer mango at harvest and after 7 days. The hexanal treated fruits had higher reducing sugar content followed by calcium chloride treated fruits while the untreated fruits had the lowest reducing sugar content despite the storage time (Fig. 8.8). The reducing sugar of Palmer mango variety was increasing with storage duration (time) despite the post-harvest technique used.

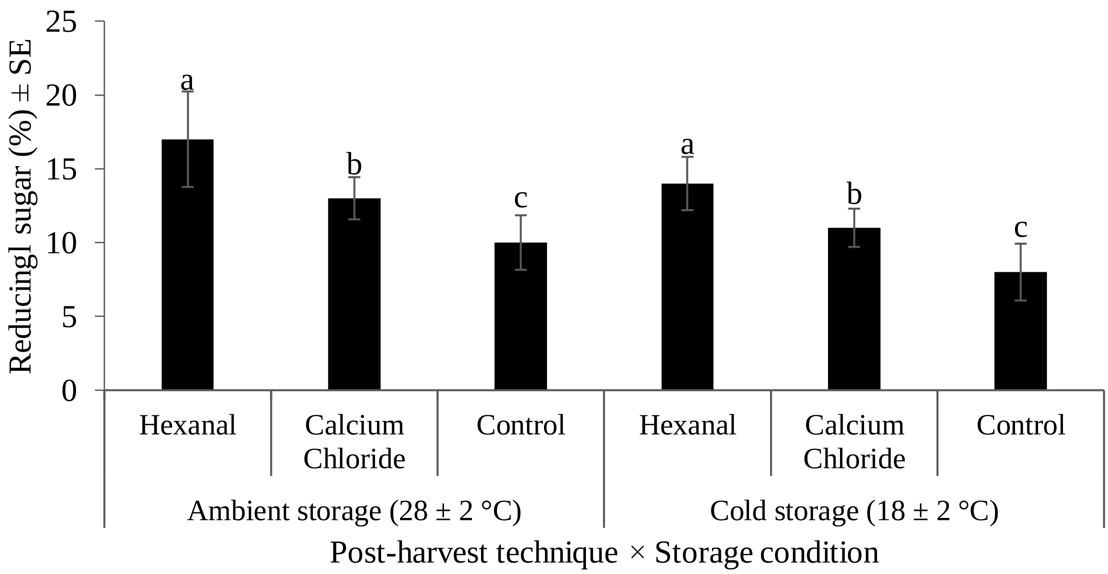

Figure 8.7: Effects of post-harvest techniques and storage conditions on reducing sugars of Apple mango fruits

Means with same letters in the same storage conditions are not significantly different at $p \leq 0.05$ (Tukey test)

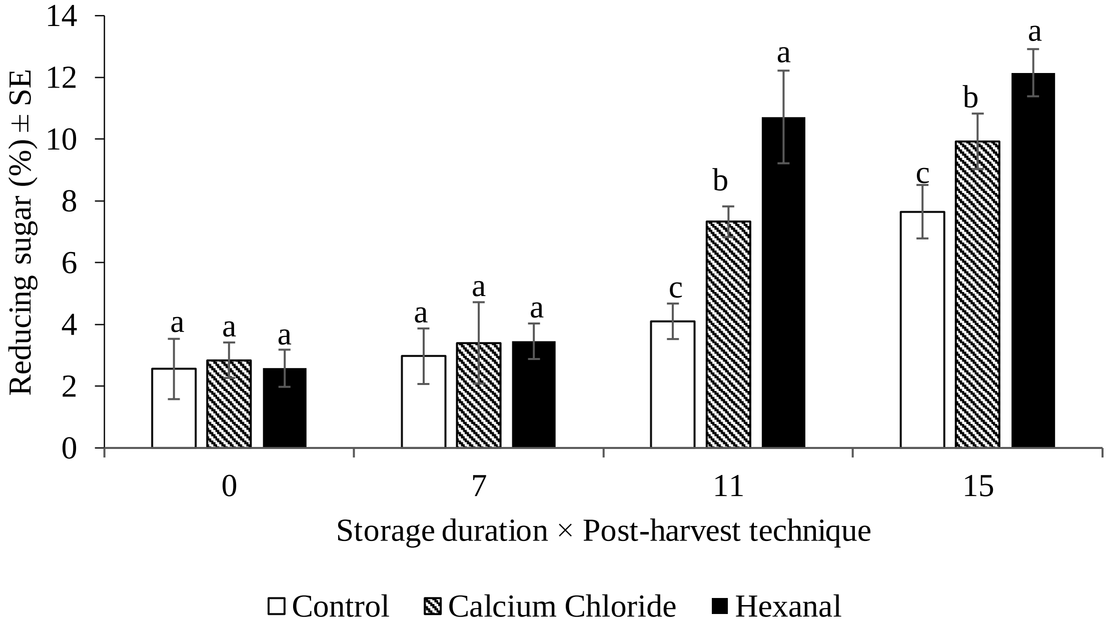

Figure 8.8: Effects of post-harvest techniques and storage duration on reducing sugars of Palmer mango fruits

Means with same letters in the same storage duration are not significantly different at $p \leq 0.05$ (Tukey test)

8.4 Discussion

Vitamin C is an important vitamin and is essential for the lives of both human and animals (Hernandez *et al*., 2006; Najwa and Azrina, 2017). More than 90% of the vitamin C in human diets is supplied by fruits and vegetables (Tareen *et al*., 2015). The vitamin C content was highest in hexanal and calcium chloride treated than in control groups of both mango varieties. Similar to these findings, Turmanidze *et al*. (2017) also found that calcium chloride treatment had the positive effect on retaining the ascorbic acid and polyphenols in the fruits.

These results are important considering the significance of vitamin C in human health and nutrition. Vitamin C is necessary for prevention of scurvy and cancer, relief from common cold, stimulate collagen synthesis, acts as antioxidant, helps in absorption of iron and is important in wound healing process (Iqbal *et al*., 2004; Teucher *et al.,* 2004; Najwa and Azrina, 2017). Based on Mustard (1945) the average range of vitamin C in different mango varieties ranges from 8.8 to 107 mg per 100 g. On the other hand, Ara *et al*. (2014) reported the average vitamin C of 26.53 to 46.53 mg per100 g in ten mango varieties. Smoot and Nagy (1980) in evaluating the effects of storage temperature and duration on total vitamin C content of canned single-strength grapefruit juice and found that vitamin C was decreasing with storage time. Other studies have shown the same trend of decreasing vitamin C in mango fruits with storage time (Shyamalamma *et al*., 1995; Gomez and Lajolo, 2008; Azad *et al*., 2009).

The decrease in vitamin C content with storage duration was due to degradation and oxidation of vitamin C. Previous studies have shown that vitamin C is highly sensitive to oxidation and leaching during storage (Davey *et al.,* 2000; Franke *et al*., 2004; Ajibola *et al*., 2009). Furthermore, Njoku *et al.* (2011) stated that vitamin C begins to degrade immediately after harvest and degrades steadily during prolonged storage period. El-Ishaq and Obirinakem (2015) reported that loss of vitamin C during storage was mainly due to chemical reactions and enzymatically driven while others are chemical reactions that occur because of the senescence. Barrett *et al.* (2010) reported that cutting stimulates ethylene production which in turn increases respiration and senescence leading to even more rapid loss of certain vitamins. Vitamin C usually degrades most rapidly and can be used as an index of freshness (Barrett *et al*., 2010). Post-harvest losses in nutritional quality, particularly vitamin C content, can be substantial and are enhanced by physical damage, extended storage duration, high temperatures, low relative humidity (Gil *et al*., 2006).

The total flavonoids of mango fruits decreased with storage time. The decrease in total flavonoid may be associated with enzymatic degradation of mango fruits caused by natural enzymes synthesized by fruits during ripening. Ozturk *et al*. (2016) reported that total flavonoids and antioxidant activity of cherry laurel (*Prunus laurocerasus,* L.) decreased throughout the storage period. The total flavonoids of mango fruits were lower at ambient than in cold storage, although there was a small change in total flavonoids of fruits under cold storage. Reduced temperatures conditions reduced metabolic activities in fruits stored in cold storage thus delayed rate of fruit ripening due to decreased ethylene production. Kim *et al. (*2007) reported that decreased ethylene production and reduced fruit sensitivity to ethylene slowed the ripening process in mango fruits.

From the current study, hexanal treated fruits gave higher values of flavonoids compared to the calcium chloride and the control. Even though calcium chloride had significantly lower values of total flavonoids relative to that of hexanal, its values were significantly higher when compared to the control suggesting that both post-harvest treatments are necessary for the increased flavonoids. In a related study, Turmanidze *et al*. (2017) found that treatment of raspberry and strawberry with calcium chloride had a positive effect on retaining the antioxidant potential in both fruit samples.

The total sugars content was significantly affected by storage duration of mango fruits. The rest of treatments were none significant. However, for the Palmer variety, post-harvest techniques, storage condition and storage duration had significant effect on total sugar. It is clear that as fruits were stored, the sugar content was increasing. This is due to the fact that when starch in the fruit is hydrolysed, simple sugars are formed (Lima *et al*., 2001). In addition, the increasing trend of total sugar with storage duration was due to ripening, as the climacteric fruits which increases sugar as fruits are ripening. Other studies have also reported on the increase of total sugar with storage time (Baloch and Bibi, 2012; Hossain *et al*., 2014). Furthermore, Azad *et al*. (2009) conducted a study on the qualitative analysis of mango fruits at different maturity stages and found that total sugar content of mango rapidly increased from harvest to ripe stage. Storage condition significantly affected the total sugar whereby, the ambient stored fruits had higher total sugar content relative to cold stored fruits. These findings agree with the previous findings reported by Baloch and Bibi (2012). The cold storage condition reduced the rate of conversion of starch to simple sugars compared fruit stored in ambient storage.

Storage duration and storage condition had significant effect on the reducing sugar of both Apple and Palmer mango varieties. The general trend observed in this study showed that the reducing sugar increased with storage time. Lima *et al*. (2001) also reported that although the reducing sugar increased with storage time, it declined from the 21 to 28 days of storage. Gupta *et al*. (2010) reported a progressive increase in the reducing sugar content of peach fruits during storage. In addition, Islam *et al*. (2013) found that reducing sugar increased trend storage time. A change in storage temperature can affect the biochemical processes and biochemical characteristics of mango fruits such as total soluble solid, titratable acidity, starch, vitamin C, total sugar, reducing and non-reducing sugars and total phenolic compounds (Hossain *et al*., 2014); Mattoo *et al*., 1975). Hossain *et al*. (2014) reported faster respiration rates of mangoes stored at higher temperatures relative to low and stable respiration rates at low temperatures in mango fruits.

8.5 Conclusions and Recommendations

Based on this study, it can be concluded that storage duration, storage conditions and post-harvest techniques are important factors to be considered for improved nutritional quality of fresh fruits. Storage duration is the major factor which affected the post-harvest nutritional quality of mango fruits. Vitamin C and total flavonoids of Apple and Palmer mango fruits decreased with storage time while total sugars and reducing sugar content increased with storage time. Hexanal maintained high vitamin C, total flavonoids, total sugar and reducing sugar content compared to calcium chloride and untreated control. fruits had the lowest values for all parameters under both storage conditions. Based on the results of this study, treatments with either hexanal formulation or calcium chloride accompanied with cold storage are recommended for the maintenance of nutritional quality of mango fruits in Tanzania. Further studies are needed to evaluate the effect of hexanal and calcium chloride treatments under different storage duration and temperature conditions on the nutritional quality of other fruits grown in Tanzania.

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CHAPTER NINE

9.0 PROFITABILITY AND VIABILITY OF POST-HARVEST TECHNIQUES IN REDUCTION OF POST-HARVEST LOSSES OF ORANGE AND MANGO FRUITS IN TANZANIA

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Abstract

The cost benefits analysis of different post-harvest techniques used for post-harvest management of orange and mango fruits was done at Sokoine University of Agriculture (SUA), Morogoro for two consecutive seasons. Three post-harvest techniques namely calcium chloride, hexanal and smoke treatment were evaluated under ambient (28 ± 2 °C) and cold/reduced (18 ± 2 °C) temperatures storage conditions. Fruits were dipped in calcium chloride solution at (2% w/v) and hexanal solution at (0.02% v/v) for five minutes. Smoke was obtained by burning 1.0 kg of dried banana leaves which was pumped into smoking chamber with a volume of 12m^3 at an interval of 12 hours for a duration of 36 hours. Untreated orange and mango fruits were included as control. The total variable costs were computed and the revenue was calculated based on marketable fruit quality and market prices of the fruit species prevailing in the local market. The analysis was done at seventh and 13th day of storage and then the net present values and benefit cost ratio were determined. The results showed that hexanal treated fruits had higher number of marketable fruits compared to other treatments. The smoke treated fruits had highest number of non-marketable fruits and higher losses of orange fruits than other post-harvest techniques used. The fruits stored for 7 days under cold storage conditions had the highest number of marketable fruits. Fruit storage for 13 days under ambient conditions resulted into higher losses regardless of the post-harvest techniques used. Mango fruits treatment with hexanal and stored under ambient storage were the most viable post-harvest techniques with positive net present value and benefit cost ratio of greater than 1.0, thus, viable investments while the other post-harvest techniques had negative net present values and benefit cost ratio of less than 1.0. For orange fruits all the post-harvest techniques under both storage conditions had negative net present values and benefit cost ratio of less than 1.0 and they were not viable investments to be recommended.

Keywords: fruits, mango, hexanal, smoke treatment, calcium chloride total variable costs, post-harvest loss, post-harvest techniques, storage conditions, net present value, benefit cost ratio

9.1 Introduction

Cost-benefit analysis is the comparison of costs and benefits of certain practice(s) to decide if they should be undertaken. Post-harvest losses in terms of quality and quantity vary significantly among commodities, production areas and seasons (Kader, 2004). Tanzania is the largest citrus fruit producer in East Africa. Citrus fruits are available throughout the year in Tanzania; however, there are differences in seasonality. Several varieties of oranges are grown in Tanzania namely Msasa, Jaffa, Valencia, Nairobi, Pamba, Washington navel and Zanzibar (Mwatawala *et al.*, 2019). The existence of different varieties allows farmers to prolong the supply of oranges as flowering and maturity vary across these varieties. The fruits that are produced in Tanga, the major orange producing region in Tanzania, are for both domestic and export markets (Tu, 2008). Citrus industry in developing countries has been facing numerous post-harvest problems, leading to both high quantitative and qualitative losses (Malik *et al.*, 2004). Orange production is constrained by destructive pests, low soil fertility, inefficient management, climate variability, unreliable markets and high post-harvest losses (Bhat *at al.*, 2015; Tu, 2008; Bhandare *et al.*, 2014). If not properly handled, fruits are liable to damage and deterioration during harvesting, transportation, marketing and storage (Ilyas *et al.*, 2007; Murthy *et al.*, 2009). Due to their perishability nature, oranges loose fruit quality through shrinking, bruises poor handling practices and decay due to microbial attack. Previous studies reveal different levels of post-harvest losses of fruits along the supply chain (Ilyas *et al.*, 2007; Murthy *et al.*, 2009).

Tanzania has been growing essentially traditional varieties of mango for domestic market. Improved mango varieties are increasing in importance and therefore extension of their market window is crucial for both regional and international markets. Tanzania mango is on the list of five top most fruit basket among bananas, oranges, pineapples, and pears (Mkenda, 2011).

Food security in developing countries can be addressed through inclusion of infrastructure development and technology improvements in post-harvest practices (Kitinoja *et al.*, 2010). Different post-harvest techniques have been adopted to reduce post-harvest losses of horticultural crops. One aspect of these technologies has been to increase the shelf life and maintain the quality of these produce (Davey *et al.*, 2000; Emese and Nagymate, 2008; Oyetade *et al.*, 2012; Turmanidze *et al.*, 2016). However, little information has been published regarding the economic benefits of these post-harvest treatments and techniques in horticultural crops. This study assessed the profitability of adopting different post-harvest techniques, storage conditions and storage duration in maintaining post-harvest quality and extending shelf life of orange and mango fruits.

9.2 Materials and Methods

9.2.1 Description of study area

Orange: The Msasa and Jaffa orange varieties were harvested from Bwembera ward (Mamboleo village) and Kilulu ward (Semngano village) in the Muheza district, Tanga region in Tanzania for 2016 and 2017 cropping seasons. The harvested fruits were transported to Sokoine university of Agriculture (SUA), Morogoro by open bodied truck. Mango: Apple and Palmer, the commonly grown fruits varieties were harvested from Association of Mango Growers in Tanzania (AMAGRO) mango plantations in Mwalusembe ward (Lunyala village) in Mkuranga district, Coast region in Tanzania during the 2016 and 2017 mango seasons. The fruits were harvested at their physiological maturity (not ripe) and transported to the Post-harvest Laboratory at SUA. The selected fruit varieties were the main varieties grown in the respective study areas. The different varieties from each fruit species were not separated during the analyses.

9.2.2 Experiments and post-harvest techniques

Both orange and mango fruits were sorted and cleaned before being exposed to different post-harvest techniques. The three post-harvest techniques namely calcium chloride, hexanal and smoke treatment were evaluated under ambient (28 ± 2 °C) and cold/reduced (18 ± 2 °C) temperatures storage conditions. Untreated fruits were included as control.

9.2.3 Identification of cost incurred and quantification of benefit gained

The costs analysis was computed based on the local prices of materials in Tanzania Shillings (TZS). The labour costs that were incurred during picking the orange and mango fruits as well as collection, sorting of fruits was recorded during the respective activities. The costs for purchasing fruits, loading, transport and unloading were considered. The cost of purchasing fruits was obtained as the product of fruit used in each technique and the purchasing price. The transportation costs were obtained by dividing the costs used for transporting the fruits from Muheza (orange) and Mkuranga (mango) to SUA, by the total number of fruits transported, multiplied by the number of fruits used in each technique. Labour charges for implementing each post-harvest technique were also considered. The total variable costs used in each post-harvest technique were estimated as the product of total quantity of each cost incurred to make the fruits ready for experiment. The cost for the installation of air conditioner unit installed in the cold room was considered, and its depreciation was calculated using the straight-line method, with the expected useful life of 10 years. The electricity costs incurred in cold storage conditions was determined by estimating the cost of electricity units used for running the AC per day multiplied by the shelf life (storage duration) of fruits under different post-harvest techniques. The non-marketable fruits were multiplied by the selling prices in each post-harvest technique under different storage conditions and were regarded as part of storage costs. The benefits gained include the number of marketable fruits multiplied by the selling market price of both orange and mango fruits.

9.2.4 Economic analyses

To compare the profit of treatments used, simple economic analyses were carried out by using marginal net returns and cost benefit analysis. Marginal net return is an incremental change resulting from a unit increase in a variable of interest, while other inputs are constant. It is calculated as the ratio between additional revenue and the additional costs. Marginal revenue was calculated as product of the differences between the total value of non-marketable fruits in untreated treatment (control) and non-marketable fruits in each post-harvest technique multiplied by their selling price. The difference obtained is the additional revenue in the respective post-harvest technique. Additional costs were calculated as the sum of all variable expenses that incurred in every post-harvest technique.

A financial cost benefit analysis (CBA) or benefit cost analysis (BCA) was used to estimate the costs involved and benefits gained in the implementation of every post-harvest technique and untreated fruits under both ambient and cold storage conditions according to (Gittinger, 1982). A financial CBA was carried out from the trader's perspective of the costs incurred and benefits gained from each post-harvest technique. The cost benefit was evaluated based on net present value and cost-benefit ratio with a discount rate of 10% (Nkang *et al.*, 2007). The project is considered profitable if the calculated NPV is positive when discounted at the opportunity cost of capital (Berlage and Renard, 1985; Gittinger, 1982; Nduku *et al.*, 2013). The NPV was calculated from (Equation 1) adopted from Shively (2000).

$$\boldsymbol{NPV} = \left[\frac{\boldsymbol{GB_1}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{1}}} + \frac{\boldsymbol{GB_2}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{2}}}\right] - \left[\frac{\boldsymbol{TVC_1}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{1}}} + \frac{\boldsymbol{TVC_2}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{2}}}\right] \ldots\ldots\ldots (\boldsymbol{1})$$

Where, *GB* is the Gross benefit in each cropping season, *TVC* is Total variable costs in each season, *1* and *2* are Number of seasons and *r* discount rate.

The discount rate determines the value today of an amount received or paid out in the future (William *et al*., 2015). The post-harvest technique is considered financially feasible if the calculated NPV is positive (greater than zero) and highest when discounted at the opportunity cost of capital (Gittinger, 1982; Poudel *et al*., 2009).

Benefit-cost ratio (BCR) is the ratio of discounted value of gross benefits (present value of benefit) to discounted value of variable costs (present value of costs). The Equation 2 adopted from Cellini and Kee (2010), Shively (2000) and William *et al*. (2015) was used.

$$\boldsymbol{BCR} = \left[\frac{\boldsymbol{GB_1}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{1}}} + \frac{\boldsymbol{GB_2}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{2}}}\right] \div \left[\frac{\boldsymbol{TVC_1}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{1}}} + \frac{\boldsymbol{TVC_2}}{(\boldsymbol{1}+\boldsymbol{r})^{\,\boldsymbol{2}}}\right] \ldots\ldots\ldots(\boldsymbol{2})$$

Where, *GB* is the Gross benefit in each cropping season, *TVC* is Total variable costs in each season, *1* and *2* are Number of seasons and *r* is discount rate.

The investment is financially feasible when the BCR is one or greater than one (Gittinger, 1982; Poudel *et al.*, 2009).

9.3 Results

9.3.1 Marginal Net Returns for Orange

The analysis of variance results showed significant effects of that the post-harvest techniques ($p < 0.001$) and storage conditions ($p = 0.021$) on number of marketable fruits. The storage duration and all interactions had non-significant ($p \geq 0.05$) effect on number of marketable fruits. Further analysis showed that post-harvest techniques had significant ($p < 0.001$) effect on number of marketable orange fruits (Table 9.1). The hexanal treated fruits had high number of marketable fruits followed by calcium chloride treated fruits, control fruits while the smoke treated fruits had the lowest number of marketable fruits (Table 8.1).

The results showed significant effects of post-harvest techniques ($p < 0.001$) and storage conditions ($p = 0.001$) on number of non-marketable fruits only. Further analysis showed that post-harvest techniques had significant ($p < 0.001$) effect on number of marketable orange fruits. The number of non-marketable fruits of orange was highest in smoke treated fruits followed by control fruits and calcium chloride treated fruits while the hexanal treated fruits had the lowest number of non-marketable fruits (Table 9.1). The non-marketability of orange fruits was caused mainly by shrinkage due to water loss and post-harvest diseases such as *Penillium* rot.

The post-harvest techniques had significant ($p = 0.020$) effects on additional revenue gained in orange fruits. The storage conditions had significant ($p < 0.001$) effect on additional revenue gained. The storage duration had non-significant ($p \geq 0.05$) effect on additional revenue gained in orange fruits. All the interactions had non-significant ($p \geq 0.05$) effects on additional revenue gained in orange fruits. Further analysis showed that post-harvest techniques had significant ($p < 0.001$) effect on additional revenue gained in orange fruits (Table 9.1). The hexanal (0.02%) treated fruits had high additional revenue followed by calcium chloride (2%) and control fruits. Smoke treated fruits had the lowest additional revenue.

The post-harvest techniques and storage conditions both had significant ($p < 0.001$) effects on additional costs incurred in orange fruits. The storage duration an all the interactions had non-significant ($p > 0.05$) effect on additional costs incurred in orange fruits. Analysis on main means further showed significant effects of post-harvest techniques had significant ($p < 0.001$) effect on additional costs incurred in orange fruits (Table 9.1). The highest additional revenue was obtained in hexanal and calcium chloride treated fruits compared to smoke treated and untreated fruits. The post-harvest techniques, storage conditions and interaction between post-harvest technique, storage conditions and all the interactions had non-significant ($p > 0.05$) effects on marginal net returns of orange fruits (Table 9.1).

Table 9. 1: Effects of post-harvest treatments of marginal revenue, additional cost and marginal net returns of orange fruits

Post-harvest Techniques	Marketable fruits	Non-marketable fruits	Marginal revenue (X)	Additional costs (Y)	MNR
Control	247±13.2ab	112±75.1ab	8064±118.6a	189±118.7c	0.67±0.1a
Calcium Chloride	309±14.4a	50±11.2b	4040±118.7b	15590±118.7a	0.63±0.1a
Hexanal	334±34.4a	27±12.3b	4220±118.7b	15945±118.7a	0.96±2.3a
Smoke	226±25.27b	135±13.47a	11023±118.16a	1189±118.68b	-5.81±3.46b

Means with the same letters in the same column are not significantly different at $p \leq 0.05$ (Tukey test).

9.3.2 Cost benefit analysis (CBA) for Orange

The variable costs used in each post-harvest technique used in orange fruits are shown in Table 8.2. The variable cost includes the costs of picking and purchasing the orange fruits at Muheza, transportation, loading and unloading, sorting and cleaning and costs incurred in the respective post-harvest technique for ambient storage conditions. The number of non-marketable orange fruits in each post-harvest technique was included in the costs of respective post-harvest techniques. But, in the cold storage conditions all the costs in ambient storage were applied plus the costs of electricity. The post-harvest techniques under ambient storage conditions had low costs than the post-harvest techniques in cold storage conditions. The high costs in cold storage were mainly due to installation costs of the facility and the electricity costs. The hexanal post-harvest technique was the most expensive techniques followed by the calcium chloride while smoke treatment was the cheapest technique, when all the techniques were compared with the untreated orange fruits irrespective of the storage condition. In addition, hexanal post-harvest technique had high benefits followed by calcium chloride and untreated fruits while the smoke treatment had the lowest benefits under both ambient and cold storage conditions (Table 9.2). The orange fruits were sold at the price of TZS 200 in both seasons.

Table 9.2: Post-harvest treatments with their respective variable costs and benefit during the 2016 and 2017 orange seasons

Seasons	Storage condition	Post-harvest Technique	Variable Costs	Benefits
2016	Ambient	Hexanal	99 288	68 800
		Calcium Chloride	95 368	63 800
		Smoke	63 100	49 800
		Control	60 100	51 800
	Cold	Hexanal	249 742	69 200
		Calcium Chloride	245 822	64 200
		Smoke	211 554	52 200
		Control	207 154	55 600
2017	Ambient	Hexanal	99 288	68 800
		Calcium Chloride	95 368	63 800
		Smoke	63 100	49 800
		Control	60 100	51 800
	Cold	Hexanal	249 742	69 200
		Calcium Chloride	245 822	64 200
		Smoke	211 554	52 200
		Control	207 154	55 600

9.3.3 Marginal net returns for mango

The analysis of variance results showed significant effects of post-harvest techniques ($p < 0.001$) and storage conditions ($p = 0.002$) on number of marketable mango fruits. The storage duration and all the interactions had non-significant ($p > 0.05$) effect on number of marketable fruits. Further analysis of post-harvest techniques showed significant ($p < 0.001$) effects on number of marketable mango fruits (Table 9.3). The hexanal treated fruits had high number of marketable fruits followed by calcium chloride and untreated control fruits while the smoke treated fruits had the lowest number of marketable mango fruits (Table 9.3).

The analysis also showed significant effects of post-harvest techniques ($p < 0.001$) and storage conditions ($p = 0.020$) on number of non-marketable mango fruits. On the other hand, storage duration and all the interactions had non-significant ($p > 0.05$) effects on number of non-marketable fruits. Further analysis of main means of post-harvest techniques had significant ($p < 0.001$) effect on number of marketable mango fruits. The number of non-marketable fruits of mango was highest in smoke treatment followed by control fruits and calcium chloride while the hexanal treated fruits had the lowest number of non-marketable fruits (Table 9.3). The non-marketability of orange fruits was caused mainly by shrinkage due to water loss, over-ripening and post-harvest diseases such as mango Anthracnose.

The post-harvest techniques had significant ($p < 0.001$) effects on additional revenue gained in mango fruits. The storage duration, storage conditions and all interactions had non-significant ($p \geq 0.05$) effects on additional revenue gained in mango fruits. Further analysis showed that post-harvest techniques had significant ($p < 0.001$) effect on additional revenue gained (Table 9.3). The hexanal treated fruits had high additional revenue followed by calcium chloride and control fruits while the smoke treated fruits had the lowest additional revenue under both storage conditions and storage durations.

The post-harvest techniques had significant ($p < 0.001$) effects on additional costs incurred in mango fruits. The storage duration, storage conditions and all interactions had non-significant ($p \geq 0.05$) effects on additional costs incurred in mango fruits. Further analysis showed that post-harvest techniques had significant ($p < 0.001$) effect on additional costs incurred in mango fruits (Table 9.3). The highest additional revenue was obtained in hexanal and calcium chloride treated fruits. The post-harvest techniques, storage conditions and all the interactions had non-significant ($p > 0.05$) effects on marginal net returns of mango fruits (Table 9.3).

Table 9. 3: Effects of post-harvest treatments of marginal revenue, marginal cost and marginal net returns of Mango fruits

Post-harvest Techniques	**Marketable fruits**	**Non-marketable fruits**	**Marginal revenue (X)**	**Additional costs (Y)**	**MNR**
Control	269 ± 14.51c	115 ± 14.26a	-11750 ± 155.4c	133 ± 76.50c	-8.96 ± 41.63a
Calcium chloride	320 ± 7.74b	50± 7.14b	51000 ± 115.5b	15889 ± 76.50a	3.21 ± 0.45a
Hexanal	345 ± 7.49a	26 ± 7.46c	74625 ± 692.8a	15534 ± 76.50a	4.80 ± 0.48a
Smoke	255 ± 19.52d	143 ± 5.48a	-33500 ± 109.7c	1133 ± 76.50b	-30.70 ± 17.88a

Means with the same letters in the same column are not significantly different at $p \leq 0.05$ (Tukey test).

9.3.4 Cost benefit analysis (CBA) of mango

The variable costs used in each post-harvest technique used in mango fruits are shown in Table 8.4. The variable costs included the costs for purchasing the orange fruits at Mwalusembe, Mkuranga and transportation to Morogoro, loading and unloading, sorting and cleaning and costs incurred in the respective post-harvest technique for ambient storage conditions. In Mkuranga, fruit picking and collecting costs were not charged to the mango traders who buy fruits at farm gate. The number of all non-marketable mango fruits in each post-harvest technique was included in costs of respective post-harvest techniques. The cold storage conditions included all the costs in ambient storage plus the costs of running the storage facility and electricity.

Generally, post-harvest techniques under ambient storage conditions had low costs than the post-harvest techniques in cold storage conditions. The high costs in cold storage were mainly due to installing costs of the facility and electricity costs. The hexanal post-harvest technique was the most expensive techniques followed by the calcium chloride while the smoke treatment was the cheapest technique, when all the techniques were compared with the untreated mango fruits (control) irrespective of the storage condition. On the other hand, the hexanal post-harvest technique had high benefits followed by calcium chloride and untreated fruits while the smoke treatment had the lowest benefits under both the ambient and cold storage conditions (Table 9.4). The mango fruits were sold at the price of TZS 800 in 2016 season and TZS 1 000 in the 2017 season.

Table 9.4: Post-harvest treatments with their respective variable costs and benefit during the 2016 and 2017 mango seasons

Seasons	Storage Condition	Post-harvest Technique	Variable Costs	Benefits
2016	Ambient	Hexanal	269 208	243 200
		Calcium Chloride	260 288	216 000
		Smoke	214 020	102 400
		Control	213 020	144 800
	Cold	Hexanal	420 062	240 800
		Calcium Chloride	411 142	237 600
		Smoke	364 874	116 800
		Control	363 874	146 400
2017	Ambient	Hexanal	269 208	321 000
		Calcium Chloride	260 288	304 000
		Smoke	214 020	132 000
		Control	213 020	180 000
	Cold	Hexanal	420 062	327 000
		Calcium Chloride	411 142	301 000
		Smoke	364 874	194 000
		Control	363 874	145 000

9.3.5 Net Present Value and Cost Befit Ratio/Benefit Cost Ratio: Orange and Mango

The net present values of both orange and mango fruits are shown in Table 8.5. All post-harvest techniques: hexanal, calcium chloride and smoke treatment used in orange fruits had negative net present values under both ambient and cold storage cold storage conditions. On the other hand, all the post-harvest techniques that were evaluated in orange fruits had the cost benefit ratio of less than 1.0. For mango fruits, only the hexanal treated mango fruits had positive net present value and the BCR of greater than 1.0 when stored under ambient storage (Table 9.5). All other post-harvest techniques under both storage conditions had negative net present values and the BCR of less than 1.0. The hexanal treated fruits stored under cold storage also had negative net present values and BCR of less than 1.0.

Table 9.5: The Net Present Value and Cost Benefit Analysis of Orange and Mango fruits

Storage Condition	Post-harvest Technique	Net Present Value (NPV)		Cost Benefit Ratio (CBR)	
		Orange	Mango	Orange	Mango
Ambient	Hexanal	-37 251	25 784	0.771	1.047
	Calcium Chloride	-57 396	-576	0.669	0.999
	Smoke	-24 182	-193 640	0.789	0.548
	Control	-15 091	-101 240	0.862	0.762
Cold	Hexanal	-310 076	-272 324	0.289	0.676
	Calcium Chloride	-330 222	-283 684	0.261	0.655
	Smoke	-289 735	-467 948	0.247	0.359
	Control	-275 553	-387 348	0.268	0.468

9.4 Discussion

Fruits and vegetables are produced seasonally, but the market requires products throughout the year (Dolan and Humphrey, 2000). Marketable fruits are the fruits which are still fresh and can attract customers in the market. This means unmarketable fruits are the fruits which lost their freshness and they can't be sold any more in the market (Kader, 2004). Hexanal treatment led to the highest number of marketable fruits and least number of unmarketable fruits compared to other post-harvest techniques. The technique resulted to higher number of improved fruit freshness and shelf life compared to control and smoke treated fruits. It is important to note that hexanal inhibits the activities of Phospholipase D enzymes which are responsible for fruits initiation of fruit ripening and senescence. El Kayal *et al.* (2017) reported enhanced membrane stability and increased longevity of horticultural produce treated with hexanal.

The reduced number of non-marketable fruits could be attributed by hexanal which is a strong inhibitor of Phopholipase D enzyme, thus delay initiation of cell membrane disintegration and deterioration which enhance fruit shelf life. Fruit freshness is an important factor in determining shelf life and quality of fruits (Lee and Kader, 2000).

Other researchers have also reported similar findings that hexanal treatments increased shelf life (Al-Harthy, 2010; Sharma *et al*., 2010; Cheema *et al*., 2014; El Kayal *et al*., 2017) which resulted into increased number of marketable fruits and high profit margin compared to other techniques used and the control fruits.

The calcium chloride treated fruits had reduced number of non-marketable fruits than untreated control and smoke treated fruits across the storage conditions. Mishra (2002) and Singh *et al*. (2007) also reported increased shelf life in calcium chloride treated fruits. Deterioration of fresh commodities can result from physiological breakdown due to natural ripening processes, water loss, temperature injury, physical damage, or invasion by microorganisms (Babatola *et al*., 2008).

The smoke treated fruits had the highest number of non-marketable fruits in all storage conditions and durations. Release of ethylene by fruits during ripening accelerated fruit ripening and senescence. Ethylene stimulates respiration and hastens senescence in fruits (Kittas *et al.,* 2013). The smoke treated fruits had not only high number of non-marketable fruits but also high incidences of post-harvest fungal diseases; which resulted into higher losses leading to negative marginal net returns. Studies have shown that ethylene concentrations higher than $0.10\mu L^{-1}$ can induce important quality loss in a wide range of commodities (Martinez-Romero *et al*., 2009). Ethylene has a profound effect on physiological activities even in trace amounts.

The high additional revenue in hexanal and calcium chloride treated fruits was due high quantity of marketable fruits in hexanal with extended shelf life than in smoke treated and untreated fruits. Munhuewyi (2012) reported increased deterioration of tomato with increase in storage time. Most fruits had rapid quality loss at relatively short period of 4 -7 days which calls for efficient means of fruit storage to reduce wastage. The deterioration of stored fruits is affected by many storage time and temperatures. Bachmann *et al*. (2000) stated that higher storage temperature increased the respiration rate results rapid spoilage and fast degradation in shelf life of the fruits and vegetables.

Cost benefit analysis estimates and totals up the equivalent money value of the benefits and costs to the community projects to establish new investments. The hexanal post-harvest technique had high total variable costs and benefits than calcium chloride. The high costs of hexanal post-harvest technique was compensated by the benefits that was obtained through improved quality, extended shelf life and expanded market window for the mango fruits. Smoke treatment was the cheapest technique with lowest benefits for both orange and mango fruits irrespective of the storage condition. Mebratie *el al*. (2015) reported smoke treatment as the affordable traditional source of ethylene for ripening fruits such as banana. The hexanal post-harvest technique was effective applied in small quantities in improving the quality of fruits.

Spraying even tiny quantities of hexanal on temperate fruit has been shown to substantially reduce post-harvest losses (Subramanian *et al*., 2014). Hexanal has been found effective in enhancing the shelf life of several temperate and tropical fruits such as apples, peaches, strawberries, sweet cherries (Paliyath *et al.,* 2008) and mangoes (Subramanian *et al*., 2014). The use of hexanal in post-harvest treatments although expensive, it is advantageous to Tanzanian fruits growers since it improves fruit quality by reducing the rate of fruits deterioration leading to higher prices in the market. The post-harvest treatment of mango fruits was more profitable than those of orange fruits.

This might be due to low prices of orange fruits compared to the mango fruits. The use of hexanal post-harvest technique is more profitable in high value fruits such as mango since farmers and traders obtain a wider profit margin than for the case of low-priced fruits. Ali and Kapoor (2008) described that cultivation of high value crops involves risks and uncertainty due to high resource requirement and high perishability which forced to farmers developed coping strategies to face the constraints they encounter in crop production.

The hexanal post-harvest techniques under ambient storage condition had the positive net present value and benefit cost ratio greater than 1.0 while all other post-harvest techniques and storage conditions had negative net present value and benefit cost ratio of less than 1.0. Hexanal treatment was the most profitable post-harvest technique and worked well under both ambient and cold storage conditions. Numerically, the post-harvest techniques under ambient storage conditions had low costs than the post-harvest techniques in cold storage conditions. Good quality of the fruits and vegetables depends upon temperature because storage at optimum temperature retards over ripening, softening, respiration rate and spoilage (Bachmann *et al*., 2000). High benefits in hexanal post-harvest technique compared with other techniques such as calcium chloride and smoke treatments under both ambient and cold storage conditions might be due to reproducible benefits such as extended shelf life. Hexanal downregulates the expression of the Phospholipase D enzyme and other catabolic ripening reactions resulting in enhanced shelf life and quality parameters of the fruit such as firmness and total soluble solids (Paliyath *et al*., 2008). Subramanian *et al*. (2014) reported 10% reduction of post-harvest losses of mango which has resulted in the greater availability of quality fruits in the market, thereby generating an additional income of about US$92 per hectare per year in India.

9.5 Conclusions and Recommendations

Based on the findings of this study, it can be summed up that post-harvest techniques and storage conditions had significant effect on number of marketable and non-marketable fruits, revenue and additional costs incurred in orange and mango fruits. The use of hexanal and calcium chloride in post-harvest management of fruits was advantageous when compared with the use of smoke treatment. Hexanal maintained high quantity and quality of marketable fruits stored fruits. The mango fruits treatment with hexanal and stored under ambient conditions was the most viable post-harvest technique with positive net present value and benefit cost ratio greater than 1. The smoke treatment led to higher number of non-marketable fruits, short shelf life and thus narrow market window than those treated with hexanal calcium chloride and untreated fruits. The calcium chloride, smoke and untreated control fruits under both ambient and cold storage, and hexanal under cold storage, had negative net present value and benefit cost ratio greater than 1, which made them non-viable post-harvest techniques in this study. Based on this study, the use of treatment is undesirable and its use in fruit treatments should be discouraged as it causes high losses even when compared with the untreated control. However, where hexanal in not available, calcium chloride can be used as a post-harvest treatment of fruits.

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CHAPTER TEN

10.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENADATIONS

10.1 General Discussion

Post-harvest food loss is defined as measurable qualitative and quantitative food loss along the supply chain, between harvest and consumption (Hodges *et al*., 2011). Post-harvest losses are experienced from production to the fork (Rugumamu, 2009). Post-harvest of 30 to 40% had been reported in fruits and vegetables (Gustavasson *et al*., 2011; Kusumaningrum *et al*., 2015). The limited shelf life of tropical fruits is the main cause of post-harvest losses that can lead to a reduction in fruit yield and deterioration in fruit quality (Kusumaningrum *et al.*, 2015). Reduction in post-harvest losses of fruits and vegetables is complementary means of increasing production since the cost of preventing post-harvest losses is less than costs of producing a similar additional amount of the produce of the same quantity (Sudheer and Indira, 2007).

The preliminary trial that was done before the start of actual experiment (chapter two) evaluated the performance of hexanal, calcium chloride and smoke using orange fruits whereby the fruit were dipped in hexanal formulation at (0.01%), (0.02%) and (0.04%) (volume/volume), or calcium chloride solution at (1%), (2%) and (4%) (weight /volume) for five minutes each, or subjected to a smoking regime, simulating a popular traditional practice, by burning (0.5 kg), (1.0 kg) and (1.5 kg) of dried banana leaves, or left untreated (control). The trial was done under ambient storage conditions.

The hexanal at (0.02%) and calcium chloride (2%) were superior due to their effectiveness in maintaining the physico-chemical quality (PWL, firmness, TSS and TA) of treated fruits, and therefore they were selected be used further in the study. The smoke in all doses showed poor performance. The current study was carried out as an effort to evaluation of three post-harvest techniques namely hexanal (0.02% v/v), calcium chloride (2% w/v) and smoke (1.0 kg) on management of post-harvest losses of orange and mango fruits under ambient (28 ± 2 °C) and cold storage (18 ± 2 °C) conditions and three storage duration. The effects of these storage conditions, storage duration and post-harvest techniques on physiological weight loss, fruit firmness, total soluble solids, titratable acidity and total soluble solids to acid ratio showed significant results during the two years experiments.

The fruit ripening process involves a series of physiological, biochemical, and organoleptic changes that lead to the development of a soft, edible, ripe fruit with desirable qualities (Tharanathan *et al.,* 2006). Ethylene, a plant growth hormone, regulates many aspects of fruit development and cell metabolism, including initiation of ripening and senescence, particularly in climacteric fruits (Tharanathan *et al.,* 2006).

Hexanal reduced physiological weight loss of both orange and mango fruit under both ambient and cold storage durations. Fruits treated with hexanal had more fresh and turgid fruits than control fruits. Hexanal treated fruits had low physiological weight loss regardless of the fruit species and variety used. Reduction in fruit water loss improves produce appearance, quality, shelf life and profitably (Holcroft, 2015).

Calcium chloride treated fruits remained fresh for a longer time compared to untreated control fruit. Calcium chloride treated fruits were reported to stabilize cellular membranes and improved cell wall which consequently maintained fruit firmness, delayed loss of freshness and senescence and extended shelf life in treated horticultural produce (Bhattarai and Gautam, 2006). Bertzer *et al.,* (2002) reported delayed senescence and reduced rates of respiration and transpiration in loquat (*Eriobotrya japonica,* L.) treated with calcium chloride.

Sweet oranges grown in Tanzania remain green even after they reach the ripe stage, which lowers their quality and consumers think that they are still unripe. Farmers and traders use smoke treatment as one of the ways of adding value to their fruits in order to meet market demand of their customer who need yellow fruits. Smoke treated fruits had wilted, shriveled, softer fruits compared to the other techniques and the control. Smoke treatment accelerated physiological weight loss, fruit softening and senescence and relatively higher rate of post-harvest diseases. Many researchers reported that high weight loss from fruits due to high transpiration rate which resulted to shriveled, soft and decayed fruits during storage (Azene *et al*., 2014; Holcroft, 2015). El Kayal *et al*. (2017) reported low weight loss in hexanal-treated raspberry compared to untreated controls. Water loss as a result of metabolic activities like respiration and transpiration (Ambuko *et al*., 2017) is the factor that contributes most to weight loss, and for products sold by weight this will have economic consequences (Holcroft, 2015).

The effect of hexanal and calcium chloride in reducing the physiological weight loss was evident in all treated fruit varieties (Palmer and Apple mango varieties and Msasa and Jaffa orange varieties) compared to untreated fruits. These treated fruits were firm and fresher compared to smoke and untreated fruits. Hexanal and calcium chloride treated fruits had low weight loss and improved freshness and shelf life which maintained quality compared to smoke treated and control fruits in both ambient and cold storage conditions. Temperature conditions is the main factor which influenced the rates of respiration, deterioration, and water loss in fresh produce leading to reduced market, food, and nutritional values (Anjum and Ali, 2004).

The post-harvest treatment used, storage conditions and the storage time at assessment influenced the fruit firmness of orange and mango fruits. Hexanal had the firmest fruits followed by calcium chloride and control while the smoke (1.0 kg) had the softest fruits regardless of storage temperatures and durations. Paliyath *et al*. (2008) and Karthika *et al*. (2015) reported high firmness in post-harvest treated hexanal fruits whereas Mishra (2002) reported that calcium chloride improved firmness of apples, strawberries, blueberries, pears, carrots and tomatoes. Calcium chloride in treated fruits accumulated in the cell walls leading to facilitation of the cross linking of the pectic polymers which increases cell wall strength (Akhtar *et al*., 2010). Hexanal acts as a strong inhibitor of Phospholipase D action, and thus slows down ethylene stimulation of fruit ripening and softening processes (Paliyath *et al*., 2008). Karthika *et al. (*2015) reported slow ethylene stimulation of hexanal treated fruit during ripening and softening to be associated with inhibition of Phospholipase D enzymatic activities.

Hexanal treated fruits had lower values of total soluble solids than smoke-treated oranges at eight days after harvest due to delayed fruit ripening. It has been reported that hexanal slows down ethylene-induced fruit ripening and softening processes (Karthika *et al*., 2015). The higher total soluble solids content in smoke-treated fruits might be due to the accelerated breakdown of starch, and ripening of the fruits caused by smoke. Goldschmidt (1997) reported that citrus fruits reveal ripening-related symptoms in response to exogenous ethylene treatment. On the contrary, Mayuoni *et al*. (2011) reported that ethylene had no effects on total soluble solids and acidic contents of citrus fruit juice. Like this study, Akhtar *et al*. (2010) also reported higher values of total soluble solids content in calcium chloride-treated fruits and the lowest values in the control group.

The reduced firmness in smoke treated fruits was caused by early ripeness of these fruits which is associated with induction of ethylene produced by the burning vegetation during the smoking process. Fruit softening is due to breakdown of the cell wall and middle lamellae induced by pectinases and cellulases and the consequent loss of cell-wall integrity has been proposed as leading to the production of ethylene (Fischer and Bennet, 1991).

The cold storage conditions led to firmer fruits than the ambient storage conditions. The reduced temperatures storage conditions reduced metabolic reactions in stored fruits which decreased respiration and retards ripening and senescence (Kays, 1991). Fischer and Bennet (1991) reported that cold storage reduced rate of respiration which retarded the ripening of stored fruits. Fruit firmness and freshness are important attributes that determine buyer's decisions to buy a particular fruit (Batu, 2003). The internal factors like respiration processes, ethylene evolution, enzymatic starch hydrolysis and other carbohydrate hydrolyses lead to cell wall softening and subsequent post-harvest deterioration in fruits (Preethi *et al*., 2017).

Total soluble solids increased with storage time, conditions and type of post-harvest techniques used. The smoke treated fruits had the highest total soluble solids followed by the control and calcium chloride while the hexanal had the lowest total soluble solids at the time of assessment. The TSS in smoke treatment might be due to the accelerated breakdown of starch, and ripening of the fruits caused by ethylene released by the burnt vegetation during the smoking treatments and their respiration. Hexanal delayed fruit ripening and softening thus low TSS at the time of assessment. Paliyath *et al*. (2008) reported similar results in cherry, pears and peach fruits.

Hexanal treated fruits had lower values of total soluble solids than smoke treated mango at eight days after harvest. This was due to delayed fruit ripening in the hexanal and calcium chloride treated fruits after four and eight days of storage compared to untreated fruits. After twelve days of storage, the hexanal treated fruit had the highest total soluble solids values than other treated and untreated fruits. Hexanal is the precursor for formation of six carbon alcohols and esters, with an important role in extending fruit freshness by inhibiting the enzyme Phospholipase (Preethi *et al*., 2017). Hexanal was reported to improve the total soluble solids of cherry, peach and pear fruits (Paliyath *et al*., 2008).

The titratable acidity of orange and mango were affected by storage time of fruits, and it was decreasing with storage time. The decreased acidity during fruit ripening is associated with the to conversion of starch and organic acids to into sugars (Abbasi *et al*., 2009) which contributes to the sweetness of the fruits. The increase in total soluble solids with time was correlated with increase in sucrose, fructose, glucose and decrease in starch and acidity. The acidity decreased with maturation were as carotene, vitamin c and aroma volatile content decreases.

The TSS/TA ratio is the determinant factor in of fruit maturity and taste of the fruits which influence the consumer's criterion for acceptance (Liu *et al*., 2016). TSS/TA ratio of mangoes was higher in hexanal treated fruits compared to fruits treated with calcium chlorides, smoke and untreated fruits. Consumer acceptance test scores for appearance, taste, aroma, texture and overall acceptability attributes showed that hexanal treated fruits were the most liked fruits than calcium chloride and untreated fruits.

Horticultural commodities are highly perishable and undergo a rapid transformation between the harvest and consumption which results spoilage and reduces market value (Yadav *et al*., 2014). Globally, post-harvest losses in fruits and vegetables vary from 35% to 60% of production (Gustavasson *et al*., 2011). The current study showed that average total post-harvest losses of orange fruits ranged from 39.60% in Msasa variety to 49.10% in Jaffa variety. The post-harvest losses documented in orange fruits similar to those reported previously by Ugoh *et al*. (2015), who reported post-harvest losses of 40 to 50% in citrus fruits. On the contrary, Strano *et al*. (2017) reported the post-harvest losses of 30 to 40% in citrus fruits. On the other hand, the average total post-harvest losses of mango fruits ranged from 42.36% in Palmer variety to 46.57% in Apple variety. The extent of post-harvest losses of orange and mango fruits along the supply chain varied with fruit species, variety and seasons.

Msogoya and Kimaro (2011) reported the post-harvest losses of 48% to 60% in ‘‘*Dodo*’’ mango variety. The average post-harvest losses of orange fruits varied with orange varieties and seasons. The post-harvest losses of fruits differed from one stage of supply chain to another. The retail stage had highest post-harvest losses followed by transport stage and wholesale stage while the lowest losses were incurred at harvest stage. The post-harvest losses at different stages of orange supply chain were either caused by mechanical/physical damages, insect pests, or post-harvest diseases such green mould and anthracnose. Kabas (2011) and Strano *et al*. (2017) reported almost similar cause of fruits losses along the supply chain. Most of the losses in developing countries occur during the post-harvest and distribution phases due to deterioration in quality of the produce and also due to seasonality resulting in unsaleable gluts (Kumar, 2018). On the other hand, grading and sorting of produce contributes to post-harvest losses in developed countries, contributes to the overall post-harvest loss (McKenzie *et al*., 2017).

Hexanal extended shelf life of both orange and mango fruits more efficiently followed by calcium chloride and control fruits while the smoke treatments had shortest shelf life under both ambient and cold storage conditions. Post-harvest dipping of fruits in hexanal improved shelf life of treated fruits as reported by Paliyath *et al*., (2008). Also, hexanal treated fruits had the lowest change in fruit firmness and incidences of post-harvest fungal diseases for both fruits varieties followed by calcium chloride and control fruits while the smoke treated fruits had the highest change in fruit firmness and disease incidences under both ambient and cold storage conditions. The observed low changes in fruit firmness in hexanal and calcium chloride was associated with their ability to maintained fruit firmness than the untreated and control fruits. Fruits with higher change in fruit firmness were softer and with shorter shelf life.

Post-harvest techniques studied showed that ascorbic acid content and total flavonoids followed calcium chloride treated fruits and smoke treatments when both were compared with untreated control fruits and it was decreasing with increasing time in storage. Water soluble vitamins, vitamin C inclusive, are susceptible to post-harvest losses due to oxidation. Losses of vitamin C are enhanced by extended storage, high temperatures, low relative humidity and physical damage (Sudheer and Indira, 2007). Saci *et al*. (2015) reported the decrease in vitamin C and total flavonoids with increase in storage temperature and time. Nevertheless, these results indicated the increased total and reducing sugars content with storage time for both fruit species, with high values in ambient storage conditions than in cold storage conditions. Fructose and sucrose represented the major components of soluble sugars in cultivated fruits, days it decreases.

Hexanal techniques under ambient storage condition had the positive net present value and benefit cost ratio greater than 1.0 which made it the best post-harvest techniques to invest compared to calcium chloride, smoke and control which had negative net present value and benefit cost ratio of less than 1 under both storage conditions. These results signify how hexanal was effective in improving the quality of fruits and by extending the shelf life and market window of the fruit. The study that was done by Subramanian *et al.* (2014) in India showed that hexanal treated mango had the longer shelf life with the wider market window and with a wider profit margin per unit area of production.

10.2 General Conclusions and Recommendations

Hexanal treatment reduced physiological weight loss and improved total soluble solids content, retained fruit firmness, vitamin C, total flavonoids and sugars of orange and mango under both ambient and cold storage conditions. Furthermore, hexanal reduced incidences of post-harvest fungal diseases, extended shelf life thus expanded the marked window and profit margin. Similarly, calcium chloride treatment also reduced physiological weight loss, maintained total soluble solids content, retained firmness, reduced incidences of post-harvest diseases and extended the shelf life of orange and of mango fruits under both ambient and cold storage durations. On the other hand, smoke treatment increased the rate of fruit ripening, physiological weight loss, loss of vitamin C and increased fruit softness, susceptibility to post-harvest diseases and shortened the shelf life of orange and mango fruits under both ambient and cold storage durations.

The fruit firmness, titratable acidity, vitamin C and total flavonoids decreased with storage duration while the total soluble solids, TSS/TA ratio, total sugars and reducing sugars were increasing with storage time. The cold storage condition reduced physiological weight loss and maintained fruit firmness and total soluble solids content better than the ambient storage condition. Fruits treated with either hexanal formulation or calcium chloride coupled with cold storage (18 ± 2 °C) are recommended for the maintenance of quality of fresh mango and orange in Tanzania.

Post-harvest losses of orange fruits ranged from 39.60% in Msasa variety to 49.10% in Jaffa variety. On the other hand, the total post-harvest losses of mango fruits ranged from 42.36% in Palmer variety to 46.57% in Apple variety. The average post-harvest losses of orange fruits varied with orange varieties and seasons. The retail stage had highest post-harvest losses followed by transport stage and wholesale stage while the lowest losses were incurred at harvest stage. Post-harvest losses at different stages of orange supply chain were either caused by mechanical/physical damages, insect pests, or post-harvest diseases such green mould and anthracnose diseases.

Research is needed to evaluate the effect of hexanal and calcium chloride techniques on quality maintenance of other fruits in Tanzania. Smoke should be discouraged for use in fruit treatment since it reduces quality and shelf life of treated fruits. Cold storage and improved transport facilities are required to reduce post-harvest losses during transport of fruits.

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