# EFFECTS OF PRE-HARVEST HEXANAL APPLICATION ON YIELD AND QUALITY OF MAJOR FRUITS IN EASTERN ZONE OF TANZANIA

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## EXTENDED ABSTRACT

Orange (*Citrus sinensis* L.), mango (*Mangifera indica* L.) and tomato (*Lycopersion esculentum* Mill.) are among the important horticultural crops in Tanzania. Fruit production in Tanzania is constrained by several pre-harvest factors which cause production of inferior quality. The major pre-harvest causes of low fruit production and quality are pests, diseases, weather conditions, especially drought stress, and improper agronomic practices. Hexanal formulation is relatively a new technology that has been reported to reduce pre-harvest and postharvest losses of fruits and vegetables in temperate and subtropical climates. However, there is limited information on the effect of pre-harvest field application of hexanal on marketable yield and quality of selected fruit varieties grown in Tanzania. Similarly, the effects of field hexanal application on pre-harvest yield losses of selected fruits are also not well known. Therefore, the objectives of this study were to: (i) determine the key fruit attributes used by buyers in selecting fruits; (ii) determine the effects of pre-harvest hexanal application on market fruit attributes, and (iii) determine the effects of field application of hexanal on pre-harvest fruit losses of selected major crops in Tanzania.

To achieve objective 1, a study was conducted at Muheza district in Tanga region and Mkuranga district in Coast region to identify key orange and mango fruit attributes preferred by buyers. A total of 179 participants were engaged to evaluate the fruit attributes that influence marketing, longevity and endurance of Orange and Mango. Of the total participants, 50.3% assessed orange fruit attributes and 49.7% assessed similar attributes for mangoes. Data were collected by interviewing consumers, farmers and traders of oranges and mango using open and close ended questionnaires. Results revealed that buyers strongly associate fruit colour, freshness, firmness, spots free and medium size

with marketability of mango and orange fruits. Moreover, buyers strongly correlate fruit freshness, colour, spots free and firmness with shelf life of mango and orange fruits whereas buyers further associate spots free, freshness and firmness fruit attributes with endurance of mango and orange fruits. It is recommended that sellers of orange and mango fruits should apply technologies which can improve fruit freshness, firmness and colour, and reduce pest incidences.

To achieve objective 2, an experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement using well established and maintained farmers' of orange, mango and tomato orchards. The factors A was hexanal concentrations (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days to harvest) for orange varieties (Early Valencia, Jaffa and Late Valencia) and mango varieties (Apple, Palmer and Keitt). For tomato (Mwanga, Rio Grande and Tanya) cultivars, the factor A was hexanal concentrations (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 14, 21 and 28 days to harvest). Each fruit species was treated as an individual factor to achieve this objective.

**Orange:** Results show that application of hexanal at 0.01% improved fruit marketable yields by increasing fruit firmness and marketable yield of Early Valencia, Jaffa and Late Valencia varieties. The orange marketable yield increased by 19.28, 26.21 and 30.74% over the controls for Early Valencia, Jaffa and Late Valencia, respectively. Similarly, fruit firmness increased by 9.07, 9.64 and 10.12 $N/mm^2$ over the control for Early Valencia, Jaffa and Late Valencia, respectively.

**Mango:** Results indicated that application of hexanal concentration 0.01% increased mango marketable yield by 24.54, 19.64 and 20.40% over the controls for Apple, Palmer and Keitt varieties, respectively. Likewise, fruit firmness increased by 11.19, 9.97 and 10.05 $N/mm^2$ over the control for Apple, Palmer and Keitt varieties, respectively.

**Tomato:** Results show that hexanal application 0.01% increased tomato marketable yield by 23.38 and 23.10% over the controls for Mwanga and Rio Grande cultivars, respectively. Similarly, hexanal application at 0.01% increased fruit firmness by 5.03, 5.77 and 5.19 $N/mm^2$ over the control for Mwanga, Rio Grande and Tanya tomato cultivars, respectively.

To achieve objective 3, an experiment was laid out as in objective 2 above.

**Orange:** Results show that application of hexanal at 0.01% reduced number of dropped fruits by 22.62, 37.73 and 46.31% over the untreated fruits (control) for Early Valencia, Jaffa and Late Valencia orange varieties, respectively. Similarly, application of hexanal at 0.01% reduced non-marketable yield by 21.39, 26.10 and 30.74% over the control for Early Valencia, Jaffa and Late Valencia orange varieties, respectively. Likewise, application of hexanal at 0.01% decreased incidences of pest damage by 21.59, 22.50 and 24.86% over the control for Early Valencia, Jaffa and Late Valencia, respectively.

**Mango:** Results further show that application of hexanal at 0.01% reduced number of dropped fruits by 25.94, 20.77 and 22.58% over the control for Apple, Palmer and Keitt mango varieties, respectively. Moreover, application of hexanal at 0.01% reduced non-marketable yield by 24.82, 19.59 and 21.40% over the controls for Apple, Palmer and Keitt mango varieties, respectively. The application of hexanal at 0.01% also reduced incidences of pest damage on fruits by 27.93, 17.05 and 19.58% over the control for Apple, Palmer and Keitt mango varieties, respectively.

**Tomato:** Results show that application of hexanal 0.01% reduced non-marketable yield by 23.24, 23.27 and 28.39% over the control for Mwanga, Rio Grande and Tanya tomato cultivars, respectively. Similarly, the application of hexanal at 0.01% also decreased incidence of pest defects by 22.53, 22.00 and 23.02% over the control for Mwanga, Rio Grande and Tanya tomato cultivars, respectively.

**General conclusion and recommendation:** According to farmers, traders and consumers the main fruit attributes which influence purchase preference of mango and orange are freshness, colour, spots free and firmness. Pre-harvest application of hexanal at 0.01% improves fruit attributes namely firmness and freedom of fruit skin from pest damage of orange, mango and tomato treated varieties. The application of hexanal at 0.01% further increases marketable yield of oranges, mango and tomato treated varieties by reducing dropped fruits, number of non-marketable yield and incidences of pest damage. It is recommended that farmers should apply hexanal at 0.01% from 42 to 7 days before fruit harvest in order to improve fruit attributes to enhance marketing, and increase marketable yield of orange (Early Valencia, Jaffa and Late Valencia), mango (Apple, Palmer and Keitt) and tomato (Mwanga, Rio Grande and Tanya).

# DECLARATION

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

**Jaspa Samwel** **Date**
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The above declaration is confirmed by;

**Prof. Theodosy J. Msogoya** **Date**
**(Supervisor)**

**Prof. Maulid W. Mwatawala** **Date**
**(Supervisor)**

## COPYRIGHT

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# DEDICATION

This thesis is dedicated to the Lord Almighty God for protecting me throught all this period while conducting the study.

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| asl | Above sea level |
| BCSL | Bussiness Care Servises Limited |
| $C_6H_{12}O$ | Hexanal |
| CAT | Catalase |
| CIDRC | Canadian International Development Research Centre |
| cm | Centemiter |
| CRD | Completely Randomized Design |
| DED | District Exacutive Director |
| DTH | Days to harvest |
| E | East |
| e.g. | For example |
| *et al.* | and others |
| FAO | Food and Agricultural Organization of the United Nations |
| Fig. | Figure |
| g | Gramm |
| GAP | Good agricultural practices |
| GBD | Global business development |
| ha | hectare |
| i.e | That is |
| m | Metre |
| mm | Millimetre |
| MMA | Match Marker Association |
| mt | Metric tons |

| | |
|---|---|
| mt/ha | Metric tons/hectare |
| IBM | International Business Machines Corporation |
| MVCA | Mango Value Chain Analysis |
| $N/mm^2$ | Newton per millimetre squared |
| NBS | National Bureau of Statistics |
| OECD | Oranization for Economic Co-operation and Development |
| *p* | Probability |
| PAL | Phenylalanine ammonia-lyase |
| PhD | Doctor of Philosophy |
| PO RALG | President's Office Regional Administration and Local Government |
| PO | Peroxide |
| PPO | Polyphenol oxidase |
| S | South |
| SCF | Small and medium Enterprice Competitiveness Facility |
| SE | Standard error |
| SOD | Superoxide dismutase |
| SUA | Sokoine University of Agriculture |
| TBS | Tanzania Bureau of Standards |
| TFNet | Tropical fruit network |
| TRCO | Tanga Regional Commissioners Office |
| USDA | United States Department of Agriculture |
| % | Percentage |
| < | Less than |
| > | Greater than |
| $^0C$ | Degree centigrade |

# CHAPTER ONE

# GENERAL INTRODUCTION

## 1.1 Background Information

Citrus (*Citrus* spp. L.) is produced all over the world and over 140 countries produce citrus (Ihueze and Mgbemena, 2017). Orange (*Citrus sinensis* L.) is one of the top citrus fruits grown in most of the countries after grapes and apple (Abobatta, 2015). Orange production and consumption have grown over the years. The current annual orange production is estimated at 50 million tons, and the increase is mainly due to expansion of area under cultivation (USDA, 2018). Orange contributes significantly to the bulk of world's citrus fruit production accounting for more than 50% of the global citrus production (Sawe, 2017). Orange is produced worldwide and 20% of the total production is sold as whole fruit while the rest is used for processing various products mainly juice (Sawe, 2017). Orange is valued for vitamin C, folacin, calcium and potassium. Currently, Tanzania is ranked 20$^{th}$ in the world in orange production with an estimated area under smallholder farmers of about 37 500 ha and production of 450 000 mt per annum and an average yield of 12 mt/ha (FAOStat, 2017).

Mango (*Mangifera indica* L.) is an important tropical fruit in tropical regions and in 2013 the global production reached 43 million metric tons (Pariona, 2017). Mango is grown in more than 100 countries and plays an integral part in lives of many, not only for its rich source of nutrients but also as source of livelihood for millions of people in the tropics (Mitra, 2016). In recent years, mangoes have become well established as a fresh fruit and processed products in the global market. World demand for mango is increasing particularly from temperate countries where mangoes are rapidly gaining popularity

(Mitra, 2016). Mango is known all over the world for its nutritional qualities, as it is rich in minerals, fibre, vitamins and provitamins, and is therefore commercialized throughout the world (GBD, 2015). Tanzania produces mango with an annual yield of more than 434 344 mt per annum from an area of 33 532 ha and annual productivity of 12.95 mt/ha, the country ranks 17$^{th}$ in the world (FAOStat, 2017).

Tomato (*Lycopersion esculentum* Mill.) is one of the most important vegetable crops grown in Tanzania. It is widespread in the country (Mushobozi, 2010) with a total production of more than 962 684 mt per annum (MMA, 2017) in an area of 26 612 ha (NBS, 2008). Tomato productivity in eastern zone of Tanzania ranges from 2.2 t/ha to 3.3 t/ha (Minja *et al*., 2011) and this value is far below the world average of 27.5 t ha$^{-1}$ (FAO, 2005). This vegetable can be eaten either fresh or processed in different products (Ahmad *et al*., 2007).

## 1.2 Yield Losses Due to Flower and Fruit Drops

Orange, mango and tomato productivity in Tanzania is low compared to other countries. According to FAOStat (2017) and NBS (2008), the productivities of orange, mango and tomato in Tanzania are 12.00, 12.95, 11.84 mt/ha, respectively while the productivity of orange is 26.18, 23.13 and 16.91 mt/ha in Brazil, USA and China, respectively. Mango productivity is 8.39, 8.36, 8.14 mt/ha in India, Thailand and China, respectively. Tomato productivity is 90.29, 56.20 and 24.2 mt/ha in USA, China and India, respectively (FAO, 2017; Pariona, 2017; TDR, 2018; Riggs and Scott, 2018). The low productivity of these fruits in Tanzania is partly caused by pre-harvest fruit losses such as flower and premature fruit drops (Atherton, 2011). Specifically, the major causes of premature and mature falling of fruits are drought stress, improper fertilizer application, too high temperature, mechanical damage, phytohormone control of abscission, competition for photo-assimilates, during fruit development periods as well as high disease incidences especially powdery mildew and anthracnose, and insect pest infestation like hopper and mealy bug. For example, mango aphids and hoppers account for up to 70 % and 25 – 60% of the total fruit losses, respectively (Chattha *et al*., 1999; Maqbool *et al*., 2007).

Individual mango panicle produces hundreds of ovule-bearing flowers but only a small proportion (0.1 to 0.25%) of the set fruits reach maturity. Despite adequate flowering and initial fruit set, severe fruit drop contributes to low fruit yields in mango orchards and causes great economic losses in various mango growing countries of the world (Sing and Malik, 2006). The natural fruit drop in mango is rather too high varying from 95 to 99% at various stages of growth. The fruit drop is heavy during the first three weeks of fruit set when the rate of fruit development is rapid and this continues up to the 5$^{th}$ week. The premature fruit drops are higher at mustard, pea and marble stage of fruit development. As the fruit develops, the retention capacity increases and abscission decreases (Roemer *et al.*, 2011). The fruit drop at maturity stage significantly affects the final fruit retention and fruit yield (Sharma, 2006). When fruits overripe on farm, they are subjected to attacks by insect pests like fruit flies, fruit piercing moth, false codling moth, and diseases like anthracnose (Kibui, 2016). Small-scale producers of fruits are forced to sell their produce at low prices at farm gate during boom for they have little or no control on ripening and timing of fruits harvests. Techniques for increasing the retention of fruits on trees, and reducing disease and insect pest infections are therefore desirable for reduction of pre-harvest losses of fruits (Humble and Reneby, 2014; Kiaya, 2014). As infections by pathogens may occur during the growing season, at harvest time or during handling and transport, the ability to control these pre-harvest infections is crucially important (Song *et al.*, 2007).

Orange produce around 50 000 flowers per tree in blooming season, orange trees normally drop some of their young fruits as a means to thin the fruit out and devote resources to the development of the fruits that remain. Beginning soon after blossom drop, and ending when the fruit has a diameter of about 1.27 cm, although 95% to more than 99% flowers drop and only a small amount of these flowers become mature fruits (Chaudhary, 2006). Orange bears a large number of flowers but they drop at early stages of development. Bloom and fruit drop at the fruit setting, natural drop and eventually fruit drop before attaining the commercial ripening is a common phenomenon (Ibrahim *et al.*, 2011). Fruit drop is one of the major agronomic problems facing fruit small-scale farmers. Thus, pre-harvest fruits loss is a formidable challenge for the growers, traders, researchers and policy makers in all producing countries (Subramanian *et al.*, 2014).

### 1.3 Effects of Hormones and Enzymes on Fruit Losses

Naturally occurring hormones play a major role in fruit growth and drop. Deficiency of auxins, gibberillins and cytokinins coupled with high level of growth inhibitors such as abscissic acid and ethylene corresponds with high level of fruit drop (Chattha *et al.*, 1999). Hormonal regulation of fruit abscission has been observed in many fruit crops, and endogenous hormones play a major role in fruit growth and fruit drop. It is well known in many fruit crops including mango and citrus that the retention of a fruit relates positively with the fruit ability to produce growth promoting hormones (Buban, 2000). The intensity of abscission of premature fruit varies considerably with the developmental stage of the fruit. Fruit retention seems to depend on plant signals sent from the fruit to the tree and thereby suppressing the activation of the abscission zone and the ability of the fruit to compete for carbohydrate (August *et al.*, 2002). Generally, plant growth regulators function at low concentrations in many fruits to regulate the formation and activation of the abscission zone within the separation layer (Singh *et al.*, 2005).

Increased respiration with a concomitant burst of ethylene production is exhibited at the onset of ripening in climacteric fruits whereas in non-climacteric fruits an increase of respiration and ethylene production are observed during fruit maturation. Respiration and ethylene production causes rapid biochemical and structural changes that determine fruit aroma, texture and nutritional components (Ezura and Hiwasa-Tarase, 2010). Phospholipase D is one of the important enzymes produced during ripening and senescence of fruits that initiates and propagates membrane degradation. The activities get further aggravated by action of several other enzymes like phosphatise and hydrolase (Karthika *et al.*, 2015).

### 1.4 Overcoming Fruit Loss and Fruit Retention

An increase in retention of fruits on trees ensures enhanced availability of fruits for extended periods, thus broadens marketing window, and increases economic returns for the growers (Subramanian *et al.*, 2014). Numerous factors affect fruit quality during all phases of the production process including plant genetics, harvest time, fruit maturity, and environmental condition as well as storage and transportation conditions (Baietto and Wilson, 2015).

Applications of proper agronomic practices are required for enhancing the retention of fruits on trees and reduction of fruits losses. Various attempts have been made to improve fruit set and retention with exogenous application of plant growth regulators, nutrients and pesticides (Singh *et al*., 2005) but their wider application is limited by either low efficacy or adoptability by small-scale growers. Some of these technologies include application of paclobutrazol plus potassium nitrate in avocado fruits to increase fruit retention on trees (Oosthuyse and Berrios, 2015) and application of polyamines to increase fruit retention on mango trees, fruit size and colour (Singh and Malik, 2006), and application of 2, 4-

Dichlorophenoxyaetic acid 2, 4-D and gibberellic acid (GA3) in calambola to reduce fruit drop and increase fruit retention on trees and yield (Bekti, 2009). In conventional and integrated production systems, pest defects are controlled by preventive application of synthesised pesticides during blooming and pre-harvest. The increase in restrictions of synthesised pesticide application has stimulated research on alternative methods for controlling fruit diseases such as use of plant volatile compound (Baggio *et al.,* 2014). Moreover, application of fungicides to control the pre-harvest fruit losses is limited by consumers' desire for reduced fungicide residues. The interest in use of natural alternative techniques to prevent fungal growth has markedly increased (Soković *et al*., 2013). Many biological active volatile compounds have been reported to reduce pre-harvest disease incidences on fruits (Romanazzia *et al.,* 2016).

## 1.5 Fruit Market Attributes

Fruit quality is judged by consumers primarily from their perception of the acceptability of the fruits based on characteristics such as visual appeal (Baietto and Wilson, 2015). The most important universal fruit attributes which guide buyers' choice of fruits are peel colour, fruit size, freshness, absence of defects on peel and firmness (OECD, 2010). Fruit colour, freshness and absence of defects on fruit skin increase visual attraction of the fruits by buyers whereas fruit firmness reduces softening, and thus increases fruit storability (El-Ramady *et al*., 2015).

According to Tanzania Bureau of Standards (TBS), the general quality requirements of fruits include peel colour, firmness, size, freshness, and absences of defect of fruit peel, longevity and brightness (TBS, 2008a; TBS, 2008b; TBS, 2014a). Fruit firmness is associated with the maturity of many horticultural products and is one of the measures of quality of fruits. Fruit firmness decreases as fruits become more mature and decrease rapidly as they ripen (Jarimopas and Kitthawee, 2007) and is the best indicator of ripening and predictor of bruising potential and shelf life (Valero *et al.,* 2003).

## 1.6 Problem Statement and Justification of the Study

Fruit attributes that guide buyers' choice of fruits are universally known (OECD, 2010), but there is limited information on the key fruit attributes that influence buyers' choice of orange, mango and tomato fruits in Tanzania. Recently, field application of hexanal was reported to be the most effective technique for improving fruit attributes (i.e. reduces superficial scald and fungal infection, and increase of fruit firmness and freshness), and marketable yield by increasing fruit retention on trees of various fruits namely apple, cherry, longan, mangoes, straw berry, guava and tomato (Subramanian *et al.*, 2014; Karthika *et al*., 2015). Naturally occurring hexanal concentration in plant is extremely low. However, applications of exogenously synthesized hexanal on fruits and vegetables have shown to extend fruit shelf life without associated ill-effects to the fruits or consumers (Karthika *et al*., 2015).

Hexanal is an alkyl aldehyde with the molecular formula $C_6H_{12}O$ that acts as a strong inhibitor of phospholipase-D action, and thus slows down ethylene stimulation of ripening processes (Subramanian *et al.*, 2014; Karthika *et al*., 2015). Hexanal is produced as an antioxidant by plants and fruits when wounded as a protective mechanism against diseases, insect pests and environmental stresses. Previous tests on the effects of hexanal were confined in Asia and North America, and thus limited tests in tropical Africa, Tanzania inclusive. The effects of field application of hexanal on fruit drop, disease and insect pest infestations are not well known. Moreover, field applications of hexanal have not been tested before on orange, and therefore there is limited information on the effects of field application of hexanal on market fruit attributes (i.e fruit colouration, freshness, firmness and pest defects on fruit peel), premature fruit drop and total marketable yield in orange. Similarly, no studies have been conducted to assess the effects of field hexanal application on fruit freshness and absence of defect on fruit peel on mango and tomato fruits. The effectiveness of hexanal application at 0.02% between 7 and 35 days before fruit harvest for increasing fruit quality and reducing fruit losses reported in previous studies depended on fruit species, varieties, farm conditions and geographical location (Subramanian *et al.*, 2014). There is limited information on the time of field application of hexanal prior to fruit harvest on fruit drops, pest defects, fruit weight, fruit diameter and total marketable yield of oranges, mangoes and tomatoes.

## 1.7 Objectives

### 1.7.1 Overall objective

The overall objective of this study is to improve yield and quality of selected fruits in the tropical environment of Tanzania through pre-harvest hexanal application.

### 1.7.2 Specific objectives

1. To determine key market fruit attributes used by buyers in selecting fruits.
2. To determine the effects of pre-harvest hexanal application on market fruit attributes.
3. To determine the effects of field application of hexanal on pre-harvest fruit losses.

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# CHAPTER TWO

## BUYERS' PREFERENCES FOR FRUIT ATTRIBUTES OF MANGO AND ORANGE IN TANZANIA

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**ABSTRACT**

There are limited reports on the most important fruit attributes that influence buyers' preferences for mangoes and oranges in Tanzania. The objective of this study was to determine the most important fruit attributes that influence buyers' preference for mangoes and oranges in selected markets in Tanzania. This study was conducted at Muheza district in Tanga region and Mkuranga district in Coast region. A total of 179 randomly selected participants were engaged to determine the fruit attributes where 50.3% of the participants (consumers, farmers and traders) assessed orange fruit attributes while 49.7% of the participants (consumers, farmers and traders) assessed similar attributes for mangoes. Data were purposively collected using close and open-ended questionnaires. Results reveal that the key fruit attributes which influence buyers' preferences were firmness, colour, medium sized fruits, spots free and freshness for orange fruits, and firmness, colour, spots free and freshness for mango fruits. Results further indicate that buyers associated fruit freshness, colour, spots free and firmness with fruit longevity (shelf life) whereas freshness, spots free and firmness were associated with fruit endurance during handling after harvest. Further studies are required to determine technologies and practices that increase fruit firmness, freshness and colour, and reduce spot defects on fruit skins of mangoes and oranges. Further studies are also required to determine other fruit attributes such as nutritional value, safety and price which influence buyers' preference to purchase mango and oranges in Tanzania.

**Key word:** Fruit attributes, Marketing, Fruit longevity, Fruit endurance, Farmers, Traders, and Consumers.

## 2.1 Introduction

Fruits are among the most liked food all over the world owing to their sweet taste, aroma and nutritive value (McCluskey, 2015) and are increasingly valued as an important component of the diet (Ernst, 2006). According to Banovic *et al.* (2009), market attributes expectations are formed at the purchase point based on perceived intrinsic and extrinsic attributes and after meal preparation and consumption. Consequently, quality experience is formed when market attributes expectations are actually confirmed or rejected. Campo *et al*. (2006) concluded that the confirmation or rejection of the expectations further determines the final satisfaction with the product, which is confirmed by repeated purchases.

Fruits appeal to consumers is largely based on visual appearance attributes as well as tactical characteristics (Fallik *et al*., 2009; Barrett *et al*., 2010). Visual fruit attributes such as shape, size, freshness, ripeness, cleanliness, and absence of defects and blemishes on fruit skin as well as non-visual fruit attributes such as firmness, nutritional value, and absence of pesticide, heavy metal and preservative residues are increasingly demanded to meet the needs and preference of buyers and consumers (Husin *et al*., 2010). During purchase of fruits, buyers mainly use visual fruit attributes and thus pay a premium for fruits which meet the attributes they prefer to (Kamila *et al*., 2016).

Visual fruit attributes such as skin colour, fruit shape, size, freshness and absence of defects on fruit skin are universally known as the most important attributes which influence the fruit acceptability by traders and consumers (Baiettor and Wilson, 2015). However, there are limited reports on the most important fruit attributes that influence buyers' preferences for mangoes and oranges in Tanzania. The objective of this study was to determine the most important fruit attributes that influence buyers' preference for mangoes and oranges in selected markets in Tanzania.

## 2.2 Materials and Methods

### 2.2.1 Brief description of the study area

A study was conducted at Muheza district in Tanga region and Mkuranga district in Coast region May to June, 2017 to determine the most preferred fruit attributes for oranges and mangoes. Tanga and Coast regions were selected due to their long experiences in orange and mango production and marketing in the country. Muheza district is the leading in orange production and marketing within the region (Izamuhaye, 2008) while Mkuranga is leading in production and marketing of improved mango varieties within the region and country (MMA, 2017). Mkuranga has a large number of both local urban and high income farmers, traders and consumers who provide market outlet for improved mango varieties produce.

### 2.2.2 Sampling design

This study was conducted in selected 43 villages and two urban markets in Muheza and Mkuranga. The villages and urban markets were selected based on availability of mango and orange farms and markets.  In two districts the total participants were 179, where by 90 (50.3) from Muheza assessed for orange and 89 (49.7) from Mkuranga assessed for mango. The sex ratio was male 115 (64.2) and female 64 (35.8) of the total participants. And the respondent category were ranked as farmers 60 (33.5), traders 60 (33.5) and consumers 59 (33). A list of all registered farmers, traders and consumers who are involved in mango and orange business were selected with assistance of agricultural extension officers in the production areas at ward level. Consumers, farmers and traders were purposive selected based on their engagement in mango and orange business for five years and above.

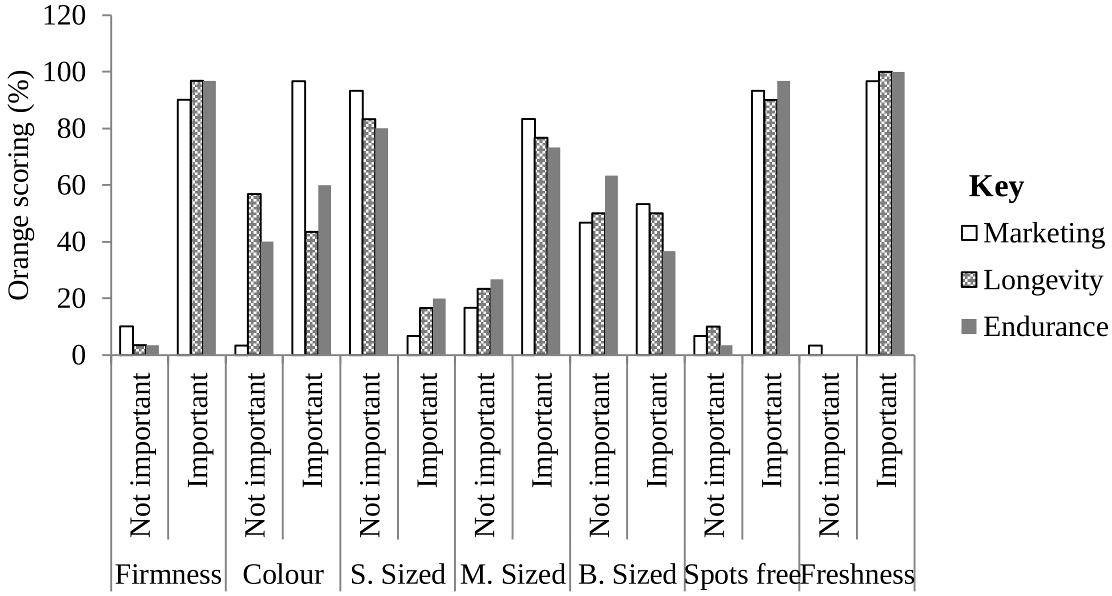
### 2.2.3 Data collection and analysis

A structured and semi-structured questionnaire (Appendix 1) with close and open-ended questions was prepared and used to collect primary data on fruit attributes from the respondents. The questionnaire was first pretested using 10 farmers, 10 traders and 10 consumers in Mkuranga and Muheza districts and was then revised accordingly to incorporate the respondents' comments. A face to face interview that involved 59 consumers, 60 farmers and 60 traders per study was conducted. One to two consumers, traders and farmers were interviewed per village making a total of 30 consumers, 30 farmers and 29 traders per district. Data were collected on fruit attributes (i.e. colour intensity, freshness, spots free, small sized fruits, medium sized fruits, big sized fruits and firmness) for fruit marketing, longevity and endurance attributes. A binary scale was used to score the respondents' responses where 1 and 2 meant 'not important' and 'important', respectively. Data were analysed using Statistical Package for Social Science (SPSS 20 Version 2.0) software (IBM, 2013) based on descriptive statistics.

## 2.3 Results

### 2.3.1 Orange fruit attributes according to farmers

Results in Figure 2.1 indicated the influence of fruit attributes in marketing, longevity and endurance of oranges according to farmers. According to farmers', the highest scored variables were fruit firmness, freshness, medium size, and spots free for marketing, longevity and endurance, respectively. Furthermore, the lowest scored variable was small sized fruits as reported by farmers for orange fruit attributes in influencing marketing, longevity and endurance.

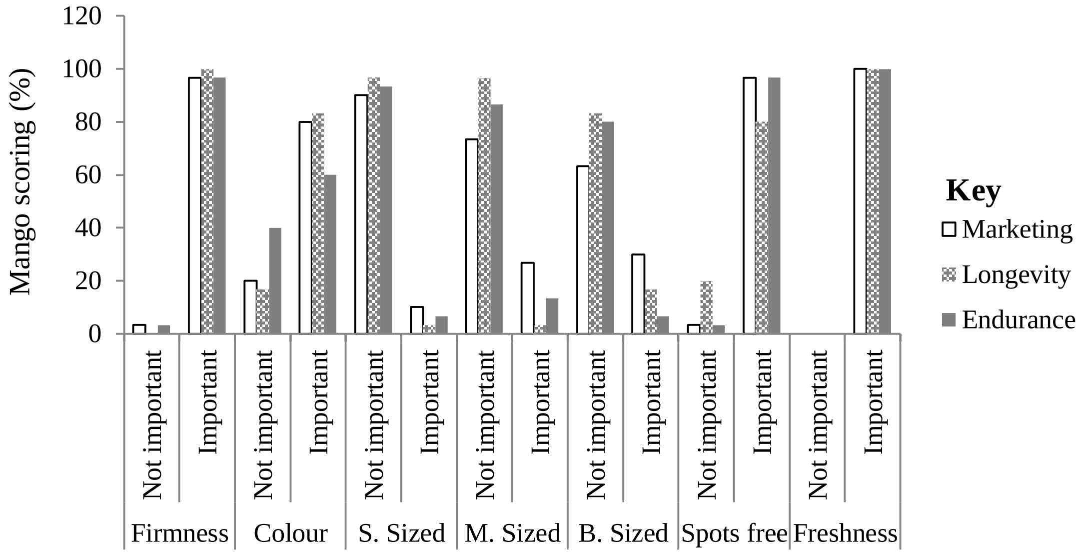



S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.1: Fruit attributes of oranges according to farmers**

### 2.3.2 Mango fruit attributes according to farmers

Results in Figure 2.2 indicated the influence of fruit attributes in marketing, longevity and endurance of mango based on the interview of the farmers. According to farmers, the highest scored were fruit firmness, colour, spots free and freshness for marketing, longevity and endurance. Conversely, small, medium and big sized fruits were reported by farmers as the lowest scored mango fruit attributes in influencing marketing, longevity and endurance.

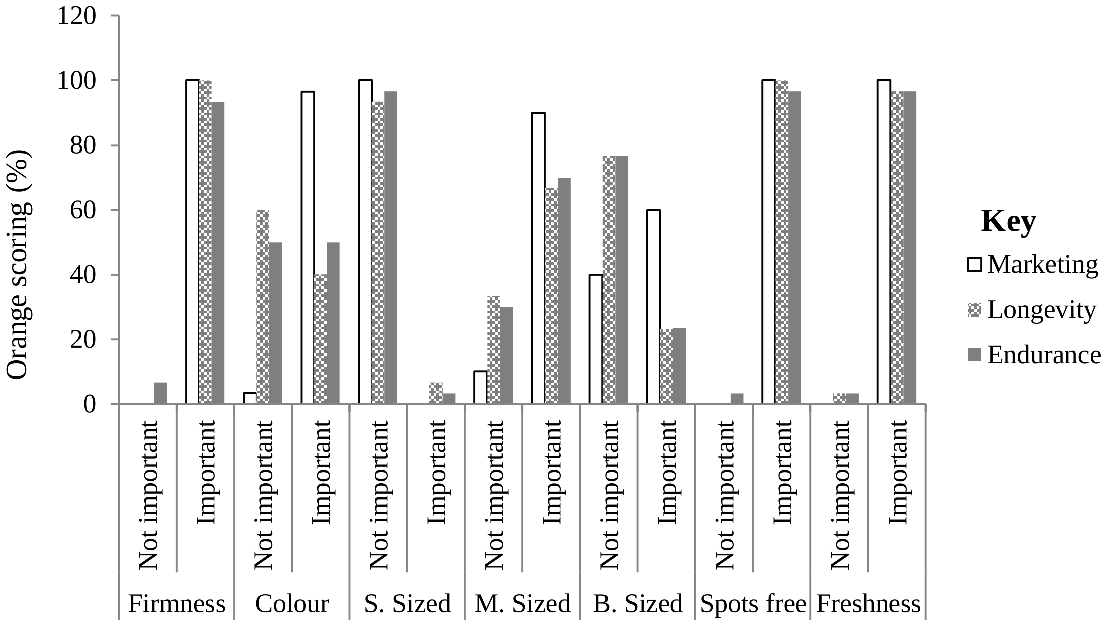



S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.2: Fruit attributes of mangoes according to farmers**

### 2.3.3 Orange fruit attributes according to traders

Results in Figure 2.3 indicated the importance of fruit attributes in influencing endurance, longevity and marketing of orange fruits based on the interview of traders. According to traders, fruit firmness, colour, medium sized fruits, spot-free on fruit skin and freshness scored high for fruit marketing, longevity and endurance. On the contrary, small and big sized fruits were reported by traders as the lowest scored orange fruit attributes in influencing marketing, longevity and endurance.

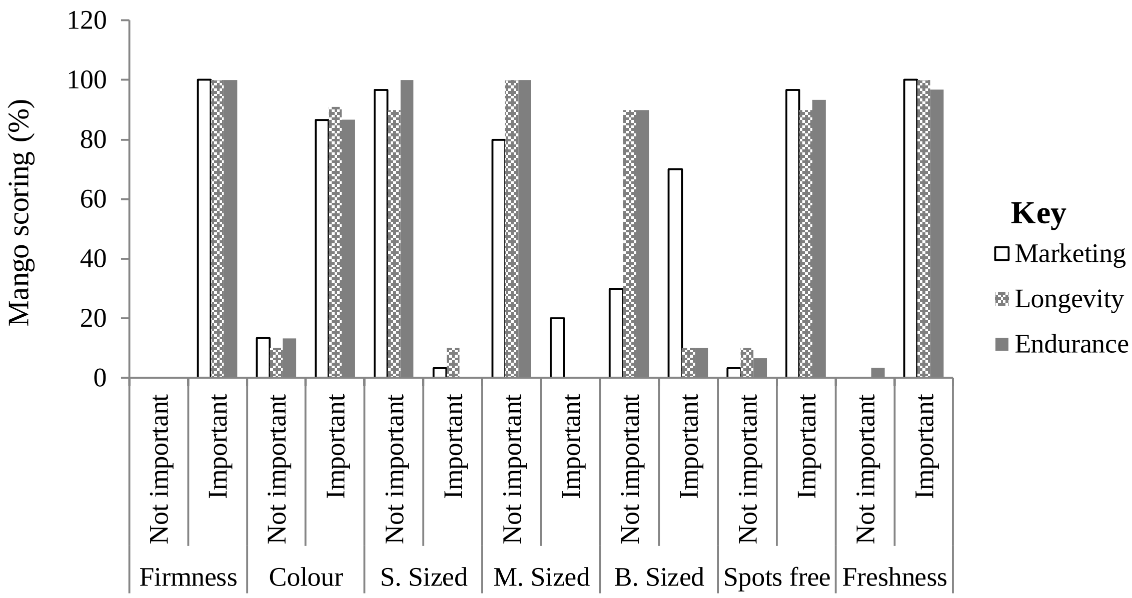



S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.3**: **Fruit attributes of oranges according to traders**

### 2.3.4 Mango fruit attributes according to traders

Results in Figure 2.4 show the importance of fruit attribute in influencing endurance, longevity and marketing of mango fruits based on the interview of the traders. Fruit firmness, fruit colour, spot- free on fruit skin and fruit freshness scored highly for marketing, longevity and endurance. Conversely, small, medium and big sized fruits were reported by traders as the lowest scored variables of mango fruit attributes in influencing marketing, longevity and endurance.

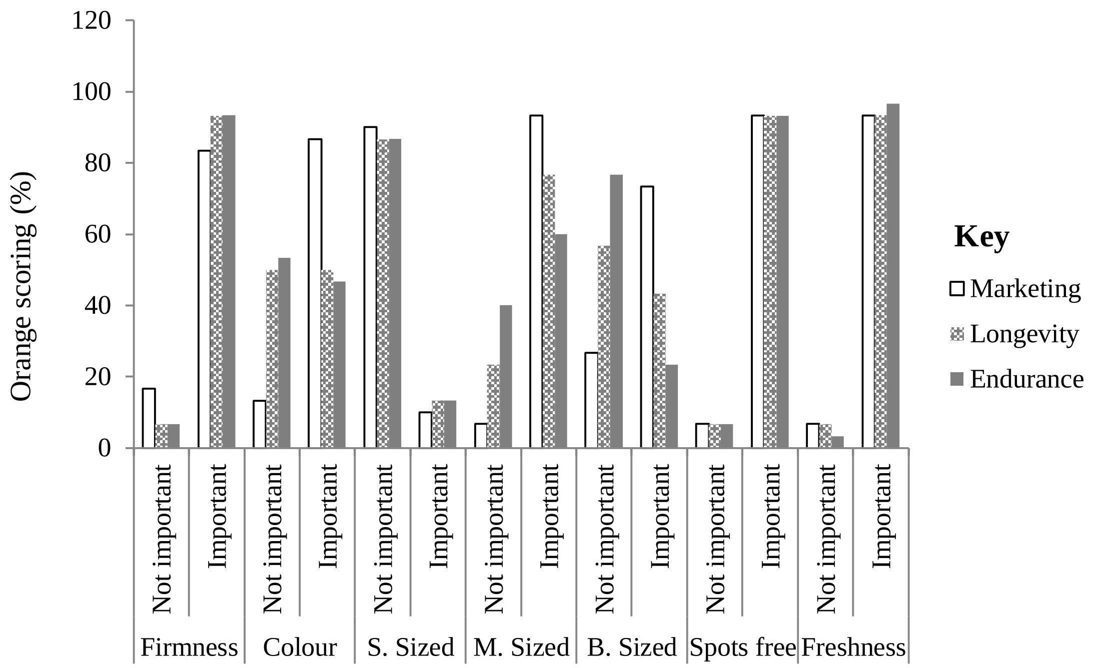



S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.4: Fruit attributes of mangoes according to traders**

### 2.3.5 Orange fruit attributes according to consumers

Results in Figure 2.5 indicated the importance of fruit attribute in influencing marketing, longevity and endurance of orange according to consumers. Fruit firmness, fruit colour, medium sized fruits spot-free on fruit skin and fruit freshness scored high for fruit marketing, longevity and endurance in that order compared to the rest.

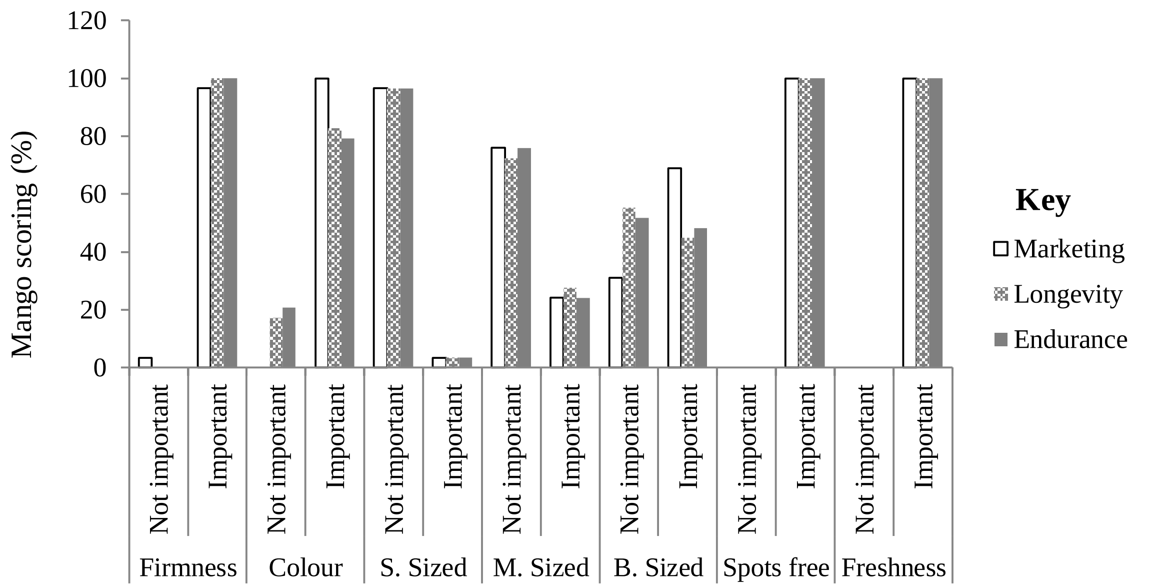



S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.5: Fruit attributes of oranges according to consumers**

### 2.3.6 Mango fruit attributes according to consumers

Results in Figure 2.6 indicated the important fruit attributes in influencing endurance, longevity and marketing of mango fruits according to consumers. The highly scored valuables were fruit firmness, fruit colour, spot-free on fruit skin and fruit firmness.




S. sized = Small size, M. sized = Medium size and B. sized = Big size

**Figure 2.6: Fruit attributes of mangoes according to consumers**

## 2.4 Discussion

Results from this study indicat that traders and consumers preferentially buy orange and mango fruits based on firmness, colour, spots free, medium sized and freshness. These results are supported by Barrett *et al*. (2010) who also reported that fruit firmness, freshness, colour and absence of spots on skin are critical to eating pleasure (ie “eating with eyes”) as they usually determine whether the product is accepted or rejected by consumers. Consumers often pay a premium price for products with desired attributes (Lancaster, 1966), which means farmers and traders can improve marketability of their orange and mango fruits by ensuring increased fruit firmness, freshness, colour and absence of spots on fruit skins.

The present study shows that buyers also use fruit firmness, colour, absence of spots on fruit skins and freshness as determinants of fruit longevity and endurance during handling after harvest. Fruit firmness is an indirect indicator of fruit ripeness, storability, shelf life and endurance during fruit handling after harvest (Harker *et al*., 2000; Garsia-Ramos *et al*., 2005).

Fruit colour is a measure of fruit ripening and deterioration level, and is therefore a good indicator of fruit shelf life and endurance after harvest (Baietto and Wilson, 2015; Oliveira, 2016). Moreover, colour is also used by farmers as an index to judge fruit maturity and therefore shelf life and endurance in watermelon (Lien, 2017) and mango (Kapilan and Anpalagan, 2015).

Freshness is a measure of high water levels in fruits and time interval from fruit harvest, and thus is associated with fruit shelf life and endurance after harvest (Baietto and Wilson, 2015). At the point of purchase, the consumers use freshness attribute as an indicator of fruit longevity and endurance after harvest (Shewfelt, 2000; Kapilan and Anpalagan, 2015).

The absence of spots on fruit skins is an indicator of absence of disease pathogens, reduced risk of decays and thus is associated with prolonged shelf life and endurance after harvest (Barrett *et al.*, 2010). The reduction of spots on fruit skin also enhanced fruit visual appeal to consumers and increased longevity in avocado and orange (Giovanelli, 2008; Sbodio *et al.*, 2017).

## 2.5 Conclusions and Recommendations

The objective of this study was to determine the most important fruit attributes that influence buyers' preference for mangoes and oranges in selected markets in Tanzania. Firmness, colour, absence of spots on fruit skin, medium sized and freshness are the most important fruit attributes that influence traders and consumers' preference during buying both orange and mango fruits. Further studies are required to determine new varieties, technologies and practices that can increase fruit firmness, freshness and colour, and absence of spots on fruit skins of mangoes and oranges. Further studies are also required to determine other fruit attributes such as nutritional value, safety for human consumption and price, which influence buyers' preference to purchase mango and orange in Tanzania.

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# CHAPTER THREE

## EFFECTS OF PRE-HARVEST HEXANAL APPLICATION ON MARKET ATTRIBUTES OF ORANGE VARIETIES GROWN IN EASTERN ZONE OF TANZANIA

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**ABSTRACT**

The study was to determine the effects of field application of hexanal on pre-harvest market attributes of orange (*Citrus sinensis* L.) fruits. The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and the factor B consisted of time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days to harvest) to Early Valencia, Jaffa and Late Valencia varieties. A fruit tree for each orange variety constituted a treatment for hexanal application and time of its application prior to fruit harvest. The results show that hexanal application at 0.01, 0.02 and 0.04% equally improved fruit marketable yields by increasing fruit firmness and number of marketable yield of Early Valencia, Jaffa and Late Valencia varieties. The number of marketable yield increased by 19.28, 26.21 and 30.74% over the controls for Early Valencia, Jaffa and Late Valencia, respectively. Similarly, fruit firmness increased by 9.07, 9.64 and 10.12 $N/mm^2$

over the control for Early Valencia, Jaffa and Late Valencia, respectively. It is recommended that farmers should treat Early Valencia, Jaffa and Late Valencia with hexanal at 0.01% from 42 to 7 days to harvest in order to increase marketable yield and fruit quality.

**Key words:** Hexanal, Early Valencia, Jaffa, Late Valencia, Pre-harvest, Marketable yield, Fruit firmness

## 3.1 Introduction

Citrus fruits are grown throughout the world in tropical and subtropical areas. Over 140 countries produce citrus (Izamuhaye, 2008; Ihueze and Mgbemena, 2017). Currently, world citrus production is around 50 million tons (USDA, 2018). Orange (*Citrus sinensis* L.) is one of the top citrus fruit grown in most of the countries after grapes and apple (Abobatta, 2015). Globaly in citrus production, orange contributes 50% with values of vitamin c, folcam, calcium, and potassium (Sawe, 2017).

Orange is the most widely grown citrus fruit in Tanzania compared with other fruits (Mgonja and Utou, 2017). Tanzania ranks 20$^{th}$ in the orange produced in world in orange production with the total area under cultivation for smallholder farmers of about 37 500 ha with the production of 4 500 000 mt per annum and an average yield of 12 mt/ha (FAOStat, 2017). Quality is one of the most important attributes for marketing of oranges. The major fruit attributes that influence marketability of oranges include fruit firmness, fruit size, freshness and lack of pest defects (Valero *et al.,* 2003; Jarimopas and Kitthawee, 2007; TBS, 2008a; TBS, 2008b; OECD, 2010; TBS, 2014a). Various attempts have been made to improve market fruit attributes including exogenous application of plant growth regulators, nutrients and pesticides. However, their wider application was limited by either low efficacy or unadoptability by small-scale fruit growers (Singh *et al*., 2005).

Recently, field application of hexanal has been reported to be the most effective for reduction of superficial scald, fungal infection, and for increasing fruit firmness, quality, freshness of various fruits namely apple, cherry, longan, mangoes, straw berry, guava and tomato (Subramanian *et al.*, 2014; Karthika *et al*., 2015). However, there is limited information on the effect of hexanal application on marketable yield, firmness, weight and diameter of orange varieties grown in Tanzania. Therefore, the objective of this study was to determine the effect of hexanal application on market fruit attributes of selected orange varieties grown in Tanzania.

## 3.2 Materials and Methods

### 3.2.1 Description of study area

The studies were carried out in Semngano (altitude, latitude and longitude of 254.0 m asl, 05$^o$14’14.8”S and 038$^o$46’33.1"E, respectively) and Mamboleo (altitude, latitude and longitude of 263.0 m, 05$^o$13’59.9”S and 038$^o$42’58.2"E, respectively) villages in Muheza district, Tanga Region. These sites had the same agro-climatic conditions. Muheza District experiences bimodal rainfall from 800 mm to 1400 mm with an average annual minimum and maximum temperatures of 24°C and 32°C, respectively (TRCO, 2008). The long rain season is between March and May while the short rainy season is between October and December. Selection of sites was based on high production of oranges in the country.

### 3.2.2 Description of orange varieties

The experiment was carried out in farmers’ orange orchards, which were well established and maintained according to recommended agricultural practices. Three orange varieties namely Early Valencia, Jaffa and Late Valencia were selected for the study. Early Valencia is the most popular variety which matures early from May to September and produces high yield. The fruits are medium-sized, thin and smooth skinned, very sweet and with high juice content, and tolerance to long distant transport. Late Valencia is a popular variety, matures late from January to March, produces high yield and fruits are retained on trees for long period. The fruits are sweet and juicy when ripe, robust to transport and tolerant to harsh environment. Variety Jaffa matures early from May to July and produces high yield of big size fruits with higher juice content but less sweet and less robust to transport (Mbiha and Maerere, 2002; Izamuhaye, 2008). Early Valencia and Late Valencia are the most preferred oranges varieties with acceptance by farmers of 45.8% and 31% of all orange varieties grown in Muheza district (Makorere, 2012).

### 3.2.3 Experimental design

The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B consisted of time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days to harvest). The experiment was done in two seasons (first season from April, 2017 to July, 2017; second season from August, 2017 to December, 2017). A fruit tree for each orange variety was taken as a treatment for hexanal application and time of its application prior to fruit harvest. A treatment was repeated ten times. Hexanal at the above concentrations and its time of application was manually sprayed on fruits using a knapsack sprayer. Hexanal was sprayed on fruits until the solution dripped from fruits. Untreated orange trees for each variety were used as controls.

### 3.2.4 Data collection and analysis

Hexanal treated and untreated fruits per treatment were randomly harvested at ripening stage. Data on number of marketable yield, fruit firmness, fruit diameter and fruit weight on fruit market attribute of orange were collected immediately after fruit harvest. Data on number of marketable yield were taken by counting the oranges from all harvested fruits per treatment with no damage, diseases and serious deterioration (OECD, 2010). Fruit firmness was measured using a hand penetrometer with a diameter of 8 mm plunger (Wagner instruments-Greenwich CT). Fruit weight was measured using digital balance (Kenwood Weighing Scales DS400) and fruit diameter was measured using digital caliper (New Type LCD Reading Long Jaw Internal Diameter Digital Vernier Callipers). Two way ANOVA was used to analyse data using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5 % probability. The sources of variation were hexanal concentration and time of application prior to harvest. Independent analyses were done for each variety during each season.

## 3.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on market attributes of orange are presented below. Independent analyses were performed for each variety and during season. Results are conveniently reported together in the same sections.

### 3.3.1 Effects of hexanal concentration on fruit firmness

Firmness of fruits of Early Valencia, Jaffa and Late Valencia fruits was significantly affected by hexanal concentration during both seasons. The effects of time of hexanal application prior to harvest and concentration x time of harvest were non-significant for all three varieties during both seasons (Table 3.1). Furthermore, the study observed significant main effects of hexanal concentration on firmness of fruits of Early Valencia, Jaffa and Late Valencia. Generally hexanal increased fruit firmness on Early Valencia, Jaffa and Late Valencia by up to 7.42, 7.70 and 8.73 $N/mm^2$ during first season, respectively and by up to by 9.07, 9.64 and 10.12 $N/mm^2$ at hexanal concentration 0.04, 0.01 and 0.04 %, respectively compared to the untreated controls in second season (Figures 3.1, 3.2 and 3.3).

**Table 3.1: Effect of hexanal concentration and time of application on orange varieties firmness**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3,\ 144}$ =80.99 | <0.001 | $F_{3,\ 32}$ =49.98 | <0.001 |
| Time | $F_{3,\ 144}$ =1.36 | 0. 257 | $F_{3,\ 32}$ =0.52 | 0. 670 |
| Conc. x Time | $F_{9,\ 144}$ =0.56 | 0.829 | $F_{9,\ 32}$ =0.62 | 0.771 |
| **Jaffa** | | | | |
| Conc. | $F_{3,\ 144}$ =134.92 | <0.001 | $F_{3,\ 64}$ =209.20 | <0.001 |
| Time | $F_{3,\ 144}$ =0.92 | 0. 435 | $F_{3,\ 64}$ =0.66 | 0. 579 |
| Conc. x Time | $F_{9,\ 144}$ =0.88 | 0.545 | $F_{9,\ 64}$ =1.03 | 0.427 |
| **Late Valencia** | | | | |
| Conc. | $F_{3,\ 144}$ =639.17 | <0.001 | $F_{3,\ 80}$ =395.25 | <0.001 |
| Time | $F_{3,\ 144}$ =1.68 | 0. 175 | $F_{3,\ 80}$ =0.91 | 0.438 |
| Conc. x Time | $F_{9,\ 144}$ =0.86 | 0.562 | $F_{9,\ 80}$ =1.13 | 0.350 |

Note: Conc. = Concentration

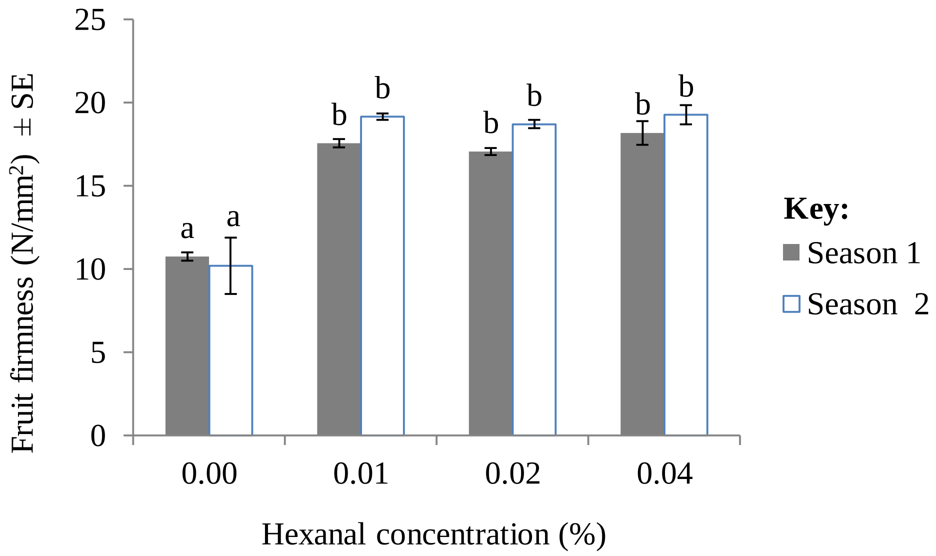


**Figure 3.1: Mean of fruit firmness of Early Valencia orange variety under different concentrations of hexanal during first season ($F_{(3,\ 36)}$ = 69.87, ($P$ < 0.001) and second season ($F_{(3,\ 8)}$ = 23.87, $P$ < 0.001), Post hoc test = Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

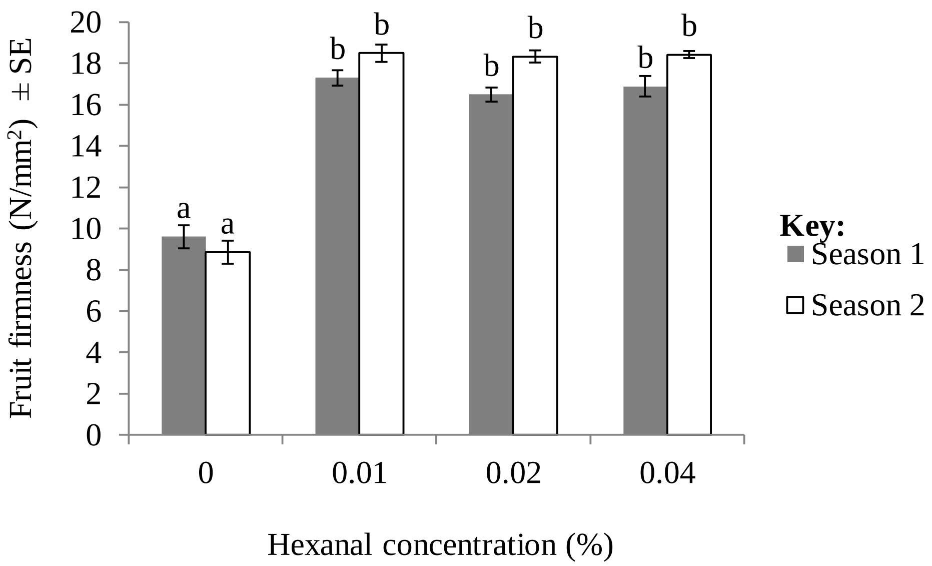


**Figure 3.2: Mean of fruit firmness of Jaffa orange variety during first season ($F_{(3, 36)} = 64.72$, $P < 0.001$) and second season ($F_{(3, 16)} = 142.71$, $P < 0.001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

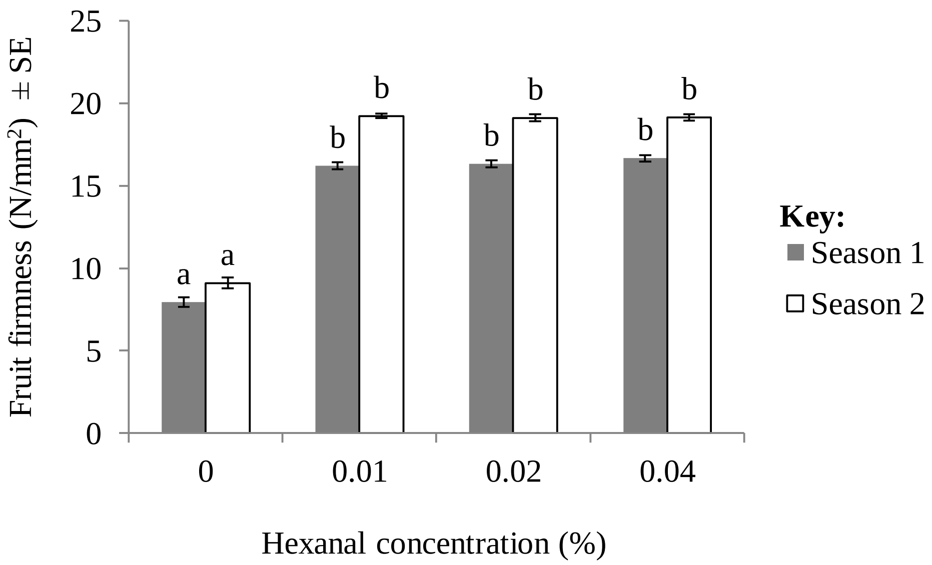


**Figure 3.3: Mean of fruit firmness of Late Valencia orange variety during first season ($F_{(3, 36)} = 353.99$, $P < 0.001$) and second season ($F_{(3, 20)} = 487.42$, $P < 0.001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 3.3.2 Effects of hexanal concentration on orange fruit marketable yield

The results show that hexanal concentration significantly improved marketable yield of Early Valencia, Jaffa and Late Valencia during both seasons. However, marketable yield did not vary significantly with the time of hexanal application prior to fruit harvest and concentration x time of application (Table 3.2). The results further showed that main effects of hexanal concentration on marketable yield of all tested orange varieties were significant during both seasons regardless of time of application. Marketable yield in Early Valencia, Jaffa and Late Valencia by up to 7.74% 10.82% and 10.84% respectively during first season and by up to 19.28%, 26.21% and 30.74% respectively during the second season (Figures 3.4, 3.5 and 3.6).

**Table 3.2: Effect of hexanal concentration and time of application on orange varieties marketable yield**

| **Effects** | **First season** | | **Second season** | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ =8.04 | <0.001 | $F_{3, 32}$ =12.09 | <0.001 |
| Time | $F_{3, 144}$ =0.47 | 0.706 | $F_{3, 32}$ =1.94 | 0.143 |
| Conc. x Time | $F_{9, 144}$ =0.70 | 0.704 | $F_{9, 32}$ =0.48 | 0.878 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =10.40 | <0.001 | $F_{3, 64}$ =24.86 | <0.001 |
| Time | $F_{3, 144}$ = 0.82 | 0.486 | $F_{3, 64}$ = 0.10 | 0.961 |
| Conc. x Time | $F_{9, 144}$ =0.82 | 0.601 | $F_{9, 64}$ =0.26 | 0.983 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =42.23 | <0.001 | $F_{3, 80}$ =47.58 | <0.001 |
| Time | $F_{3, 144}$ =0.47 | 0.704 | $F_{3, 80}$ =0.33 | 0.804 |
| Conc. x Time | $F_{9, 144}$ =0.72 | 0.692 | $F_{(9,80)}$ =0.78 | 0.635 |

Note: Conc. = Concentration

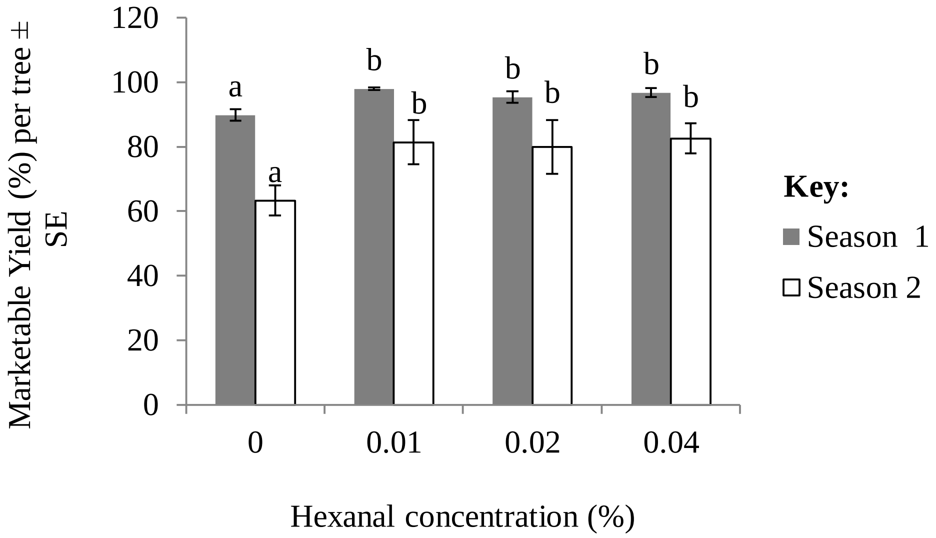


**Figure 3.4: Mean of fruit marketable yield of Early Valencia orange variety during first season ($F_{(3, 36)}$ = 6.17, $P$ = 0.002) and second season ($F_{(3, 8)}$ = 2.06, $P$ = 0.027), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

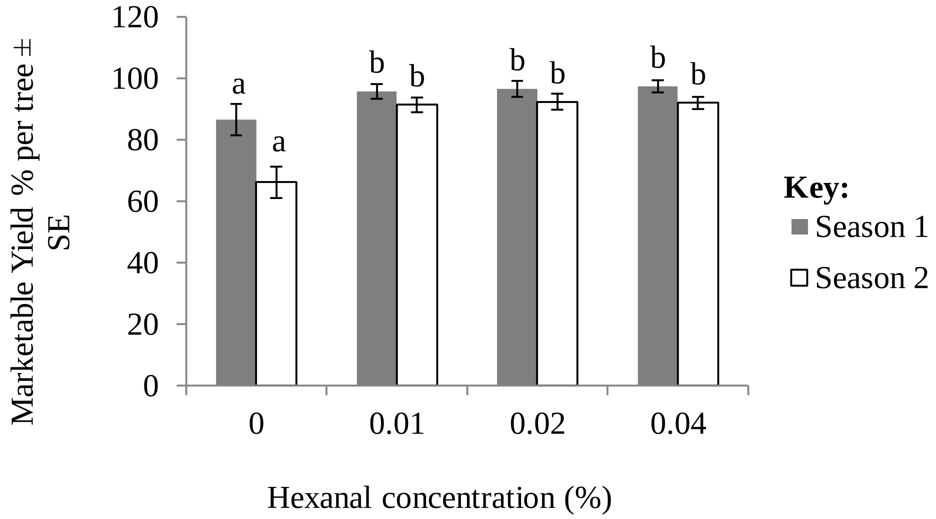


**Figure 3.5: Mean of fruit marketable yield of Jaffa orange variety during first seson ($F_{(3, 36)}$ = 4.77, $P$ = 0.007) and second season ($F_{(3, 16)}$ = 15.46, $P$ < 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

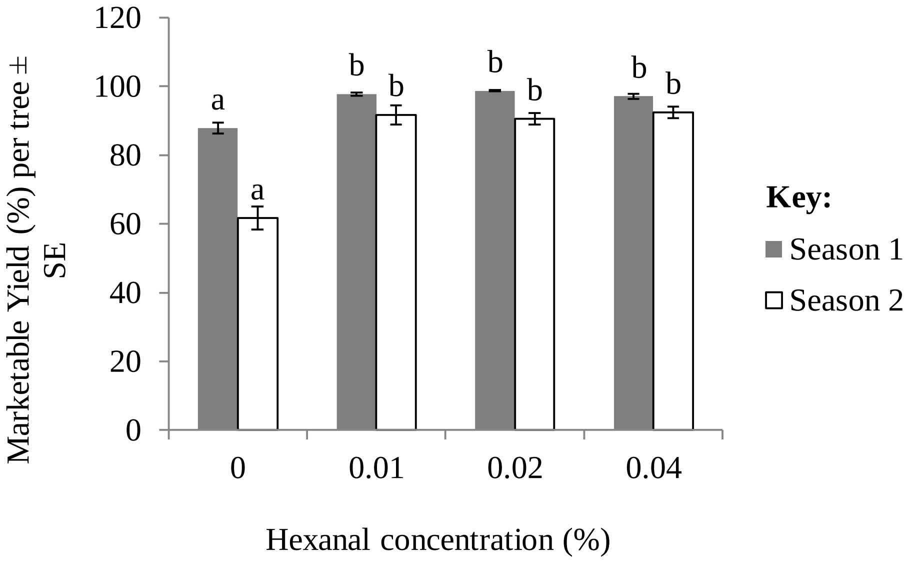


**Figure 3.6: Mean of fruit marketable yield of Late Valencia orange variety during first season ($F_{(3, 36)}$ = 29.49, $P$ < 0.001) and second season ($F_{(3, 20)}$ = 36.19, $P$ < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 3.3.3 Effects of hexanal concentration and time of application on fruit weight and size

The results show non-significant effects of hexanal concentration, time of its application prior to fruit harvest and concentration x time of application prior to fruit harvest weight of fruits of three orange varieties as in Table 3.3. Similarly, we observed non-significant effects of concentration, time of its application and concentration x time of application prior to fruit harvest on size of fruits of three orange varieties during both seasons as in Table 3.4.

Fruit weight ranged from 182.52 to 277.97 g for Early Valencia, 172.54 to 267.11 g for Jaffa and 172.53 to 296.98 g for Late Valencia. While fruit diameter ranged from 6.82 to 7.97 cm for Early Valencia, 6.62 to 7.87 cm for Jaffa and 6.55 to 8.11 cm for Late Valencia.

**Table 3.3: Effect of hexanal concentration and time of application on orange varieties fruit weight**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ =0.26 | 0.851 | $F_{3, 32}$ =0.48 | 0.696 |
| Time | $F_{3, 144}$ =0.49 | 0.687 | $F_{3, 32}$ =0.21 | 0.892 |
| Conc. x Time | $F_{9, 144}$ =1.31 | 0.239 | $F_{9, 32}$ =0.69 | 0.712 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =0.12 | 0.947 | $F_{3, 64}$ =1.86 | 0.144 |
| Time | $F_{3, 144}$ =0.37 | 0.776 | $F_{3, 64}$ =0.21 | 0.892 |
| Conc. x Time | $F_{9, 144}$ =0.45 | 0.906 | $F_{9, 64}$ =0.29 | 0.976 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =0.22 | 0.880 | $F_{3, 80}$ =0.28 | 0.843 |
| Time | $F_{3, 144}$ =2.33 | 0.077 | $F_{3, 80}$ =1.85 | 0.145 |
| Conc. x Time | $F_{9, 144}$ =0.30 | 0.973 | $F_{9, 80}$ =1.72 | 0.098 |

Note: Conc. = Concentration

**Table 3.4: Effect of hexanal concentration and time of application on orange varieties fruit diameter**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ =1.42 | 0.241 | $F_{3, 32}$ =0.93 | 0.437 |
| Time | $F_{3, 144}$ =1.07 | 0.364 | $F_{3, 32}$ =0.69 | 0.568 |
| Conc. x Time | $F_{9, 144}$ =1.35 | 0.215 | $F_{9, 32}$ =0.76 | 0.652 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =0.85 | 0.469 | $F_{3, 64}$ =0.39 | 0.759 |
| Time | $F_{3, 144}$ =0.89 | 0.450 | $F_{3, 64}$ =0.19 | 0.900 |
| Conc. x Time | $F_{9, 144}$ =0.43 | 0.918 | $F_{9, 64}$ =0.27 | 0.980 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =1.13 | 0.338 | $F_{3, 80}$ =0.03 | 0.994 |
| Time | $F_{3, 144}$ =0.81 | 0.492 | $F_{3, 80}$ =0.03 | 0.994 |
| Conc. x Time | $F_{9, 144}$ =0.57 | 0.818 | $F_{9, 80}$ =0.77 | 0.648 |

Note: Conc. = Concentration

## 3.4 Discussion

Results of the current study show that hexanal improved orange fruit firmness compared to untreated fruits of Early Valencia, Jaffa and Late Valencia. The Firmness of fruits of Early Valencia, Jaffa and Late Valencia varieties were significantly lower in control compared to hexanal treated fruits. The time of hexanal application had no significant effects on fruit firmness. Previous studies also reported that hexanal application increased fruits firmness of mango, peach, pear and apple (Sousa *et al.*, 2007; Shen *et al.*, 2014; Anusuya *et al.*, 2016). Hexanal application increases fruit firmness by slowing down fruit ripening and increasing fruit freshness (Sousa *et al*., 2007; Anusuya *et al*., 2016), strengthening cell wall structure of the fruit (Ahemand and Kibret, 2014; Wang *et al*., 2014) and inhibiting phospholipase D (PLD), which is involved in fruit deterioration (Paliyath and Murr, 2007; Sholberg and Randall, 2007; Yadar *et al*., 2013; Karthika *et al*., 2015; Anusuya *et al*., 2016). As a result of hexanal application, fruit membrane remains stable, and fruit firmness increases and ripening is delayed (Sholberg and Randall, 2007; Anusuya *et al*., 2016). Kumar *et al*., (2018) reported that hexanal formulation induced a highly significant reduction in transcript levels of three PLD genes, five N-glycoprotein group genes, and other genes involved in ripening and softening processes. The study indicated that a delay in the ripening process caused by hexanal formulation may be associated with the modulation of the expression of key ripening related genes, enhancing shelf life and quality of nectarines. Fruit firmness is a metric of fruit textural quality, organoleptic taste and longevity after harvest (En-Tai *et al*., 2014). Moreover, fruit firmness is the best indicator of ripening changes and predictor of bruising potential (Valero *et al.,* 2003). Furthermore, when hexanal is sprayed on plants, fruits and trees before the set of ripening and it keeps the fruit a little bit longer on tree and also a very gradually slows down the ripening process. Fruit membrane remain intact and stable and ripening is slowly delayed so fruits remain fresh and firm for longer (Sholberg and Randall, 2007; Anusuya *et al*., 2016).

The present study also found that that application of hexanal increased fruit marketable yields of Early Valencia, Jaffa and Late Valencia varieties than the untreated fruits. Similar results were reported on mango, peach, apple and pear (Paliyath and Murr, 2007; Karthika *et al*., 2015; Anusuya *et al*., 2016). Marketable yield is characterized by fruit freshness, absence defects (e.g pest and disease, cracks and bruising) on peel. Researchers have found that hexanal application strengthens fruit skin (Jarimopas and Kitthawee, 2007; Karthika *et al*., 2015) and membrane stability which results in increased fruit freshness for longer period (Sholberg and Randall, 2007; Anusuya *et al*., 2016). Hexanal has been found to downregulate the expression of PLD, and other several ripening related genes resulting in marketable yield of fruits such as apple, sweet cherry, guava, strawberry (Paliyath and Subramanian, 2008). It is also reported that application of hexanal increases marketable yield by inhibiting enzyme PLD, which enhances fruit deterioration (Karthika *et al*., 2015). We have observed that application of hexanal increased fruit marketable yields of 'Early Valencia', 'Jaffa' and 'Late Valencia' varieties than the untreated fruits. These results are supported by previous studies in which hexanal application also increased in net fruit marketable yield of mango, peach, apple and pear (Paliyath and Murr, 2007; Karthika *et al*., 2015; Anusuya *et al*., 2016).

The results show hexanal concentration has no significant effects to fruit weight ($p > .05$) and diameter ($p > .05$) for Early Valencia ("Msasa"), Jaffa and Late Valencia varieties treated independently. Shen*et al*. (2014) also reported that pre-harvest fruit weight is not affected by hexanal spray on peach fruit. However, reduction of fruit drop and maintained fruit retention on trees for orange varieties treated with hexanal was expected increased more competition for resources and thus reduce fruit size (weight and diameter). Brummell (2018) states that despite complexities of fruit growth and development there is some overall consistencies in patterns of cell division and enlargement, as well as tissue differentiation and enlargement. Fruit can increase mass (weight), volume, and length from fertilization to maturity. Furthermore, there is usually a positive correlation between the number of seed and fruit size (weight and diameter) and such interdependence between development and fruit growth shows up in final stage of fruit size as the fruit become mature prior to ripening.

### 3.5 Conclusions and Recommendations

The objective of this study was to determine the effect of hexanal treatment on market fruit attributes of orange varieties grown in Tanzania. It is concluded that hexanal application at 0.01% improves fruit firmness and marketable yield of orange Early Valencia, Jaffa and Late Valencia varieties. It is recommended that farmers should pre harvest treat Early Valencia, Jaffa and Late Valencia orange with hexanal concentration of 0.01% from 42 to 7 days to harvest in order increase fruit firmness and marketable yield. Further studies are required to determine the effects of pre-harvest hexanal application on keeping quality of orange fruits after harvest.

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# CHAPTER FOUR

## EFFECTS OF PRE-HARVEST HEXANAL APPLICATION ON MARKET ATTRIBUTES OF MANGO FRUIT IN EASTERN ZONE OF TANZANIA

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## ABSTRACT

Studies were conducted to determine the effects of field application of hexanal on pre-harvest market attributes of mango (*Mangifera indica* L.) fruits. The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement using farmers' mango orchards. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days to harvest) assessed in mango varieties Apple, Palmer and Keitt. A fruit tree for each mango variety constituted a treatment for hexanal application and time of its application prior to fruit harvest. The results show that hexanal application at 0.01, 0.02 and 0.04% equally improved fruit marketable yields by increasing fruit firmness and marketable yield of Apple, Palmer and Keitt varieties. Marketable yield increased by

24.54, 19.64 and 20.40% over the controls for Apple, Palmer and Keitt, respectively. Similarly, fruit firmness increased 11.19, 9.97 and 10.05 $N/mm^2$ over the control for Apple, Palmer and Keitt, respectively. It is recommended that farmers should treat Apple, Palmer and Keitt mango varieties with hexanal at 0.01% from 42 to 7 days to harvest in order to increase fruit firmness and marketable yield.

**Key word:** Hexanal, Apple, Palmer, Keitt, Pre-harvest, Market attributes, Firmness, Marketable yield.

## 4.1 Introduction

Mango (*Mangifera indica* L.) is a tropical fruit tree which produce fruits with various varieties colour including orange, red, green, and yellow. Mango has been cultivated for centuries and is an important crop in tropical regions. The global production reached 43 million metric tons (Pariona, 2017). Mangoes are grown in more than 100 countries. It plays an integral part in lives of many, not only by being a rich source of nutrients but also as source of livelihood for millions of people in the ropics (Mitra, 2016). In recent years, mangoes have become well established as a fresh fruit and processed product in global market. World demand for mango is ascertained to be increased particularly from temperate countries where mangoes are rapidly gaining popularity (Mitra, 2016).

Mango is one of the most popular fruit produced in Tanzania (MMA, 2008, Ihueze and Mgbemena, 2017). Tanzania ranks 17$^{th}$ wordwide in mango production. There are about 33 532 ha producing 434 344 mt per annum with average yield is 12.95 mt/ha (FAOStat, 2017; MMA, 2017). The productivity of mango in Tanzania is lower than the average productivity reported worldwide. According to NBS (2008) productivity of mango in Tanzania is 7.67 mt/ha while mango productivity in India, Thailand and China are 8.39, 8.36 and 8.14 mt/ha, respectively (FAO, 2017; TDR, 2018). The low productivity of mango is largely caused by flower and fruit drops (Atherton, 2011). Various attempts have been made to improve fruit set, retention on trees and quality, including exogenous application of plant growth regulators, nutrients and pesticides but their wider application is limited by small-scale fruit growers because they are not economically and technologically viable (Ezura and Hiwasa-Tarase, 2010; Khandaker *et al*., 2011; Ahemad and Kibret, 2014; Wang *et al.*, 2014; Baietto and Wilson, 2015; Oosthuyse and Berrios, 2015).

Recently, field application of hexanal was reported to be the most effective techniques comparing with the other technique for reduction premature of fruit drop, superficial scald, fungal infection, and for increase of fruit firmness, freshness and fruit retention on trees of various fruits namely apple, cherry, longan, mangoes, straw berry, guava and tomato (Subramanian *et al.*, 2014; Karthika *et al*., 2015; Anusuya *et al*., 2016). Hexanal is an alkyl aldehyde with the molecular formula $C_6H_{12}O$ compound that acts as a strong inhibitor of phospholipase-D action, and thus slows down ethylene stimulation of ripening processes (Subramanian *et al.*, 2014; Karthika *et al.*, 2015). The effectiveness of hexanal is dependent on hexanal concentration, treatment duration and the sensitivity of fungal pathogen to hexanal (Song *et al*., 2010; Shen *et al*., 2014). However, there is limited information on the effect of hexanal application on marketable yield and quality of mango varieties grown in Tanzania. Therefore, the objective of this study was to determine the effect of pre-harvest hexanal application on fruit market attributes of mango varieties grown in Tanzania.

## 4.2 Materials and Methods

### 4.2.1 Description of study area and mango varieties

The study was carried out at Kise and Mwarusembe villages in Kiparanganda and Mwarusembe wards, respectively in Mkuranga district, Coast region. Kise village is located at altitude, latitude and longitude of 95.20 m asl, 7$^o$9'22.296"S and 39$^o$5'5.382"E, respectively) and Mwarusembe village is located at altitude, latitude and longitude of 58.30 m, 7$^o$14'35.172"S and 3905'42.690"E, respectively. These sites had the same agro-climatic conditions, with rainfall of 800 to 1000 mm per annum and average temperature of 28$^o$C per year. The rainfall is a bimodal with the long rains period between March and May and short rains period between October and December (DED, 2017). The study was conducted using already established and well managed mango farms belonging to famers. Three mango varieties were selected for the study namely Apple, Palmer and Keitt.

Apple is a medium maturing variety and produces medium to large (280 – 580 g) fruits, which are less affected by anthracnose and powdery mildew diseases (TFNet, 2011). Palmer is late maturing variety, consistent flowerer, sets a lot of fruit but its flowering is erratic, which often results in low yields (Kansci *et al.*, 2008; TFNet, 2011). Keitt is the late maturing variety, and has high productivity and procudes fruits with good marketing qualities. Moreover, the variety has the largest fruits (567 - 737 g) which are fairly firm and have long shelf life (Kansci *et al.*, 2008; TFNet, 2011; Jonathan, 2017).

### 4.2.2 Experimental design

The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement using well established and maintained farmers' mango orchards. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days to harvest) assessed in mango varieties Apple, Palmer and Keitt. The experiment was conducted in two seasons (first season from October, 2016 to January, 2017; second season from October, 2017 to January, 2018). A fruit tree for each mango variety was taken as a treatment for hexanal application and time of its application prior to fruit harvest. A treatment was repeated ten times. Hexanal at the above concentrations and its time of application was manually sprayed on mango fruits using a knapsack sprayer. Hexanal was sprayed on fruits until the solution dripped from them. Untreated mango fruits for each variety were used as controls.

### 4.2.3 Data collection and analysis

Hexanal treated and untreated mango fruits were harvested at physiological maturity stage according to Brecht (2010). Fifteen fruits were harvested per tree (treatment) (Roscoe, 1975). During harvesting, the fruits were selected using a simple random method.

Data on marketable attributes of mango varieties collected were fruit firmness, fruit weight, fruit diameter and number of marketable yields per tree. Fruit firmness was measured from 15 mango fruits using penetrometer with a plunger diamter of 8 mm (Wagner instruments-Greenwich CT). Fifteen mango fruits were weighed using digital balance (Kenwood Weighing Scales DS400). Fruit diameter was measured from 15 fruits by using digital caliper (New Type LCD Reading Long Jaw Internal Diameter Digital Vernier Callipers). The marketable yield was determined by selecting mango fruits from all harvested on the treatment without damage, disease and pests defects, which affect their appearrance, edibility and keeping quality (OECD, 2010).

Two way ANOVA was used to analyse data using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5% probability. The sources of variation were hexanal concentration and time of application prior to harvest. Independent analyses were done for each variety during each season.

## 4.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on market attributes of mango are presented below. Independent analyses were performed for each variety and during season. Results are conveniently reported together in the same sections.

### 4.3.1 Effects of hexanal on Fruit Firmness at Harvesting

Hexanal concentrations significantly increased firmness of fruits of Apple, Palmer and Keitt varieties during both trial seasons. However, time of hexanal application insignificantly affected fruit firmness of all three mango varieties in both seasons. The effects of concentration x time to harvest were non-significant for all three varieties during both seasons (Table 4.1). Further analysis of the main means showed that hexanal concentration significantly affected firmness of fruits of Apple, Palmer and Keitt varieties during both seasons regardless of time of application. Compared to control, hexanal concentration significantly increased fruit firmness of Apple, Palmer and Keitt by up to 3.41, 5.14 and 5.55 N/mm$^2$ respectively during first season and by up to 11.19, 9.97 and 10.05 N/mm$^2$ respectively during second season (Figures 4.1, 4.2 and 4.3).

**Table 4.1: Effect of hexanal concentration and time of application on mango firmness**

| **Effects** | **First season** | | **Second season** | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108}$ =2.86 | 0.040 | $F_{3, 144}$ =2280.30 | <0.001 |
| Time | $F_{2, 108}$ =0.48 | 0.621 | $F_{3, 144}$ =1.37 | 0.255 |
| Conc. x Time | $F_{6, 108}$ =0.50 | 0.806 | $F_{9, 144}$ =2.31 | 0.069 |

| | | | | |
|---|---|---|---|---|
| **Palmer** | | | | |
| Conc. | $F_{3, 108}$ =81.03 | <0.001 | $F_{3, 96}$ =370.07 | <0.001 |
| Time | $F_{2, 108}$ =0.38, | 0.687 | $F_{3, 96}$ =0.26 | 0.855 |
| Conc. x Time | $F_{6, 108}$ =0.55 | 0.768 | $F_{9, 96}$ =1.22 | 0.294 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144}$ =91.19 | <0.001 | $F_{3, 80}$ =76.40 | <0.001 |
| Time | $F_{3, 144}$ =0.94 | 0.425 | $F_{3, 80}$ =1.01 | 0.394 |
| Conc. x Time | $F_{9, 144}$ =1.09 | 0.376 | $F_{9, 80}$ =1.04 | 0.418 |

Note: Conc. = Concentration

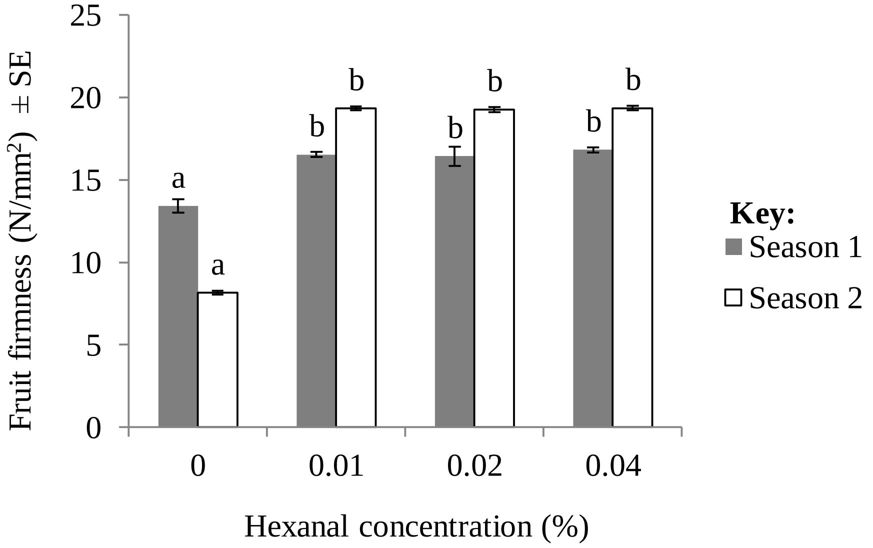


**Figure 4.1: Mean of firmness of fruits of Apple mango variety during first season ($F_{(3, 36)}$ = 40.38, $P$ < 0.001) and second season ($F_{(3, 36)}$ = 1767.50, $P$ < 0.001) Post Hoc test = Tukey HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

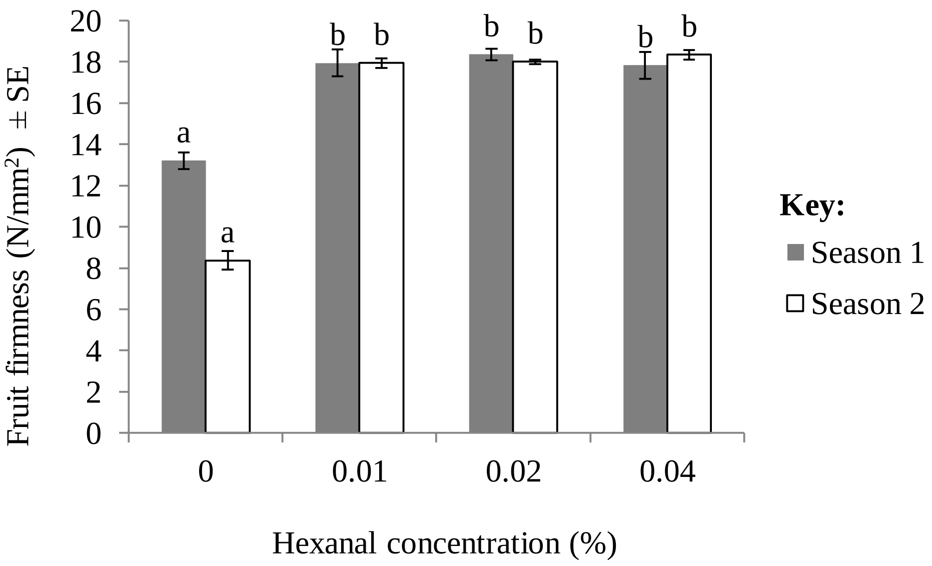

**Figure 4.2: Mean of firmness of Palmer mango variety during first season ($F_{(3, 36)}$ = 21.21, $P$ < 0.001) and second season ($F_{(3, 23)}$ = 268.34, $P$ < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same column bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

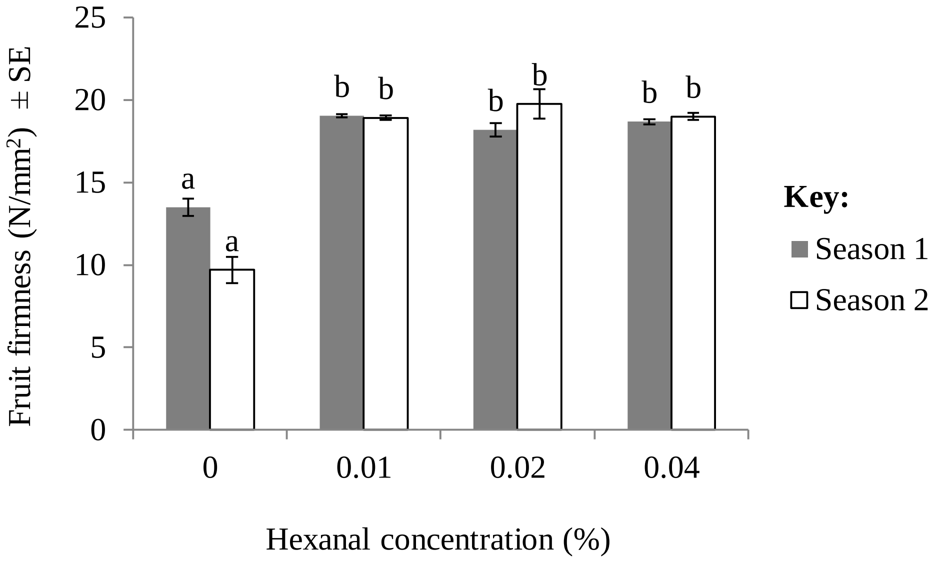


**Figure 4.3: Mean of firmness of Keitt mango variety during first season ($F_{(3, 36)}$ = 57.66, $P$ < 0.001) and second season ($F_{(3, 20)}$ = 60.46, $P$ < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 4.3.2 Effects hexanal on number of marketable yield

The recorded significantly higher number of marketable fruits of Apple, Palmer, Keitt varieties exposed to different concentrations of hexanal. However, time of hexanal application significantly affected number of marketable fruits of Palmer variety during the second season only. The effects of concentration x time to harvest were non-significant for all three varieties during both seasons (Table 4.2). Main effects of hexanal concentration on number of marketable fruits were significant on all three mango varieties during both seasons regardless of time of application. Marketable yield of Apple, Palmer and Keitt fruits significantly increased by up to 9.83%, 15.26%, 13.90% during first season and by up to 24.54, 19.64 and 20.40% respectively during second season, compared to control.

However, marketable yield on fruits among trees exposed to different concentrations of hexanal were not significantly different (Figures 4.4, 4.5 and 4.6).

**Table 4.2: Effect of hexanal concentration and time of application on mango marketable yield**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108}$ =6.41 | <0.001 | $F_{3, 144}$ =211.04 | <0.001 |
| Time | $F_{2, 108}$ =0.26 | 0.771 | $F_{3, 144}$ =1.27 | 0.286 |
| Conc. x Time | $F_{6,108}$ =0.40 | 0.879 | $F_{9, 144}$ =1.40 | 0.193 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108}$=6.96 | <0.001 | $F_{3, 96}$=58.39 | <0.001 |
| Time | $F_{2,108}$=0.09 | 0.911 | $F_{3, 96}$ =7.66 | <0.001 |
| Conc. x Time | $F_{6, 108}$ =0.59 | 0.738 | $F_{6, 96}$ =0.38 | 0.940 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144}$ =8.88 | <0.001 | $F_{3, 80}$=45.78 | <0.001 |
| Time | $F_{3, 144}$ = 0.78 | 0.509 | $F_{3, 80}$=1.91 | 0.135 |
| Conc. x Time | $F_{9, 144}$ = 0.37 | 0.950 | $F_{9, 80}$ =0.34 | 0.960 |

Note: Conc. = Concentration

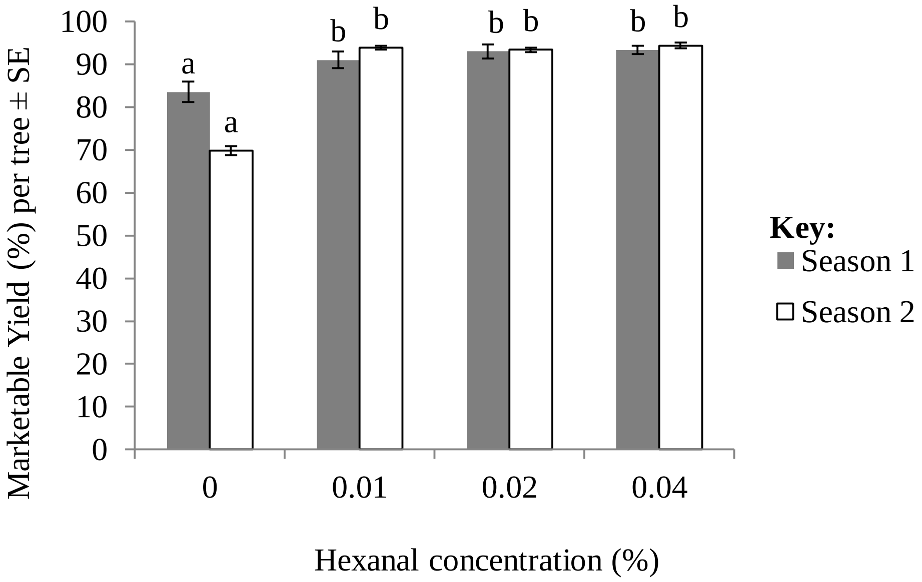


**Figure 4.4: Mean of marketable yield of Apple mango variety during first season ($F_{(3, 36)}$ = 6.54, $P$ = 0.001) and second season ($F_{(3, 36)}$ = 281.73, $P$ < 0.001), Post Hoc Tukey HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

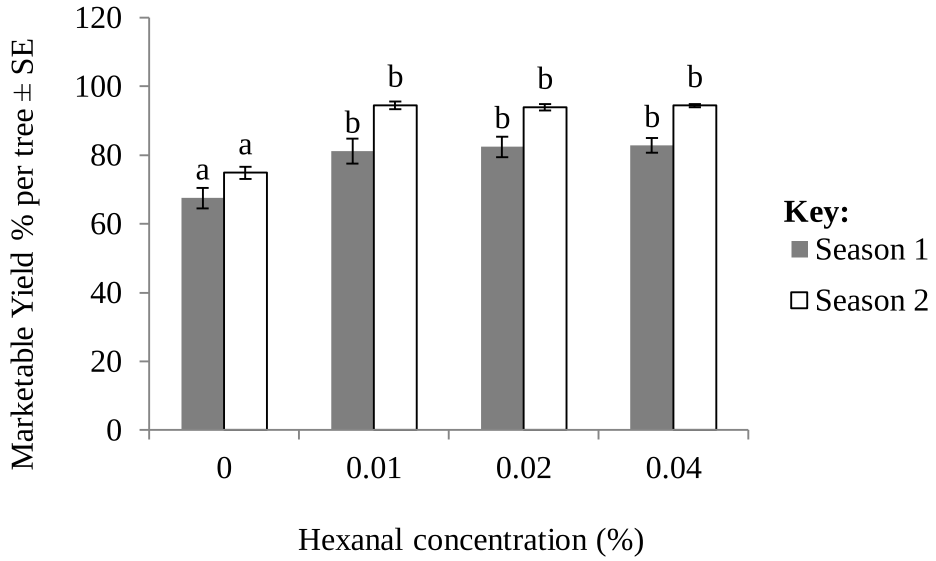


**Figure 4.5: Mean of marketable yield of Palmer mango variety during first season ($F_{(3, 36)} = 5.38$, $P = 0.004$) and second season ($F_{(3, 23)} = 64.99$, $P < 0.001$), Post Hoc Tukey HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

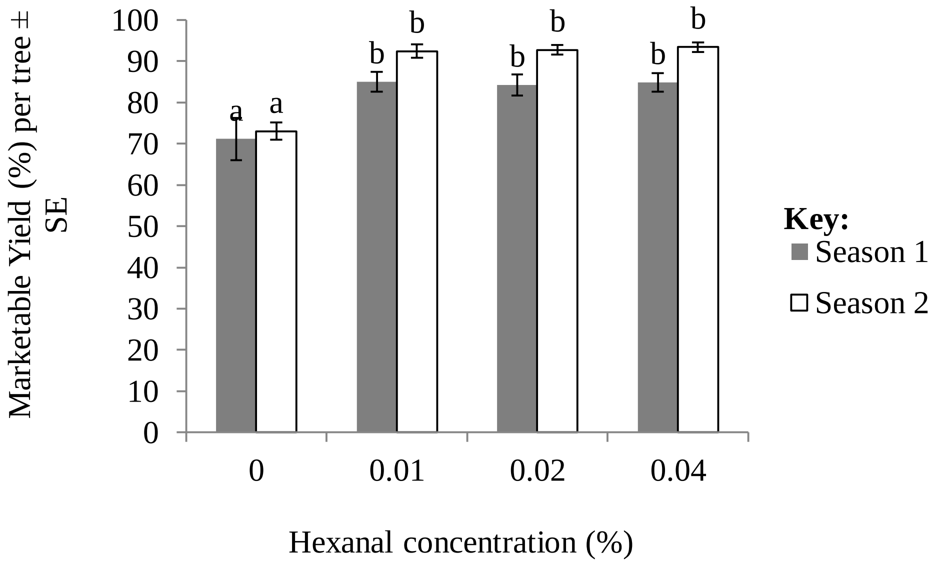


**Figure 4.6: Mean of marketable yield of Keitt mango variety during first season ($F_{(3, 36)} = 3.75$, $P = 0.019$) and second season ($F_{(3, 23)} = 0.73$, $P = 0.034$), Post Hoc Tukey HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 4.3.3 Effects of hexanal concentration and time of application on fruit weight and size

There was not recorded significant effects of hexanal concentration, time of its application prior to fruit harvest and the interaction between hexanal concentration and its time of application prior to fruit harvest on weight and diameter of fruits of Apple, Palmer and Keitt varieties (Table 4.3 and 4.4). Fruit weight ranged from 155.03 to 536.93 g for Apple, 413.72 to 590.80 g Palmer and 360.69 to 710.86 g for Keitt. While fruit diameter ranged from 6.23 to 8.32 cm for Apple, 6.66 to 8.32 cm for Palmer and 8.32 to 9.42 cm for Keitt

**Table 4.3: Effect of hexanal concentration and time of application on mango fruit weight**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108}$ =0.65 | 0.583 | $F_{3, 144}$ =1.12 | 0.342 |
| Time | $F_{2, 108}$ =0.56 | 0.573 | $F_{3, 144}$ =1.19 | 0.317 |
| Conc. x Time | $F_{6, 108}$ =0.61 | 0.723 | $F_{9, 144}$ =0.80 | 0.616 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108}$ =0.07 | 0.976 | $F_{3, 96}$ =1.40 | 0.246 |
| Time | $F_{2, 108}$ =0.56 | 0.576 | $F_{3, 96}$ =1.74 | 0.164 |
| Conc. x Time | $F_{6, 108}$ =0.40 | 0.878 | $F_{9, 96}$ =0.74 | 0.674 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144}$ =0.81 | 0.491 | $F_{3, 80}$ =0.47 | 0.705 |
| Time | $F_{3, 144}$ =0.75 | 0.524 | $F_{3, 80}$ =0.51 | 0.677 |
| Conc. x Time | $F_{9, 144}$ =0.35 | 0.956 | $F_{9, 80}$ =1.16 | 0.332 |

Note: Conc. = Concentration

**Table 4.4: Effect of hexanal concentration and time of application on mango fruit diameter**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108}$ =0.31 | 0.818 | $F_{3, 144}$ = 0.36 | 0.786 |
| Time | $F_{2, 108}$ =0.70 | 0.497 | $F_{3, 144}$ = 0.09 | 0.963 |
| Conc. x Time | $F_{6, 108}$ =0.69 | 0.660 | $F_{9, 144}$ = 0.12 | 0.999 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108}$ =1.03 | 0.382 | $F_{3, 96}$ = 0.29 | 0.835 |
| Time | $F_{2, 108}$ =0.35 | 0.707 | $F_{3, 96}$ = 0.65 | 0.583 |
| Conc. x Time | $F_{6, 108}$ =0.75 | 0.607 | $F_{9, 96}$ =1.06 | 0.397 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144}$ =0.22 | 0.880 | $F_{3, 80}$ =1.03 | 0.385 |
| Time | $F_{3, 144}$ =1.04 | 0.377 | $F_{3, 80}$ =1.45 | 0.235 |
| Conc. x Time | $F_{9, 144}$ =0.53 | 0.848 | $F_{9, 80}$ = 0.87 | 0.554 |

Note: Conc. = Concentration

## 4.4 Discussion

The study found that hexanal sprays significantly increased fruit firmness of Apple, Palmer and Keitt mango varieties compared to untreated. However, firmness was not significantly affected by time of hexanal application. Fruit firmness is influenced by the physiological development, degree of ripeness, damage and turgidity and it is an attribute, which has to be maintained throughout from the field to the final user (Sousa *et al*., 2007). Fruit softening is caused by cell wall disassembly and the reduction of cell to cell adhesion, as a result of middle lamella dissolution (Brummell and Harpster, 2001; Brummell, 2006). The significant modifications in the cell wall structure leading to loss of firmness include the depolymerization of matrix glycans, the solubilisation and (or) depolymerization of pectins, and the loss of neutral sugars from side chains of pectins (Brummell 2006; Goulão and Oliveira, 2008). Martinez-Romero *et al*. (2006) reported a linear correlation between turgor pressure and firmness in sweet cherries. Hexanal inhibits phospholipase D (PLD) enzyme which is responsible for breaking cell membranes during a fruit ripening process (Karthika *et al*., 2015). According to Kumar *et al*. (2018) hexanal inhibits PLD and related enzymes (Subramanian *et al*., 2014; El Kayal *et al*., 2017; Tridjaja and Mahendra, 2000), thus ensures membrane integrity and enhances fruit firmness. PLD causes membrane deterioration through catalysing the hydrolysis of phospholipids, which maintain cell viability and homeostasis into phosphatidic acid (Dawidowicz, 1987; Exton, 1997). Suppressing such enzymes in fruit tissues considerably reduces the softening rate, improves fruit quality and extends shelf life (Brummell *et al*., 1999; Sesmero *et al*., 2007, 2009; Meli *et al*., 2010). Cheema *et al*. (2014) reported that hexanal treatment resulted in down regulation of genes involved in ethylene biosynthesis and signal transduction processes, cell wall breakdown and lipid metabolism. Also El Kayal *et al*. (2017) reported that hexanal application could eventually suppress the PLD activity and which enhance membrane stability and thereby increased longevity as it was observed in raspberry fruit.

The increased fruit firmness of a fruit as a result of hexanal application is due to increased fruit membrane strength and stability, and slow ripening process caused by slower respiration and ethylene evolution rates (Martinez-Romero, 2006; Anusuya *et al*., 2016). Exogenous application of hexanal slowed down the lipogenase in the skin of the fruit which would have assisted in delayed ripening process Anusuya *et al*. (2016). Increase in firmness results in slow softening, reduced mechanical damage and extended shelf life (Valero *et al.*, 2003). Therefore, this extends the longevity of the fruits in the field and when harvested. According to Brecht (2010) firmness of a fruit is linked to the state of matury and ripeness and may be infuluenced by the variety as well as region of production and the growing conditions. Baietto and Wilson (2015) stated that one of the most important quality features of any fruit species or variety is the duration or longervity that optimal fruit characteristics can be maintained prio to decline an unsalble state which is determined by firmness. Fruit firmness is the best indicator of ripening changes and predictor of bruising potential and it must use to control ripening at the retail ends (Valero *et al.*, 2003), but also reduces damages to fruits as the skin firm for external damage resistance (Cheema *et al*., 2014). The results from the present study further confirms that hexanal application increased fruit firmness as previously reported (Sholberg and Randall, 2007), peach (Shen *et al*., 2014), mango (Anusuya *et al*., 2016) and sweet cherries (Martinez-Romero *et al*., 2006).

Results from the present study also show that pre-harvest application of hexanal significantly increased marketable yield of Apple, Palmer and Keitt mango varieties. Similar finding were earlier reported in sweet cherry, peach, apple and pear (Karthika *et* *al*., 2015; Anusuya *et al*., 2016). Marketable yield is composed by extended shelf life (high firm) and free from disease and pest damage. The increase in marketable yield is largely due to a drastic reduction of disease infections (Ahemad and Kibret, 2014; Wang *et al*., 2014). The decrease in disease infections as a result of hexanal application was previously attributed to increased fruit cell wall biosynthesis and membrane strength and stability (Sharmer *et al*., 2010). Karthika *et al*. (2015) reported that hexanal effectively prevented browning reaction reduced premature fruit drop, reduce superficial scald and increase firmness in apple fruit. Hexanal enhanced firmness in sweet cherry which determines quality and shelf life as marketable to consumers. The physiological mechanisms such as inhibition of phospholipase D and slowing down ethylene evolution that may have contributed for the shelf-life extension of tropical fruits like mango which increase marketability of fruits (Anusuya *et al*., 2016).

The study results of hexanal concentration on fruit weight and diameter of Apple, Palmer and Keitt mango varieties had non-significant effects. The study in chapter 7 showed that hexanal concentrations retain fruits by reducing fruit drop on treated mango varieties. Therefore, that causes more fruits per tree which leads to more competition of nutrients and results non significant of hexanal on fruit weight and diameter. Also, Anusuya *et al*. (2016) reported that fruit weight of mango at harvested from sprayed and unsprayed fruit trees did not differ at harvesting stage. Also, Shen *et al*. (2014) reported that weight of the peach were non-significant with hexanal at harvesting stage.

## 4.5 Conclusions and Recommendations

The objective of this study was to determine the effect of pre-harvest hexanal application on fruit market attributes of mango varieties grown in Tanzania. It is concluded that hexanal application at 0.01% increases fruit firmness and marketable yield by reducing pest-infected defects on mango fruits. It is recommended that farmers should treat mango fruits with hexanal 0.01% from 42 to 7 days before harvest in order increase fruit firmness and marketable yield. Further studies are required to determine the effects of pre-harvest hexanal application on keeping quality of mango fruits after harvest.

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# CHAPTER FIVE

## EFFECTS OF PRE-HARVEST HEXANAL FIELD APPLICATION ON FRUIT MARKETABLE YIELD AND QUALITY OF TOMATO FRUIT GROWN IN EASTERN ZONE OF TANZANIA

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**ABSTRACT**

As Tomato (*Lycopersion esculentum* Mill.) cultivars grown in Tanzania have narrow materials on the outcome of hexanal application on market yield and quality. The objective of this study was to determine the effects of pre-harvest application of hexanal on market yield and quality of tomato fruits. The experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A consisted of hexanal concentration (0.01, 0.02, 0.04% m/v and control - untreated fruits) and factor B consisted of time of hexanal application prior to fruit harvest (7, 14, 21 and 28 days to harvest) treated on tomato cv. Mwanga, Rio Grande and Tanya. A plot of 12 tomato plants constituted a treatment for hexanal concentration and time of its application prior to fruit harvest. Results show that pre-harvest hexanal application at 0.01, 0.02 and 0.04% equally improved fruit firmness and marketable yield of tomato cv. Mwanga, Rio Grande and

Tanya. Marketable yield increased by 23.38 and 23.10% over the controls for tomato cv. Mwanga and Rio Grande, respectively. Similarly, fruit firmness increased by 5.03, 5.77 and 5.19 N/mm$^2$ over the control for tomato cv. Mwanga, Rio Grande and Tanya, respectively. The time of hexanal application prior to fruit harvest and interactions between hexanal concentrations and time of application did not significantly affect fruit firmness and marketable yield of tomato cv. Mwanga, Rio Grande and Tanya. It is recommended that farmers should apply hexanal concentration 0.01% from 14 to 7 days before fruit harvest in order to improve fruit firmness and marketable yield of tomato cv. Mwanga, Rio Grande and Tanya.

**Key word:** Hexanal, Pre-harvest, Firmness, Marketable yield, Tomato, Mwanga, Rio Grande, Tanya.

## 5.1 Introduction

Tomato (*Lycopersion esculentum* Mill.) is widely grown all over the country in Tanzania (Mushobozi, 2010). Its total production accounts for 51% of total production of fruits vegetables and is higher than any other fruits vegetables produced in Tanzania (NBS, 2008). Tomato is cultivated all over the country with production of more than 962 684 tons in an area of 26 612 ha (MMA, 2017) with productivity ranging from 2.2 t/ha to 3.3 t/ha in Eastern zone (Minja *et al.*, 2011). This is far below the world average of 27.5 t ha$^{-1}$ (FAO, 2005). Tomato can be eaten either fresh or processed in different products (Ahmad *et al.*, 2007) and its nutritional value has made it one of the most popular production menus (BCSL, 2009). Tomato provides vitamin A, B and C, iron and phosphorus (Yilmaz, 2001; Sowley and Damba, 2013).

Growers look for tomato cultivars with high yields, firm and medium fruit size, and resistant to diseases (Barickman *et al.*, 2017). Flower and fruit drops are serious constraints in tomato production especially during hot season while diseases and insect pests are major constraints affecting yield and quality, especially during rainy season (Asgedom *et al*., 2011). The most popular techniques to reduce pre-harvest flower and fruit drops, and fruit defects include fungicide application prior to flowering, irrigation and fertilizer application during flowering and fruit development (Mertely *et al*., 2002; Bulletin, 2009). Application of calcium and magnesium fertilizers increases tomato fruit size, firmness and marketable yield (Hao and Paradopoulos, 2003). Application of hexanal is relatively new technology which has shown to be effective in reducing pest defects, extending shelf life and increasing fruit quality (Cheema *et al*., 2014). Hexanal, an inhibitor of phospholipase D, has been used for pre-harvest treatment of fruit and vegetables. Phospholipase D is a key enzyme involved in membrane deterioration that occurs during fruit ripening and senescence (Cheema *et al*., 2014).

Field application of hexanal was reported to be the most effective technique comparing with the other technique for reduction premature fruit drop, superficial scald, fungal infection, and for increase of fruit firmness, quality, freshness and fruit retention on trees of various fruits namely apple, cherry, longan, mangoes, straw berry, guava and tomato (Subramanian *et al*., 2014; Karthika *et al*., 2015; Anusuya *et al*., 2016). However, there is limited information on the effect of hexanal application on market yield and quality of tomato cultivars grown in Tanzania. Therefore, the objective of this study was to determine the effect of hexanal application on fruit market yield and quality of tomato cultivars grown in Tanzania.

## 5.2 Materials and methods

### 5.2.1 Description of study area and tomato cultivars

The study was carried out at Horticulture Unit of Sokoine University of Agriculture in Morogoro region. Horticulture Unit is located at altitude, latitude and longitude of 523.40

m asl, 6°50’41.478”S and 37°39’43.476”E, respectively. There are two rain seasons with short rains from October to January, and long rains from March to May. Annual precipitation ranges from 700 to 2 300 mm and temperatures from 18 to 30° C (ZP, 2016). Three tomato cultivars were selected for the study namely ‘Mwanga’, ‘Rio Grande’ and ‘Tanya’. Rio Grande is a popular early maturity cultivar (75 – 85 days from planting) with eating and excellent keeping quality (Ahmad *et al*., 2007; Jonathan, 2017). Tanya cultivar is characterized by early maturing and medium fruit size, which are highly firm and withstand long and rough transportation conditions (NTIF, 2018). Mwanga is an early maturity cultivar, high yielding and produces medium fruit size with moderate firmness (Testen *et al*., 2016).

### 5.2.2 Experimental design

The experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A consisted of hexanal concentrations (0.01, 0.02, 0.04% m/v and control - untreated fruits) and factor B consisted of time of hexanal application prior to fruit harvest (7, 14, 21 and 28 days). A plot with 11 tomato plant cultivar was taken as a treatment for hexanal concentration and its time of its application prior to fruit harvest. A treatment was repeated three times. The spacing per plot was 1 m and per replicate 1.5 m, plot size was 2.1 m x 2.8 m with 11 plants. Seedlings planted three weeks after sowing followed by other manegment practices of gap filling, application of pestsides, fungalsides, ferlitilizer and weeding. Hexanal was manually sprayed on tomato fruits until the solution dripped off using a knapsack sprayer. Untreated tomato fruits for each cultivar were used as controls.

### 5.2.3 Data collection and analysis

Tomatoes treated with hexanal and untreated per treatment were all harvested at ripening stage. Harvested tomato fruits in each treatment were sorted into marketable and non marketable fruits. Data on marketable attributes of tomato varieties were collected immediately after fruit harvest based on marketable yield. For fruit firmness, fruit diameter and fruit weight, fifteen tomatoes were randomly sorted and measured. Data on marketable yield was scored by counting tomato fruits with no damage, disease and insect pest defects, and serious deterioration. Fruit firmness was measured using a hand penetrometer with a plunger diameter of 8 mm plunger (Wagner instruments-Greenwich CT). Fruit weight was measured by using digital balance (Kenwood Weighing Scales DS400) and fruit diameter was measured by using digital caliper (New Type LCD Reading Long Jaw Internal Diameter Digital Vernier Callipers).

Two way ANOVA was used to analyse data using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5% probability. Independent analysis was carried out for each cultivar.

## 5.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on market attributes of tomato are presented below. Independent analyses were performed for each variety. Results are conveniently reported together in the same sections.

### 5.3.1 Effects of hexanal concentration on tomato fruit firmness

The effects of hexanal concentration on fruits firmness was significantly higher for Mwanga, Rio Grande and Tanya cultivars compared to controls. However, time of hexanal application and concentration x time to harvest were non-significant to fruit firmness of all three tomato cultivars (Table 5.1). Analysis of the main means showed a significant difference among treatments on Mwanga, Rio Grande and Tanya cultivar where by the results of hexanal concentration significantly increased fruit firmness on Mwanga, Rio Grande and Tanya cultivars by 5.03 N/mm$^2$ , 5.77 N/mm$^2$ and 5.19 N/mm$^2$ respectively compared to the untreated controls (Figures 5.1, 5.2 and 5.3).

**Table 5.1: Effects of hexanal concentration and time of its application on firmness of tomato fruits**

| Effects | *F* - ratio | *P* |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ = 23.54 | <0.001 |
| Time | $F_{3, 32}$ =0.85 | 0.477 |
| Conc. x Time | $F_{9, 32}$ =0.93 | 0.510 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =99.17 | <0.001 |
| Time | $F_{3, 32}$ =0.48 | 0.700 |
| Conc. x Time | $F_{9, 32}$ =0.58 | 0.807 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ =179.80 | <0.001 |
| Time | $F_{3, 32}$ =0.55 | 0.373 |
| Conc. x Time | $F_{9, 32}$ =1.13 | 0.373 |

Note: Conc. = Concentration

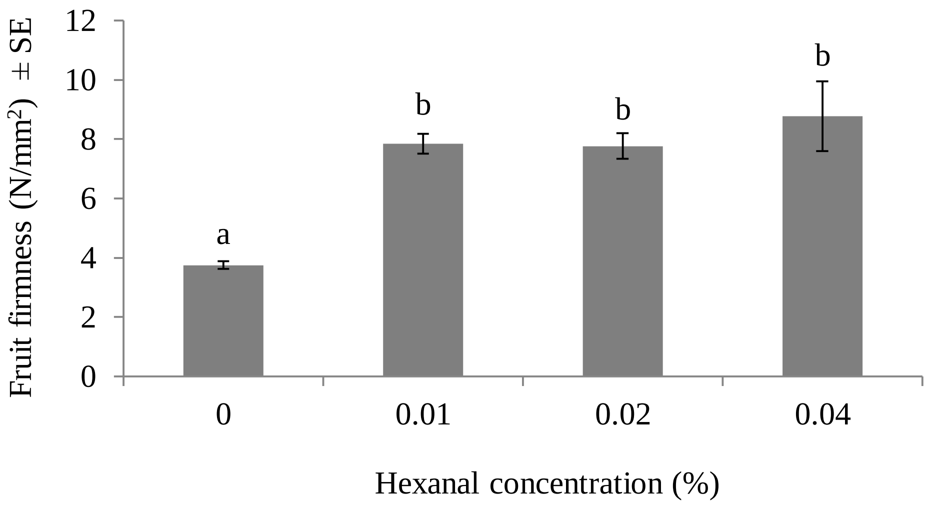


**Figure 5.1: Mean of fruit firmness of Mwanga tomato cultivar ($F_{(3, 8)}$ = 11.81, *P* =0.003), Post Hoc test = Tukey HSD** $_{(p=0.05)}$**.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

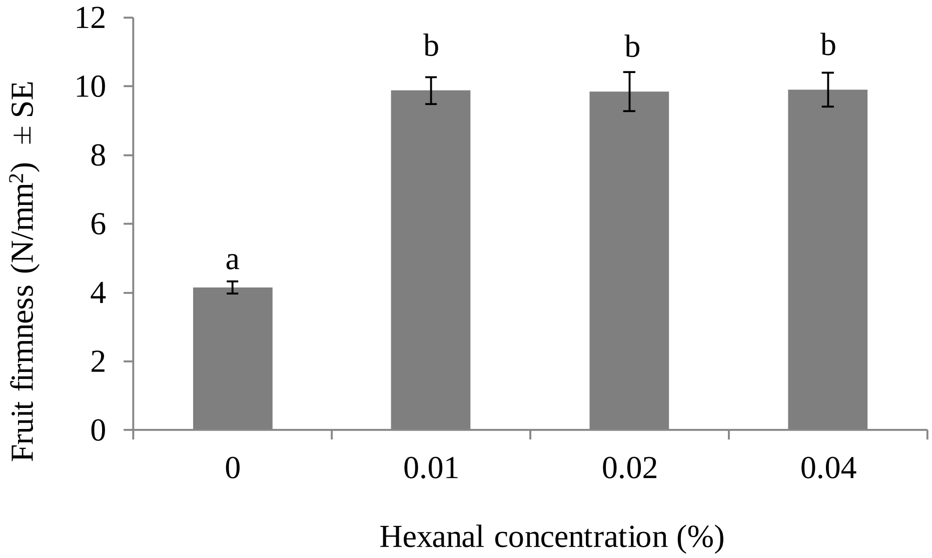


**Figure 5.2: Mean of fruit firmness of Rio Grande tomato cultivar ($F_{(3, 8)}$ = 44.29, $P$ <0 .001), Post Hoc test = Tukey HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

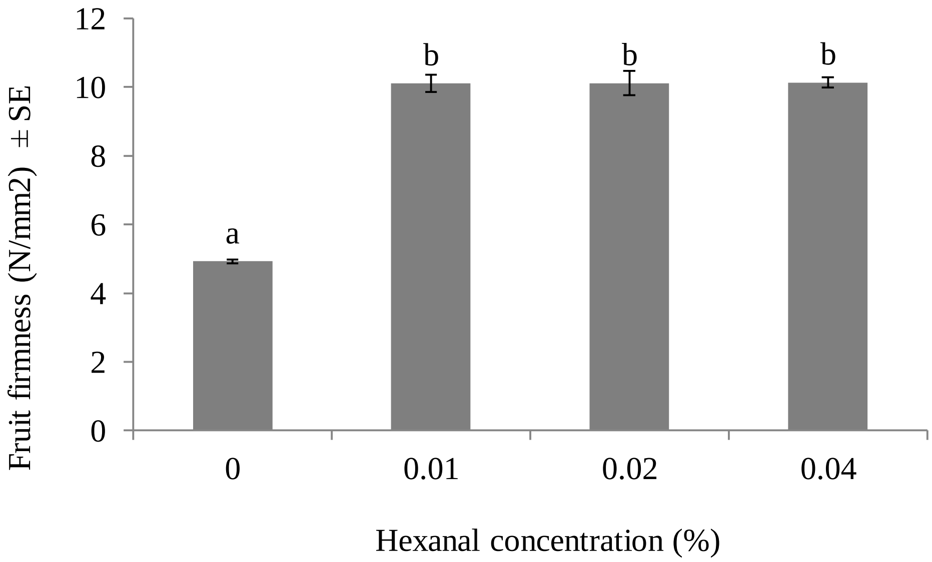


**Figure 5.3: Mean of fruit firmness of Tanya tomato cultivar ($F_{(3, 8)}$ = 126.61, $P$ < 0.001), Post Hoc test = Tukey HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 5.3.2 Effects of hexanal concentration on tomato fruit marketable yield

Results show that hexanal concentration significantly increased marketable yield of Mwanga and Rio Grande cultivars but insignificant effect for Tanya cultivar. However, the time of hexanal application prior to fruit harvest and the interaction between hexanal concentrations x its time of application prior to fruit harvest to fruit harvest did not significantly affect marketable yield of three treated tomato cultivars (Table 5.2). Analysis of the main means showed that hexanal concentration significantly affected fruit marketable yield of Mwanga and Rio Grande cultivars with an increase in fruit marketable yield by 23.38% and 23.10% respectively compared to the untreated fruits (Figures 5.4 and 5.5).

**Table 5.2: Effect of hexanal concentration and time of application on marketable yield of tomato fruits**

| **Effects** | ***F* - ratio** | ***P*** |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ =34.88 | <0.001 |
| Time | $F_{3, 32}$ =1.14 | 0.348 |
| Conc. x Time | $F_{9, 32}$ =0.32 | 0.963 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =76.28 | <0.001 |
| Time | $F_{3, 32}$ = 0.57 | 0.636 |
| Conc. x Time | $F_{9, 32}$ =0.77 | 0.641 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ =1.15 | 0.344 |
| Time | $F_{3, 32}$ =0.09 | 0.964 |
| Conc. x Time | $F_{9, 32}$ =1.39 | 0.233 |

Note: Conc. = Concentration

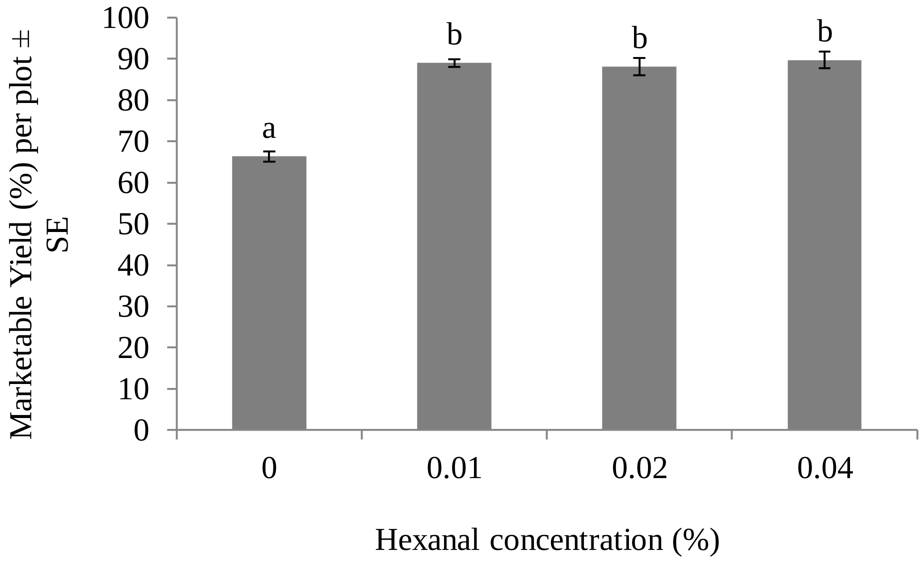


**Figure 5.4: Main mean of fruit marketable yield of Mwanga tomato cultivar ($F_{(3, 8)}$ = 46.76, $P$ < 0.001), Post Hoc test = Tukey HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

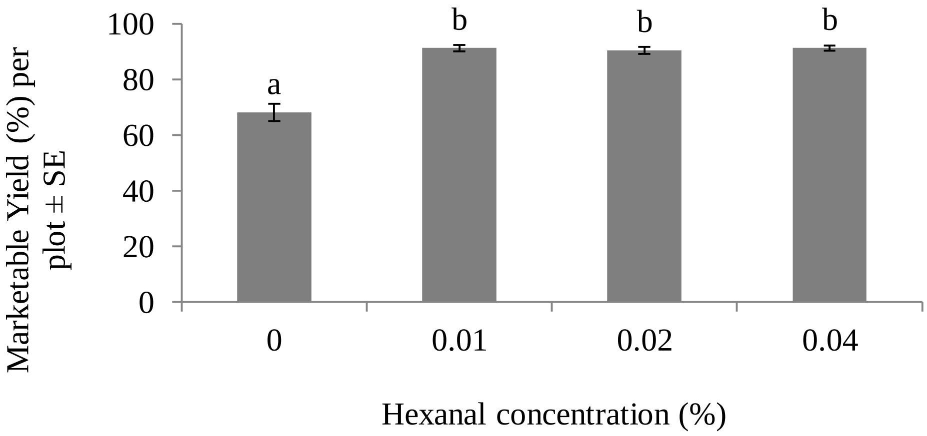


**Figure 5.5: Mean of fruit marketable yield of Rio Grande tomato cultivar ($F_{(3, 8)}$ = 39.05, $P$ < 0.001), Post Hoc test = Tukey HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 5.3.3 Effects of hexanal concentration and time of application on fruit weight and diameter

Results show that hexanal concentration, time of its application prior to fruit harvest and the interaction between hexanal concentration x its time of application prior to fruit harvest had no significant effects on weight and diameter of fruits of Mwanga, Rio Grande and Tanya cultivars (Tables 5.3 and 5.4). Fruit weight ranged from 62.05 to 91.91 g for

Mwanga, 68.81 to 85.30 g for Rio Grande and 59.91 to 85.65 g for Tanya. While fruit diameter ranged from 4.46 to 5.11 cm for Mwanga, 4.73 to 5.12 cm for Rio Grande and 4.69 to 5.82 cm for Tanya.

**Table 5.3: Effects of hexanal concentration and its time of application on weight of tomato fruits**

| Effects | *F* - ratio | *P* |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ =0.07 | 0.974 |
| Time | $F_{3, 32}$ =1.06 | 0.379 |
| Conc. x Time | $F_{9, 32}$ =1.06 | 0.415 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =0.72 | 0.545 |
| Time | $F_{3, 32}$ =0.38 | 0.769 |
| Conc. x Time | $F_{9, 32}$ =0.46 | 0.892 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ = 0.30 | 0.824 |
| Time | $F_{3, 32}$ =1.97 | 0.138 |
| Conc. x Time | $F_{9, 32}$ =0.83 | 0.590 |

Note: Conc. = Concentration

**Table 5.4: Effects of hexanal concentration and time of its application on Diameter of tomato fruits**

| Effects | *F* - ratio | *P* |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ =1.01 | 0.402 |
| Time | $F_{3, 32}$ =0.99 | 0.411 |
| Conc. x Time | $F_{9, 32}$ =1.08 | 0.402 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =1.01 | 0.399 |
| Time | $F_{3, 32}$ =0.30 | 0.828 |
| Conc. x Time | $F_{9, 32}$ =0.76 | 0.653 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ =1.10 | 0.364 |
| Time | $F_{3, 32}$ =0.40 | 0.753 |
| Conc. x Time | $F_{9, 32}$ =1.13 | 0.370 |

Note: Conc. = Concentration

## 5.4 Discussion

Results from the present study show that pre-harvest application of hexanal at 0.01% increases fruit firmness of treated tomato compared to the control while time of hexanal application had insignificant effects on tomato varieties. The increased tomato fruit firmness in this study is supported by Sharma *et al*. (2010), who also reported on increased fruit firmness and shelf life in cherry following pre-harvest hexanal application. Previous studies also reported that application of hexanal increased fruit firmness in apple, pears (Sholberg and Randall, 2007), peach (Shen *et al*., 2014) and mango (Anusuya *et al*., 2016). Fruit firmness is a metric of fruit textural quality, organoleptic taste and longevity after harvest (En-Tai *et al*., 2014). Firmness is an important quality of fresh tomatoes as delays fruit softening, increases fruit tolerance to rough handling practices, fruit retention on plants, delays fruit ripening, and extends fruit shelf life (Sholberg and Randall, 2007; Anusuya *et al*., 2016). Fruit firmness is influenced by the physiological development, degree of ripeness, damage and turgidity and it is an attribute, which has to be maintained throughout from the field to the final user (Sousa *et al*., 2007).

Hexanal application increases fruit firmness by drastically strengthening cell wall structures of the fruit (Ahemad and Kibret, 2014; Wang *et al*., 2014). The study indicated that a delay in the ripening process caused by hexanal formulation may be associated with the modulation of the expression of key ripening related genes, enhancing shelf life and quality of nectarines. Hexanal inhibits phospholipase D (PLD) enzyme which is responsible for breaking cell membranes during a fruit ripening process (Karthika *et al*., 2015). According to Kumar *et al*. (2018) hexanal inhibits PLD and related enzymes, thus ensures membrane integrity and enhances fruit firmness (El Kayal *et al.*, 2017). PLD causes membrane deterioration through catalysing the hydrolysis of phospholipids, which maintain cell viability and homeostasis into phosphatidic acid (Dawidowicz, 1987; Exton, 1997).

Pre-harvest application of hexanal at 0.01% increased significantly marketable yield of the three tomato cultivars. Marketable yield is composed by extended shelf life (high firm) and free from disease and pest damage. The increase in marketable yield is largely due to a drastic reduction of disease infections (Ahemad and Kibret, 2014). The increase in marketable yield in this study agrees with previous studies where application of hexanal significantly increased marketable yield of peach, apple and pear (Paliyath and Murr, 2007; Karthika *et al*., 2015; Anusuya *et al*., 2016). The high marketable yield as a result of hexanal application is largely due to reduced fruit drops in the orchard, and thus extended fruit retention on plants (Dek *et al*., 2018). Furthermore, researchers have found that hexanal application strengthens fruit skin (Jarimopas and Kitthawee, 2007; Karthika *et al*., 2015) and membrane stability which results in increased fruit freshness for longer period (Sholberg and Randall, 2007; Anusuya *et al*., 2016). Growth regulators that increase fruit retention on plants also improve fruit firmness for both fruit abscission and ripening are ethylene-mediated events in fruit development (Dek *et al*., 2018).

The results show hexanal concentration has no significant effects to fruit weight ($P > .05$) and diameter ($P > .05$) for of Mwanga, Rio Grande and Tanya tomato varieties treated independently. Previous studies have reported that fruit weight of mango harvested from sprayed and unsprayed fruit trees did not differ at harvesting stage of peach (Anusuya *et al*., 2016; Shen *et al*., 2014). However, reduction of fruit drop and maintained fruit retention on trees for orange varieties treated with hexanal was expected increased more competition for resources and thus reduce fruit size (weight and diameter). Brummell, (2018) states that despite complexities of fruit growth and development there is some overall consistencies in patterns of cell division and enlargement, as well as tissue differentiation and enlargement. Fruit can increase mass (weight), volume, and length from fertilization to maturity. Furthermore, there is usually a positive correlation between the number of seed and fruit size (weight and diameter) and such interdependence between development and fruit growth shows up in final stage of fruit size as the fruit become mature prior to ripening.

## 5.5 Conclusions and Recommendations

The objective of this study was to determine the effects of pre-harvest hexanal application on tomato marketable yield and quality. Pre-harvest hexanal application at 0.01% can remarkably increase tomato fruit firmness and marketable yield for Mwanga, Rio Grande and Tanya cultivars. It is recommended farmers should apply hexanal concentration 0.01% from 21 to 7 days prior to fruit harvest in order to reduce non-marketable yield and pest defects of tomato in Mwanga, Rio Grande and Tanya cultivars. Further studies are required to evaluate the effect of pre-havest hexanal application on keeping quality of tomato fruits after harvest. Further studies also required to determine the effect of hexanal application on fruit firmness and marketable yield of tomato cultivars during the dry season.

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# CHAPTER SIX

# EFFECTS OF PRE-HARVEST FIELD APPLICATION OF HEXANAL ON LOSSES OF ORANGE FRUITS IN EASTERN ZONE OF TANZANIA

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## ABSTRACT

The studied in three Orange (*Citrus sinensis* L.) varieties namely Early Valencia, Jaffa and Late Valencia on effect of hexanal. The objective of this study was to determine the effects of field application of hexanal on pre-harvest yield losses of orange (*Citrus sinensis* L.) fruits. The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits for Early Valencia, Jaffa and Late Valencia) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days). A fruit tree for each orange variety constituted a treatment for hexanal application and time of its application prior to fruit harvest. A treatment was replicated ten times. Results show that hexanal at 0.01% was statistically as effective as hexanal at 0.02 and 0.04% in reduction of number of dropped fruits ($p < .001$) , number of non-marketable yield ($p < .001$) and incidences of pest damage on orange fruits ($p < .001$). Hexanal at 0.01% reduced dropped fruits by 22.62, 37.73 and 46.31% compared to the untreated fruits (control) for Early Valencia, Jaffa and Late Valencia, respectively. Moreover, hexanal application at 0.01% decreased non-marketable by 21.39, 26.10 and 30.74% for Early Valencia, Jaffa and Late Valencia, respectively while incidences of pest damage was reduced by 21.59, 22.50 and 24.86% for Early Valencia, Jaffa and Late Valencia, respectively. The time of hexanal application prior to fruit harvest as well as the interactions between hexanal concentrations and its time application did not significantly affect the number of dropped fruits, number of non-marketable yield and incidences of pest damage on orange fruits. It is recommended that orange producers should apply hexanal at 0.01% from 42 to 21 days to harvest in order to improve marketable yield of orange Early Valencia, Jaffa and Late Valencia varieties.

**Key word:** Hexanal, Early Valencia, Jaffa, Late Valencia, Dropped fruits, Non-marketable yield, Incidences of pest damage

### 6.1 Introduction

Orange (*Citrus sinensis* L.) is one of the most important fruit crops due to distinct flavours, therapeutic and economic values of its fruits (Nawaz *et al.*, 2008). Orange production in Tanzania is 249 641 mt (MMA, 2017) from an area of 42 335 ha with an annual productivity of 4.67 tons/ha, respectively (NBS, 2008). Orange production is constrained by several factors but the major ones include premature and mature fruit drops, improper fertilizer application, too high temperature, unfavourable climatic conditions during fruit development periods such as drought and hail storms, incidences of serious diseases like powdery mildew and anthracnose, and insect pests like hopper and mealy bugs (Chattha *et al.*, 1999; Maqbool *et al.*, 2007).

Pre-harvest fruit drop is a major cause of low productivity of orange fruits worldwide (Ezura and Hiwasa-Tarase, 2010; Khandaker *et al.*, 2011; Oosthuyse and Berrios, 2015). Orange trees bear a large number of fruits but most of them drop at early stages of development or before attaining the commercial ripening stage (Malik *et al*., 2004; Ibrahim *et al*., 2011). Several techniques have been reported to reduce fruit drops and increase retention of fruits on orange trees (Roemer, 2011; Hussein *et al*., 2012; Ahemand and Kibret, 2014; Shen *et al*., 2014; Wang *et al*., 2014; Amro *et al*., 2016). For example, aldehyde improves fruit retention on trees, and fruit quality such as aroma, skin colour and firmness (Shen *et al*., 2014). Similarly, auxin alleviates fruit abscission at post bloom and early development stages of the fruits, which results in excessive reduction of fruit drop (Roemer, 2011). Moreover, 3, 5, 6-TPA increases fruit thinning percentage, fruit weight, diameter, length and leaf/fruit ratio (August *et al*., 2002) whereas fungicides and combination of 2, 4-D and $GA_3$ improve fruit retention on trees by reducing high flower and fruit drop (Bekti, 2009). A combination of urea and $GA_3$ enhances fruiting and fruit quality, fruit set and fruit retention on trees (Amro *et al*., 2016).

Field application of hexanal was recently reported to be the most effective for reduction of premature fruit drop, superficial scald, fungal infection, and for increasing fruit firmness, quality, freshness and fruit retention on trees of various fruit species such as apple, cherry, longan, mango, strawberry, guava and tomato (Tiwani and Paliyath, 2011; Subramanian *et al*., 2014; Karthika *et al*., 2015). The effects of field hexanal application on pre-harvest yield losses in oranges are not well known. Therefore, the objective of this study was to determine the effects of field application of hexanal on pre-harvest yield losses of orange fruits.

## 6.2 Materials and Methods

### 6.2.1 Description of study area

The study was carried out at Semngano (altitude, latitude and longitude of 254.0 m asl, 05°14’14.8”S and 038°46’33.1"E, respectively) and Mamboleo (altitude, latitude and longitude of 263.0 m, 05°13’59.9”S and 038°42’58.2"E, respectively) villages in Muheza District, Tanga Region. These sites had the same agro-climatic conditions. Muheza district experiences bimodal rainfall from 800 mm to 1400 mm with an average annual minimum and maximum temperatures of 24°C and 32°C, respectively (TRCO, 2008). The long rain season is between March and May while the short rain season is between October and December. The experiments were carried out in farmers’ orange orchards, which were well established and maintained according to recommended agricultural practices.

### 6.2.2 Description of orange varieties

Three orange varieties namely Early Valencia, Jaffa, and Late Valencia were selected for the study. Early Valencia is the most popular variety with an extended production from May to September, high yield and firm fruits which tolerate long distant transportation (Mbiha and Maerere, 2002; Tu, 2008; OECD, 2010; Said, 2013). Late Valencia is a popular variety which matures from January to March, produces high yield, retains maturity on trees for an extended period and its fruits are robust to harsh transport and environment conditions (Izamuhaye, 2008; Tu, 2008; Said, 2013). Jaffa variety matures from May to July, produces high yield but its fruits are less robust to harsh transport conditions (Izamuhaye, 2008; Tu, 2008; OECD, 2010; Said, 2013). Early Valencia and Late Valencia are the most preferred orange varieties in Muheza District, with acceptance by farmers of 45.8 and 31% of all orange varieties grown in the district, respectively (Makorere, 2012).

### 6.2.3 Experimental design

The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A was hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days). The experiment was done in two seasons with the first season extended from April, 2017 to July, 2017, and the second season extended from August, 2017 to December, 2017. A fruit tree constituted a treatment and was independently treated with hexanal concentration and time of its application prior to fruit harvest. A treatment was replicated ten times. Hexanal was manually sprayed on fruits using a knapsack sprayer until the solution dripped from fruits. Untreated orange trees for each variety were used as controls.

### 6.2.4 Data collection and analysis

Hexanal treated and untreated fruits were harvested when ripe. Data were collected immediately after fruit harvest based on number of dropped fruits, number of non-marketable yield and incidences of pest damage. Dropped fruits per tree were collected and counted at an interval of one week from the $7^{th}$ day after hexanal application and stopped just before the first fruit harvest. Thereafter, the colleted fruits were buried in the soil to control the spread of diseases. Harvested orange fruits were sorted into marketable and non - marketable fruits per tree. According to OECD (2010), orange fruits with sunburn, stem end rot, anthracnose, bruising, scar and powdery mildew infections were considered non - marketable. Data on incidences of pest damage were obtained by sorting and counting fruits with pest defects. The major pest defetcs were caused by fruit flies, fruit piercing moth, false codling moth and anthracnose.

Data in percentage were transformed by using arcsine scale. Two way ANOVA was used to analyse data using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5% probability. The sources of variation were hexanal concentration and time of application. Analyses were performed separately for each variety during each season.

## 6.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on losses of orange are presented below. Independent analyses were performed for each variety and during season. Results are conveniently reported together in the same sections.

### 6.3.1 Effects of hexanal concentration on number of dropped fruits per tree

Results show that the hexanal concentration significantly reduced the number of dropped fruits from trees of Early Valencia, Jaffa and Late Valencia during both seasons. The number of dropped fruits significantly decreased with the time of hexanal application on trees Early Valencia, Jaffa (during both seasons) and Late Valencia (for second season only). The effects of hexanal concentration x time of application were significant on Late Valencia during the second season only (Table 6.1). Results further showed that main effects of hexanal concentration were significant on number of dropped fruits of varieties of Early Valencia (for both seasons, Figure 6.1), Jaffa and Late Valencia had significant effects during the first season only (Figures 6.2 and 6.3), regardless of time of application. Simple effects of hexanal concentration were significant on number of dropped fruits of Jaffa and Late Valencia varieties at all tested times of application during the second season (Tables 6.2 and 6.3). The number of dropped fruits per tree of Early Valencia, Jaffa and Late Valencia were lowered by up to 22.62%, 37.73%, 46.31% respectively when exposed to various concentrations of hexanal compared to the control.

**Table 6.1: Effect of hexanal concentration and time of application on dropped fruit in orange varieties**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ = 16.71 | <0.001 | $F_{3, 32}$ =19.89 | <0.001 |
| Time | $F_{3, 144}$ =5.43 | 0.001 | $F_{3, 32}$ =13.84 | <0.001 |
| Conc. x Time | $F_{9, 144}$ =1.08 | 0.381 | $F_{9, 32}$ =1.61 | 0.154 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =12.66 | <0.001 | $F_{3, 64}$ =37.94 | <0.001 |
| Time | $F_{3, 144}$ =2.53 | 0.029 | $F_{3, 64}$ =20.64 | <0.001 |
| Conc. x Time | $F_{9, 144}$ =1.00 | 0.439 | $F_{9, 64}$ =2.23 | 0.031 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =28.83 | <0.001 | $F_{3, 80}$ =57.52 | <0.001 |
| Time | $F_{3, 144}$ =0.48 | 0.700 | $F_{3, 80}$ =10.69 | <0.001 |
| Conc. x Time | $F_{9, 144}$ =0.69 | 0.716 | $F_{9, 80}$ =3.16 | 0.003 |

Note: Conc. = Concentration

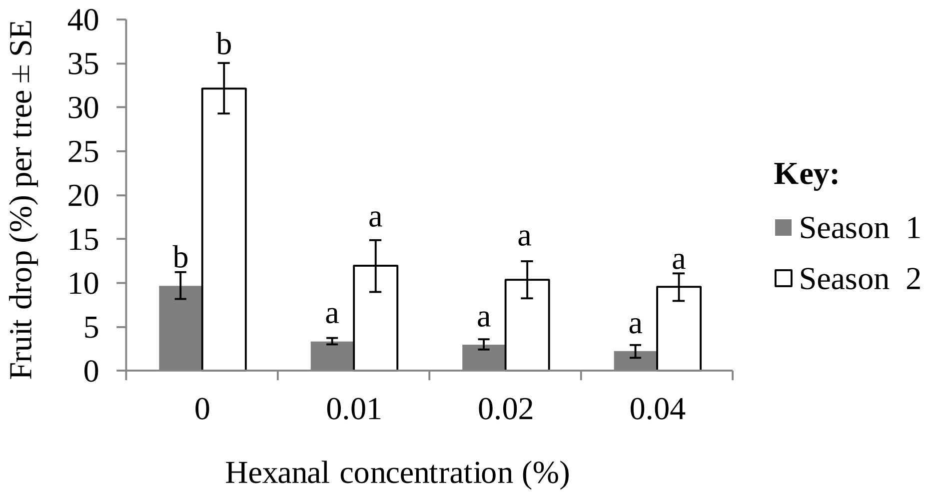


**Figure 6.1: Mean of number of dropped fruits of Early Valencia orange variety during first season ($F_{(3, 36)}$ = 12.67, $P$ < 0.001) and second season ($F_{(3, 8)}$ = 19.77, $P$ < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

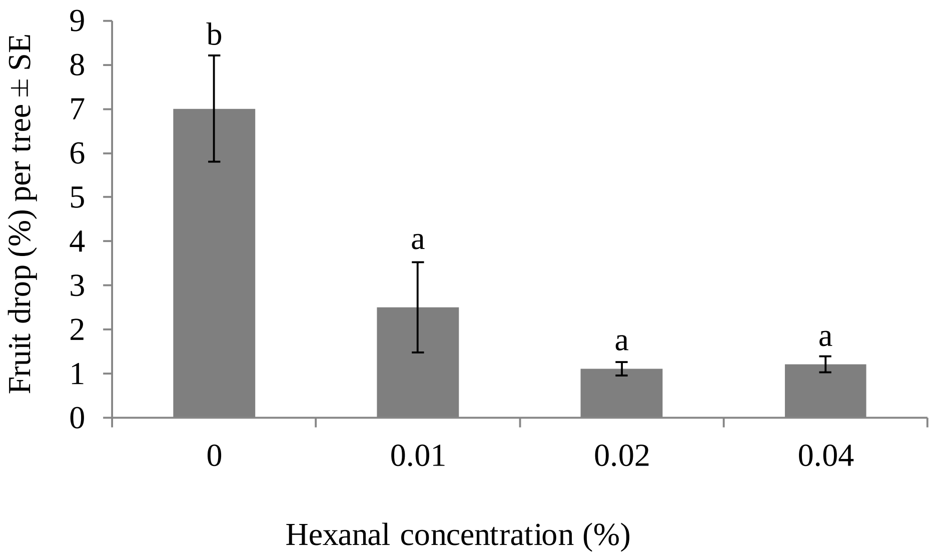


**Figure 6.2: Mean of number of non marketable fruits of Jaffa orange variety during first season ($F_{(3, 36)} = 4.64$, $P = 0.008$) and second season ($F_{(3, 16)} = 15.46$, $P < 0.001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

**Table 6.2: Simple mean of number of dropped fruits of Jaffa orange variety during second season**

| **Hexanal conc. (%)** | **60 (DTH)** | **42 (DTH)** | **21 (DTH)** | **7 (DTH)** |
|---|---|---|---|---|
| 0 | 46.14b | 43.60b | 23.28b | 13.33b |
| 0.01 | 15.14a | 13.73a | 2.30a | 1.50a |
| 0.02 | 8.40a | 11.00a | 3.78a | 3.03a |
| 0.04 | 12.08a | 21.72a | 4.03a | 2.38a |
| F ratio | $F_{(3, 16)} = 9.86$ | $F_{(3, 16)} = 9.81$ | $F_{(3, 16)} = 27.85$ | $F_{(3, 16)} = 16.56$ |
| P | $P < 0.001$ | $P<0.001$ | $P < 0.001$ | $P < 0.001$ |

Means in the same column bearing the same letter(s) are not significantly different. Post Hoc Tukey test = HSD $_{(p=0.05)}$. Note: Conc. = Concentration, DTH = Days to harvest

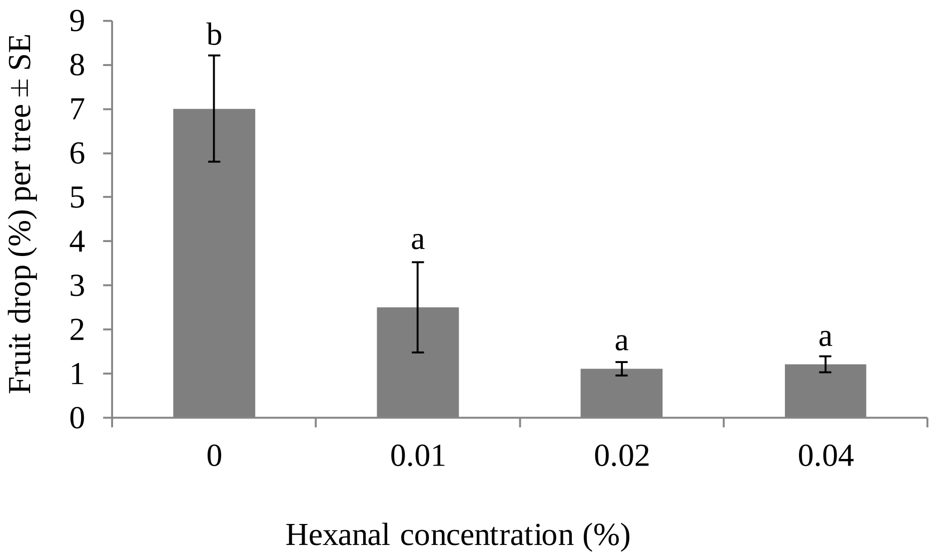


**Figure 6.3: Mean of number of dropped fruits of Late Valencia orange variety during first season ($F_{(3, 36)} = 29.46$, $P < 0.001$) and second season ($F_{(3, 20)} = 36.19$, $P < 0.001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

**Table 6.3: Simple mean of number of dropped fruits of Late Valencia orange variety during second season**

| Hexanal conc. (%) | 60 (DTH) | 42 (DTH) | 21 (DTH) | 7 (DTH) |
|---|---|---|---|---|
| 0 | 41.69b | 51.66b | 30.17b | 13.57b |
| 0.01 | 9.84a | 6.13a | 9.08a | 0.00a |
| 0.02 | 6.07a | 5.35a | 4.30a | 0.00a |
| 0.04 | 6.30a | 7.50a | 2.74a | 0.00a |
| F ratio | $F_{(3, 20)} = 10.13$ | $F_{(3, 20)} = 31.89$ | $F_{(3, 20)} = 10.96$ | $F_{(3, 20)} = 67.49$ |
| P | $P < 0.001$ | $P < 0.001$ | $P < 0.001$ | $P < 0.001$ |

Means in the same column bearing the same letter(s) are not significantly different. Post Hoc Tukey test = HSD $_{(p=0.05)}$. Note: Conc. = Concentration, DTH = Days to harvest

### 6.3.2 Effects of concentration on number of non marketable yield per tree

The results further show that hexanal concentrations significantly reduced number of non-marketable fruits of Early Valencia, Jaffa and Late Valencia during both seasons. The time of hexanal application prior to harvest had no significant effects on number of non-marketable fruits of all three mango varieties. Furthermore, the effects of hexanal concentration x time of application had no significant effects on non-marketable yield on tested varieties (Table 6.4). We found significant main effects of hexanal concentration on number of non - marketable fruits of all three varieties during both seasons regardless of time of application. The numbers of non-marketable fruits of Early Valencia, Jaffa and Late Valencia varieties were reduced by up to 21.39%, 26.10% and 30.74% when exposed to various concentrations of hexanal compared to the control (Figures 6.4, 6.5 and 6.6).

**Table 6.4: Effect of hexanal concentration and time of application on non marketable in orange varieties**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ =14.66 | <0.001 | $F_{3, 32}$ =12.09 | <0.001 |
| Time | $F_{3, 144}$ =0.16 | 0.925 | $F_{3, 32}$ =1.94 | 0.143 |
| Conc. x Time | $F_{9, 144}$ =0.33 | 0.965 | $F_{9, 32}$ =0.48 | 0.878 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =10.33 | <0.001 | $F_{3, 64}$ =24.86 | <0.001 |
| Time | $F_{3, 144}$ =0.74 | 0.530 | $F_{3, 64}$ =0.10 | 0.961 |
| Conc. x Time | $F_{9, 144}$ =0.76 | 0.655 | $F_{9, 64}$ =0.26 | 0.983 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =42.14 | <0.001 | $F_{3, 80}$ =47.58 | <0.001 |
| Time | $F_{3, 144}$ =0.47 | 0.701 | $F_{3, 80}$ =0.33 | 0.804 |
| Conc. x Time | $F_{9, 144}$ =0.71 | 0.697 | $F_{9, 80}$ =0.78 | 0.635 |

Note: Conc. = Concentration

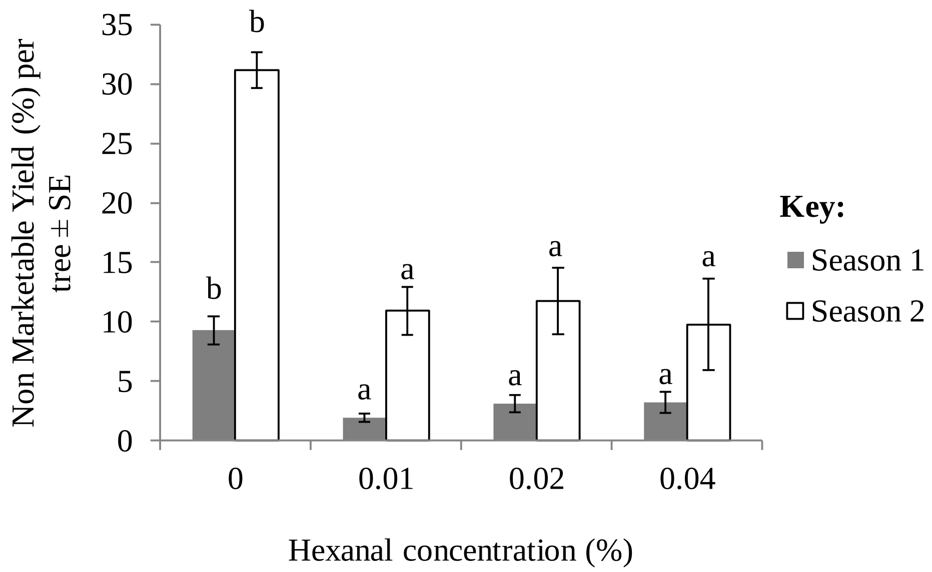


**Figure 6.4: Mean of number of non marketable fruits in Early Valencia orange variety during first season ($F_{(3, 36)}$ = 6.32, *P* = 0.001) and second season ($F_{(3, 8)}$ = 14.47, *P* = 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

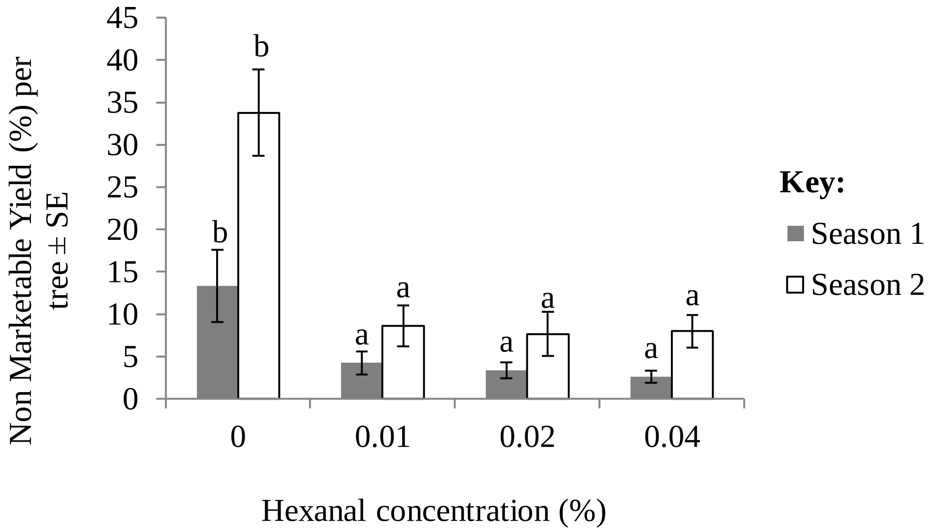


**Figure 6.5: Mean of number of non marketable fruits of Jaffa orange variety during first season ($F_{(3, 36)}$ = 4.64, $P$ = 0.008) and second season ($F_{(3, 16)}$ = 15.46, $P$ < 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

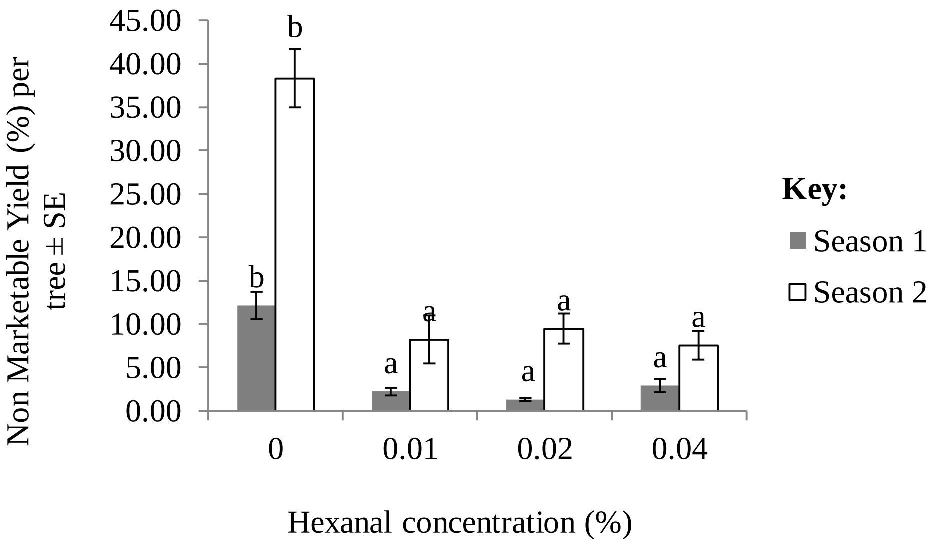


**Figure 6.6: Mean of number of non marketable fruits of Late Valencia orange variety during first season ($F_{(3, 36)}$ = 29.46, $P$ < 0.001) and second season ($F_{(3, 20)}$ = 36.19, $P$ < 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 6.3.3 Effects of hexanal concentration and time of application on incidences of pest damage fruits

Incidences of pest damage on mango fruits were significantly reduced by concentrations of hexanal applied on trees of Early Valencia, Jaffa (during both seasons) and Late Valencia (during second season only). The time of application had significant effects on Late Valencia during the first season only. Furthermore, the effects of hexanal concentration x time of application had no significant effects on incidences of pests on tested varieties (Table 6.5). Analyses of the main means showed significant differences on incidences of pest damage on fruits of Early Valencia, Jaffa (during both season) and Late Valencia (during second season only). The incidences of pest damage in Early Valencia, Jaffa and Late Valencia fruits significantly decreased by up to 21.59%, 22.50% and 24.86% respectively when exposed to various concentrations of hexanal compared to the control (Figures 6.7, 6.8 and 6.9).

**Table 6.5: Effect of hexanal concentration and time of application on incidence of pest defects in orange varieites**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Early Valencia** | | | | |
| Conc. | $F_{3, 144}$ =16.58 | <0.001 | $F_{3, 32}$ =17.68 | <0.001 |
| Time | $F_{3, 144}$ =0.04 | 0.989 | $F_{3, 32}$ =2.12 | 0.118 |
| Conc. x Time | $F_{9, 144}$ =0.45 | 0.905 | $F_{9, 32}$ =0.59 | 0.793 |
| **Jaffa** | | | | |
| Conc. | $F_{3, 144}$ =8.38 | <0.001 | $F_{3, 64}$ =37.34 | <0.001 |
| Time | $F_{3, 144}$ =1.75 | 0.160 | $F_{3, 64}$ = 0.52 | 0.669 |
| Conc. x Time | $F_{9, 144}$ =0.96 | 0.474 | $F_{9, 64}$ =0.41 | 0.926 |
| **Late Valencia** | | | | |
| Conc. | $F_{3, 144}$ =1.10 | 0.350 | $F_{3, 80}$ =55.78 | <0.001 |
| Time | $F_{3, 144}$ =5.44 | 0.001 | $F_{3, 80}$ =1.04 | 0.381 |
| Conc. x Time | $F_{9, 144}$ =0.74 | 0.675 | $F_{9, 80}$ =0.87 | 0.551 |

Note: Conc. = Concentration

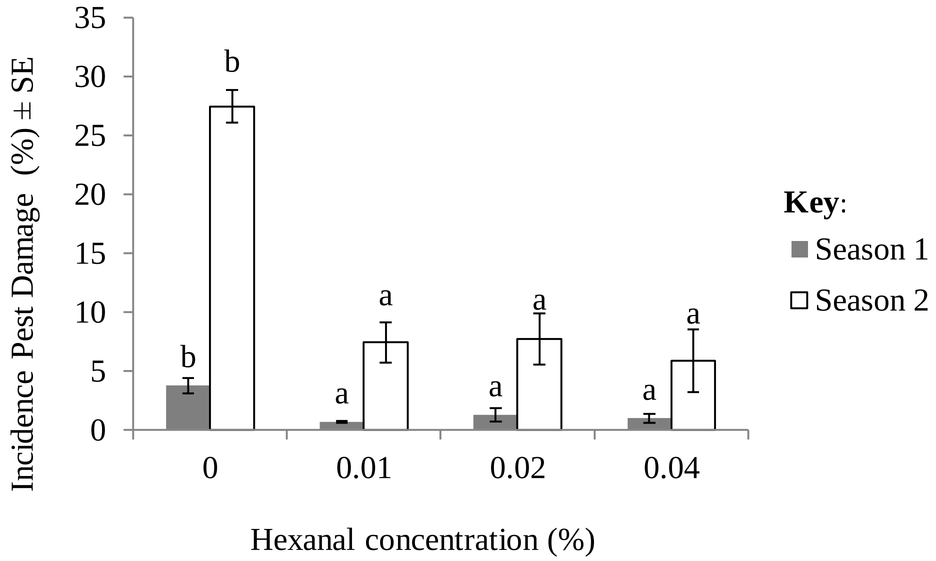


**Figure 6.7: Means of incidences of pest damage of Early Valencia orange variety during first season ($F_{(3, 36)} =$ 8.48, $P < 0.001$) and second season ($F_{(9, 32)} =$ 0.59, $P = 0.793$), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

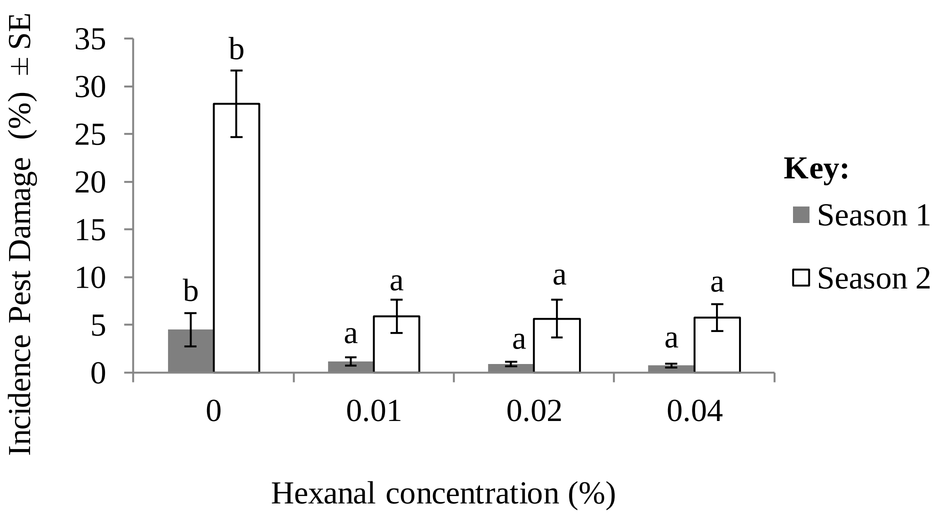


**Figure 6.8: Means of incidences of pest damage of Jaffa orange variety during first sesson ($F_{(3, 36)} =$ 3.80, $P = 0.018$) and second season ($F_{(3, 16)} =$ 23.35, $P <$ 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

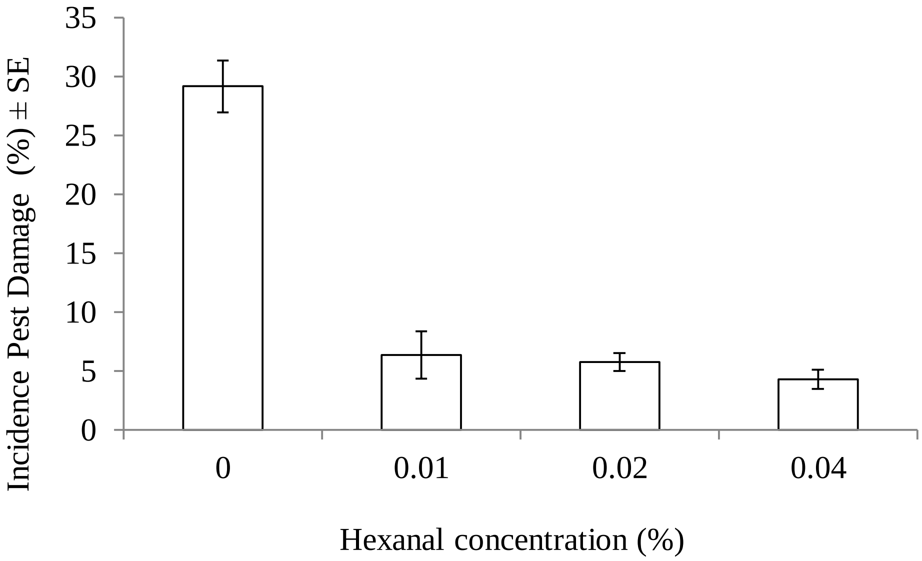


**Figure 6.9: Means of incidences of pest damage of Late Valencia orange fruits during second seson (*F* $_{(3,\ 20)}$ = 55.42, *P* < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same c bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

## 6.4 Discussion

The results demonstrated that various concentrations of hexanal effectively reduced the numbers of dropped fruits in all the three varieties of orange tested Early Valencia, Jaffa and Late Valencia. However, time of hexanal application prior to harvest had non - significant effects on firmness of fruits of tested orange varieties. Previous studies associated retention mango and nectarines of fruits in trees to PLD activity as affected by hexanal application (Anusuya *et al*., 2016 and Kumar *et al*., 2018). Hexanal alters the discalcium expression genes in addition to reducing the PLD gene activity in raspberry (El Kayal *et al*., 2017). PLD acts on phospholipids, and generate phosphatidic acid which underdo sequential catabolic breakdown downstream. Therefore, once Phospholipase D is inhibited, the whole cycle is slowed down and this results in increased fruit retention on trees (Subramanian *et al*., 2014; Karthika *et al*., 2015). Anusuya *et al*. (2016) reported that hexanal application assists in retention of fruits due to dilution of abscission. Fruit abscission was previously linked to high accumulation of peroxidase, RNA and protein in the abscission zone (Shen *et al*., 2014; Anusuya *et al*., 2016). Kumar *et al*., (2018) observed a positive correlation between synthesis of peroxidase, RNA, protein and PLD.

Hexanal extends fruit retention by slowing down the synthesis of peroxidase, RNA and protein in fruit stalks. Retention of fruits is extended due to slow down in synthesis of the peroxidase, RNA and protein synthesis in the abscission due to application of hexanal. The increased retention of fruits on orange trees due to hexanal application was also closely associated with the reduction of abscission in previous studies. A study by El Kayal *et al* (2017a) showed that that hexanal reduced the activities of phospholipase D (PLD) genes as well as genes regulated by Abscisic Acid (ABA) which accelerates leaf and fruit drop in strawberries. Previous studies showed that hexanal reduced fruit drop in mango (Anusuya *et al*., 2016), strawberry, raspberry (El Kayal *et al*., 2017a, b) and nectarines (Kumar *et al*., 2018) by maintaining retention on sprayed trees.

Results also show that hexanal concentrations reduced non marketable fruits of orange. The effects of time of hexanal application before harvest were however insignificant. The reduction in non-marketable yield is mainly due to reduction of incidences of diseases and pests such as sooty mould as well as other disorders such as cracking and blossom end rot. Effects of hexanal on incidences of pest defects has been previously studied (Sholberg and Randall, 2007; Anusuya *et al*., 2016). According to Sholberg and Randall (2007), hexanal can exhibit antifungal properties by altering the lipoxygenase pathway. Lipoxygenase are key enzymes that play an important role in the response of plants to wounding and pathogen attack (Gobel *et al*., 2001). Aldehydes including hexanal derived from the lipoxygenase pathway induce a subset of defence related genes (Kuo and Gadner, 2005). In our study, hexanal application remarkably reduced the incidences of anthracnose disease, fruit flies, aphids, stem end rot and black spot. The actual loss of citrus fruits due to pre-harvest only is quite variable and depends upon the area of production, citrus variety, tree age and condition, weather condition during growing and harvest season, degree of injuries during harvesting operations (Naqvi, 2004). Losses from some diseases are due to reduced yields whereas in other case losses are due to reduction in the external quality of the fruit (Ashebre, 2015). Diseases may reduce fruit yield directly, by attacking the fruit, or indirectly by causing defoliation or stem injury that affects fruit development and yield. Some diseases cause superficial blemishes that do not affect yield or juice quality but may affect market appeal (Whiteside *et al*., 1988).

## 6.5 Conclusions and Recommendations

The objective of this study was to determine the effects of pre-harvest field application of hexanal on yield losses of orange fruits. It is concluded that hexanal application at 0.01% remarkably reduces pre-harvest orange fruit losses by reducing the number of dropped fruits, and incidences of pest damage on fruits of orange variety Early Valencia, Jaffa and Late Valencia. It is recommended that farmers should apply hexanal at concentration of 0.01% from 42 to 7 days to harvest in order to reduce the number of dropped fruits, number of non-marketable yield and incidence of pest defects in orange Early Valencia, Jaffa and Late Valencia varieties.

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# CHAPTER SEVEN

## EFFECTS OF PRE-HARVEST FIELD APPLICATION OF HEXANAL ON FRUIT LOSSES OF MANGO FRUIT GROWN IN EASTERN ZONE OF TANZANIA

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**ABSTRACT**

The studied were to determine effect on hexanal application for pre-harvest fruit drop, non-marketable yield, and pest infestations on mango (*Mangifera indica* L.) varieties grown in Tanzania. The experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A consisted of hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days for Apple, Palmer and Keitt). A fruit tree constituted a treatment for hexanal application and time of its application prior to fruit harvest. Results show that hexanal at 0.01% was statistically as effective as hexanal at 0.02 and 0.04% in reduction of number of dropped fruits, number of non-marketable yield and incidences of pest damage on mango fruits. Hexanal at 0.01% reduced the number of dropped fruits by 25.94, 20.77 and 22.58% for Apple, Palmer and Keitt, respectively; non-marketable yield was reduced by 24.82, 19.59 and 21.40% for Apple, Palmer and Keitt, respectively, and

incidences of pest damage was reduced by 27.93, 17.05 and 19.58% for Apple, Palmer and Keitt, respectively compared to the untreated fruits (controls). The time of hexanal application prior to fruit harvest as well as the interactions between hexanal concentrations and its time application did not significantly affect the number of dropped fruits, number of non-marketable yield and incidences of pest damage on mango fruits of Apple, Palmer and Keitt. It is recommended that hexanal concentration 0.01% from 42 to 7 days to harvest should be applied in order to improve marketable yield of mango Apple, Palmer and Keitt varieties.

**Key word:** Hexanal, Pre-harvest losses, Dropped fruits, Non-marketable yield, Incidences of Pest Damage, Apple, Palmer, Keitt, Mango

## 7.1 Introduction

Tanzania is currently ranked 17$^{th}$ in the world in mango (*Mangifera indica* L.) production with an annual yield of more than 490 434 metric tonnes (MMA, 2017) from an area of 38 000 ha and an annual productivity of 11.71 metric tonnes/ha (FAOStat, 2012). The low productivity of mango fruits in Tanzania is partly caused by high pre-harvest fruit losses such as flower and premature fruit drops (Atherton, 2011). Mango trees produce a large number of flowers but only 0.1 to 0.25% of the flowers set fruits (Roemer, 2011). Moreover, mango trees have high natural fruit drop varying from 95 to 99% with heavy fruit drop occurring from the first 3 to 5$^{th}$ weeks of the date of fruit set (Roemer, 2011).

The major causes of premature fruit drops are fruit competition for photo-assimilates, unfavourable climatic conditions, especially drought stress, too much rains and high incidences of diseases like powdery mildew and anthracnose, and insect pests such as mealy bugs (Chattha *et al.*, 1999; Roberts *et al.*, 2002; Maqbool *et al.*, 2007; Normand *et* *al*., 2009; Roemer, 2011). The most popular techniques to control pre-harvest fruit drop include fungicide application prior to flowering, irrigation and fertilizer application during flowering and fruit development (Mertely *et al*., 2002; Bulletin, 2009). However, application of fungicides to control pre-harvest fruit losses is limited by consumers' desire for the reduced fungicide residues in fruits (Song *et al*., 2010; Moser *et al*., 2011; McCluskey, 2015).

Hexanal is an alkyl aldehyde with the molecular formula $C_6H_{12}O$ that acts as a strong inhibitor of enzyme phospholipase-D activity, which slows down ethylene-stimulated ripening processes (Subramanian *et al.*, 2014; Karthika *et al.*, 2015). Consequently, field application of hexanal has been reported to be the most effective in increasing fruit firmness, freshness and fruit retention on trees in several fruit species like apple, cherry, longan, guava and tomato (Subramanian *et al.*, 2014; Karthika *et al.,* 2015). Moreover, field application of hexanal was earlier reported to reduce premature fruit drop, pest and disease infections in various fruits such as mangoes, straw berry, apple, cherry, guava and tomato (Subramanian *et al.*, 2014; Karthika *et al.*, 2015). However, there is limited information on the effect of hexanal application on pre-harvest fruit drop, non-marketable yield, and pest infestations on local mango varieties grown in Tanzania. Therefore, the objective of this study was to determine the effects of field application of hexanal on pre-harvest fruit losses and quality of mango fruits in the eastern zone of Tanzania.

## 7.2 Materials and Methods

### 7.2.1 Description of study area and mango varieties

The studies were carried out at Kise and Mwarusembe villages in Kiparanganda and Mwarusembe wards, respectively in Mkuranga District, Coast Region. Kise village is located at altitude, latitude and longitude of 95.20 m asl, $7^o9'22.296"$S and $39^o5'5.382"$E, respectively and Mwarusembe village at altitude, latitude and longitude of 58.30 masl, 7°14’35.172”S and 3905’42.690”E, respectively. These sites had the same agro-climatic conditions with rainfall of 800 to 1 000 mm per annum and average temperature of 28°C per year. The rainfall is a bimodal with the long rainy season from March and May and short rainy season from October to December (DED, 2017). The study was conducted using already established and well managed mango farms belonging to famers.

Three mango varieties were selected for the study namely Apple, Palmer and Keitt. Apple variety produces medium to large (280–580 g) fruits which are tolerant to anthracnose and powdery mildew infections (TFNet, 2011). Palmer variety flowers erratically, generally sets a lot of fruit but sheds most of them during fruit development, produces low yield and its fruits are too susceptible to bacterial black spot disease. Keitt is the late maturing variety, produces high yield with good marketing quality fruits which are resistant to diseases especially mildew and anthracnose but highly susceptible to bacterial black spot disease, internal breakdown of the flesh and sunburn (Kansci *et al.*, 2008; TFNet, 2011; Jonathan, 2017).

### 7.2.2 Experimental design

The experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A consisted of hexanal concentration (0.01, 0.02, 0.04% and control - untreated fruits) and factor B was time of hexanal application prior to fruit harvest (7, 21, 42 and 60 days) for Apple, Palmer and Keitt). The experiment was repeated for two seasons with the first season from October, 2016 to January, 2017 and the second season from October, 2017 to January, 2018. A fruit tree for each mango variety was a treatment, which was replicated ten times. Hexanal was manually sprayed on mango fruits using a knapsack until the solution dripped from them. Untreated mango fruits for each variety were used as controls.

### 7.2.3 Data collection and analysis

Hexanal treated and untreated mango fruits were harvested at physiological maturity stage as described by Brecht (2010). Data were collected immediately after fruit harvest based on number of dropped fruits, incidences of pest damage on fruit peel and number of non-marketable yield. Dropped fruits per tree were collected and counted at an interval of one week from the $7^{th}$ day of hexanal application and the collection was stopped just before the first fruit harvest. The collected fruits were buried in the soil to control spreading of diseases and insect pests and to clean the area for next data collection. Harvested mango fruits were sorted into marketable and non marketable fruits per tree. According to OECD (2010), mango fruits with sunburn, stem end rot, anthracnose, bruising, scar and powdery mildew infections were considered non marketable. Data on incidences of pest damage were obtained by sorting and counting fruits with pest defects. The major pest defects were caused by fruit flies, fruit piercing moth, false codling moth and anthracnose.

Data in percentage were transformed by using arcsine scale. Data analysis was conducted using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5% probability. The sources of variation were hexanal concentration and time of application. Analyses were done separately for each variety during each season.

## 7.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on losses of mango are presented below. Independent analyses were performed for each variety and during season. Results are conveniently reported together in the same sections.

### 7.3.1 Effects of hexanal application on mango fruit drops

Results show significantly effect of hexanal concentration on number of dropped fruits of varieties Apple, Palmer (during both seasons) and for Keitt (during the second season only). Time of application significantly affected number of dropped fruits of Apple, Palmer (during the second season) and Keitt variety (for both seasons). Interactions between hexanal concentration and time of application harvest had significant effects on Apple and Keitt varieties during the second season only (Table 7.1). The study also observed significant main effects of hexanal concentration on number of dropped fruits of Apple variety during the first season (Figure 7.1) and Palmer fruits during both seasons (Figure 7.2). Simple effects of hexanal concentration on number of dropped fruits of Apple and Keitt varieties were significant at 60, 42, 21 and 7 DTH during the second season (Tables 7.2 and 7.3). Hexanal concentration reduced the number of dropped fruits on Apple by up to 8.71% and 25.94%, for Palmer by up to 19.24% and 20.77%, Keitt varieties by up to 4.17 and 22.58% during the first and second season respectively.

**Table 7.1: Effect of hexanal concentration and time of application on dropped fruit of mango fruit varieties**

| **Effects** | **First season** | | **Second season** | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108} = 7.32$ | <0.001 | $F_{3, 144} = 111.21$ | <0.001 |
| Time | $F_{2, 108} = 2.35$ | 0.100 | $F_{3, 144} = 11.95$ | <0.001 |
| Conc. x Time | $F_{6, 108} = 0.33$ | 0.917 | $F_{9,144} = 8.69$ | <0.001 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108} = 5.16$ | 0.002 | $F_{3, 96} = 9.32$ | <0.001 |
| Time | $F_{2, 108} = 4.48$ | 0.053 | $F_{3, 96} = 8.79$ | <0.001 |
| Conc. x Time | $F_{6, 108} = 0.87$ | 0.516 | $F_{9, 96} = 0.48$ | 0.888 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144} = 1.49$ | 0.219 | $F_{3, 80} = 57.93$ | <0.001 |
| Time | $F_{3, 144} = 9.10$ | <0.001 | $F_{3,80} = 13.10$ | <0.001 |
| Conc. x Time | $F_{9, 144} = 1.09$ | 0.375 | $F_{9, 80} = 3.13$ | 0.003 |

Note: Conc. = Concentration

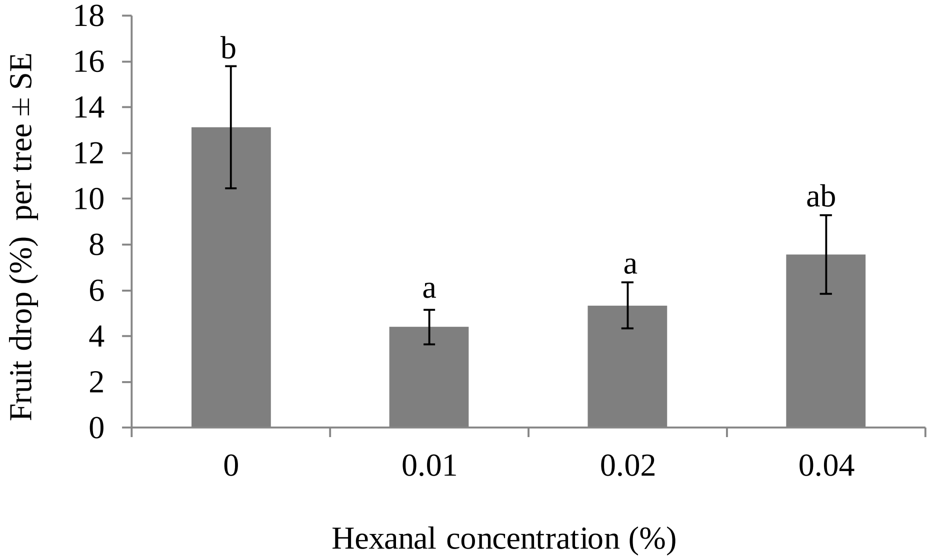


**Figure 7.1: Effects of hexanal on concentration concentration for first season of main mean on number of dropped fruits of mango variety Apple**.

Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means; the Turkey$_{(p=0.05)}$ was used for posthoc; (n = 108 for all samples in first season)

**Table 7.2: Simple means of number of dropped fruits of Apple mango variety during second season**

| **Hexanal Conc. (%)** | **60 (DTH)** | **42 (DTH)** | **21 (DTH)** | **7 (DTH)** |
|---|---|---|---|---|
| 0 | 26.80b | 30.85b | 14.84b | 11.29b |
| 0.01 | 6.50a | 5.77a | 4.67a | 6.61a |
| 0.02 | 4.75a | 5.10a | 4.18a | 3.79a |
| 0.04 | 3.79a | 4.91a | 3.95a | 3.12a |

Note: Means in the same column bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means; the Turkey$_{(p=0.05)}$ was used for posthoc; (n = 144 for all samples in second season)

DTH = Days to harvest

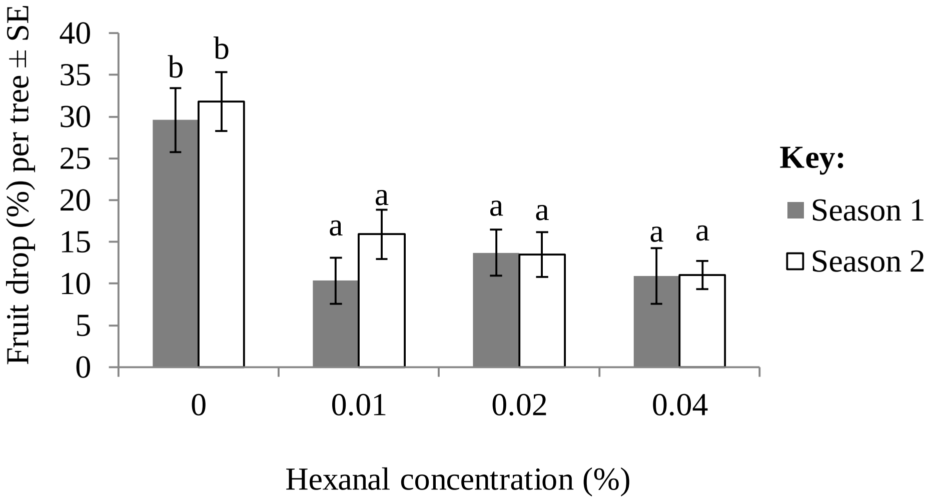


**Figure 7.2: Mean of number of dropped fruits of Palmer mango variety during first season ($F_{(3, 36)}$ = 8.03, $P$ < 0.001) and second season ($F_{(3, 23)}$ = 14.54, $P$ = 0.021), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same column bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

**Table 7.3: Simple mean of number of dropped fruits of Keitt mango variety during second season**

| Hexanal Conc. (%) | 60 (DTH) | 42 (DTH) | 21 (DTH) | 7 (DTH) |
|---|---|---|---|---|
| 0 | 27.24b | 21.29b | 21.56b | 7.92b |
| 0.01 | 7.95a | 6.86a | 3.36a | 2.52a |
| 0.02 | 4.66a | 5.75a | 5.518a | 2.40a |
| 0.04 | 8.09a | 5.21a | 5.30a | 2.47a |

Note: Means in the same column bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means; the Turkey$_{(p=0.05)}$ was used for posthoc; (n = 80 for all samples in second season)

DTH = Days to harvest

### 7.3.2 Effects of hexanal application on mango number of non-marketable yield

The results further show number non - marketable fruits of Apple, Palmer and Keitt varieties varied significantly among hexanal concentrations during both seasons. However, the time of hexanal application had no significant effects except for Palmer variety during the second season. The effects of hexanal concentrations x time of application were not significant for all varieties (Table 7.4). Main effects of hexanal concentration on non - marketable fruits were significant on all tested mango varieties. Number of non-marketable fruits of Apple, varieties was reduced by up to 9.10 and 24.82%, Palmer was reduced by 15.26% and 19.59%, and Keitt dropped by up to 13.90% and 21.40% during the first and second season respectively (Figures 7.4, 7.5 and 7.6).

**Table 7.4: Effect of hexanal concentration and time of application on non marketable yield of mango fruit varieties**

| **Effects** | **First season** | | **Second season** | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108}$ = 9.80 | <0.001 | $F_{3, 144}$ = 227.04 | <0.001 |
| Time | $F_{2, 108}$ = 0.16 | 0.849 | $F_{3, 144}$ = 1.73 | 0.164 |
| Conc. x Time | $F_{6, 108}$ = 0.46 | 0.834 | $F_{9, 144}$ = 1.29 | 0.250 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108}$ = 7.13 | <0.001 | $F_{3, 96}$ = 55.85 | <0.001 |
| Time | $F_{2, 108}$ =0.10 | 0.907 | $F_{3, 96}$ = 7.78 | <0.001 |
| Conc. x Time | $F_{6, 108}$ =0.59 | 0.738 | $F_{9, 96}$ = 0.40 | =0.934 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144}$ = 8.88 | <0.001 | $F_{3, 80}$ = 84.49 | <0.001 |
| Time | $F_{3, 144}$ = 0.78 | 0.509 | $F_{3, 80}$ = 0.17 | 0.917 |
| Conc. x Time | $F_{9, 144}$ = 0.37 | 0.950 | $F_{9, 80}$ = 0.72 | 0.691 |

Note: Conc. = Concentration

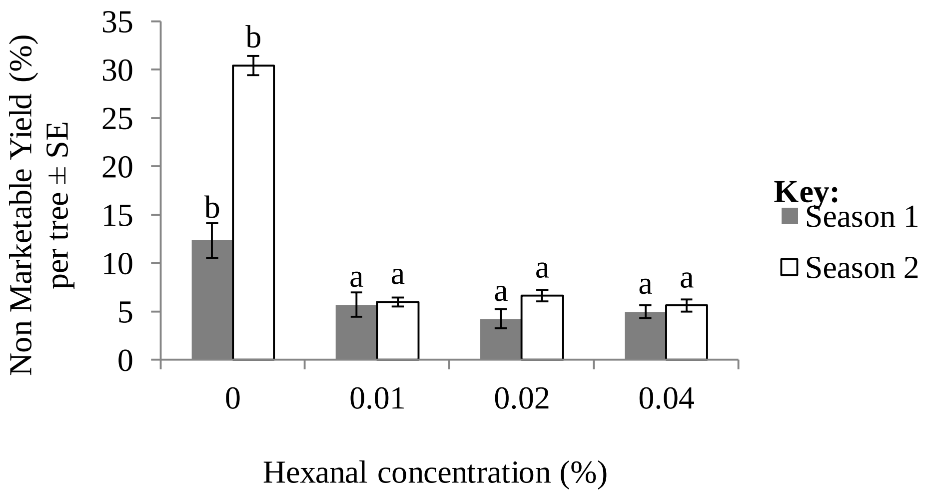


**Figure 7.3: Mean number of non-marketable fruits of Apple mango variety during first season ($F_{(3, 36)}$ = 8.96, *P* < 0.001) and second season ($F_{(3, 36)}$ = 306.57, *P* < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

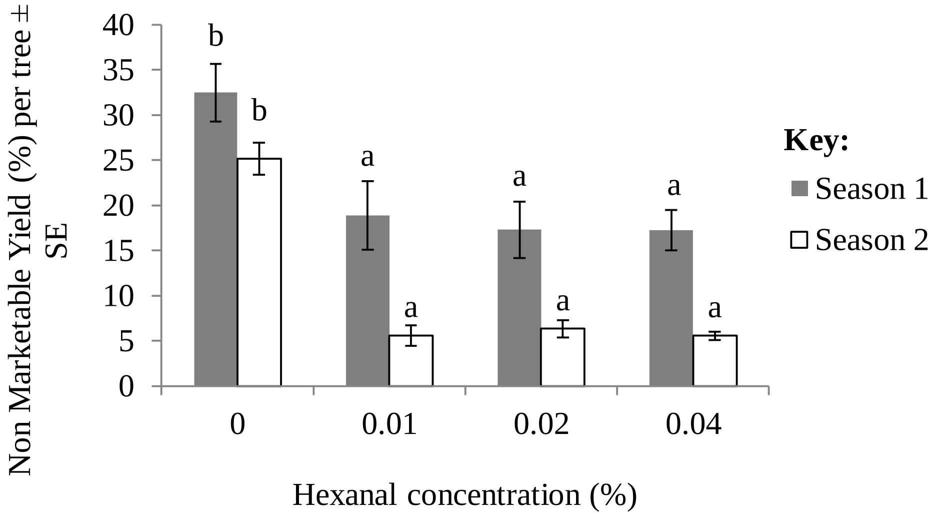


**Figure 7.4: Mean number of non-marketable fruits of Palmer mango variety during first season ($F_{(3, 36)} =$ 5.47, $P$ = 0.003) and second season ($F_{(3, 23)} =$ 63.08, $P <$ 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

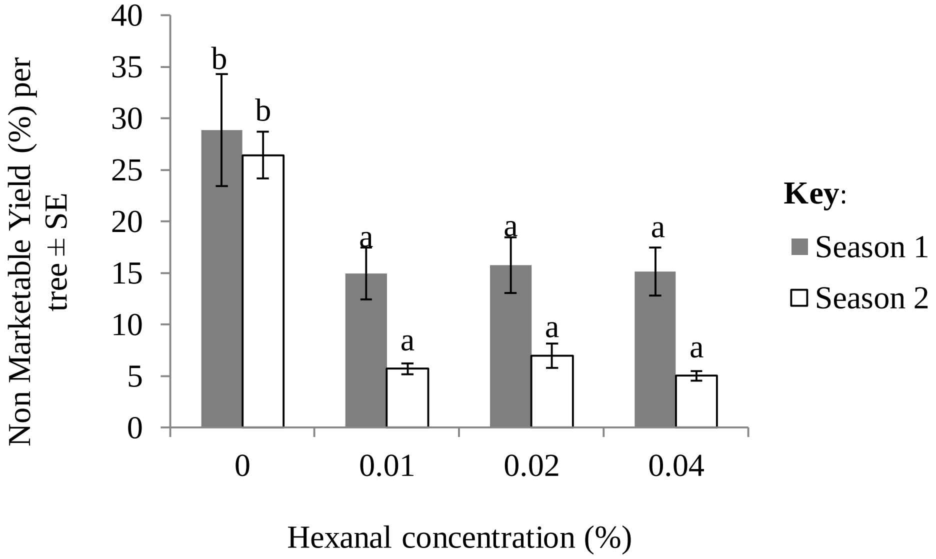


**Figure 7.5: Mean number of non-marketable fruits of Keitt mango variety during first season ($F_{(3, 36)} =$ 3.75, $P$ = 0.019) and second season ($F_{(3, 20)} =$ 60.10, $P <$ 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$. Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 7.3.3 Effects of hexanal application on incidences of pest damage on mango fruits

Hexanal concentrations significantly reduced incidences of pest damage on mango fruits of varieties Apple, Palmer and Keitt during both seasons. However, the time of hexanal application had no significant effects except for Palmer variety during the second season. Moreover, the hexanal concentrations x time of application had insignificant effects on incidences of pest damage (Table 7.5). Further analysis showed significant main effects of hexanal concentration on incidences of pest damage on all three mango varieties during both seasons. Incidences of pest damage in Apple fruits significantly decreased by 8.05% and 18.97%, in Palmer fruits were reduced by 13.91 and 17.05%, and Keitt fruits were reduced by 15.32 and 19.58% during the first and second season respectively (Figures 7.7, 7.8 and 7.9).

**Table 7.5: Effect of hexanal concentration and time of application on Pest defects of mango fruit varieties**

| Effects | First season | | Second season | |
|---|---|---|---|---|
| | ***F* - ratio** | ***P*** | ***F* - ratio** | ***P*** |
| **Apple** | | | | |
| Conc. | $F_{3, 108} = 8.92$ | <0.001 | $F_{3, 144} = 171.48$ | <0.001 |
| Time | $F_{2, 108} = 0.18$ | 0.835 | $F_{3, 144} = 3.10$ | 0.029 |
| Conc. x Time | $F_{6, 108} = 0.47$ | 0.828 | $F_{9, 144} = 1.85$ | 0.064 |
| **Palmer** | | | | |
| Conc. | $F_{3, 108} = 11.99$ | <0.001 | $F_{3, 96} = 43.37$ | <0.001 |
| Time | $F_{2, 108} = 0.04$ | 0.959 | $F_{3, 96} = 6.04$ | <0.001 |
| Conc. x Time | $F_{6, 108} = 0.24$ | 0.963 | $F_{9, 96} = 0.27$ | 0.982 |
| **Keitt** | | | | |
| Conc. | $F_{3, 144} = 15.14$ | <0.001 | $F_{3,80} = 69.10$ | <0.001 |
| Time | $F_{3, 144} = 0.67$ | 0.572 | $F_{3, 80} = 0.18$ | 0.910 |
| Conc. x Time | $F_{9, 144} = 0.42$ | 0.923 | $F_{9, 80} = 0.78$ | 0.637 |

Note: Conc. = Concentration

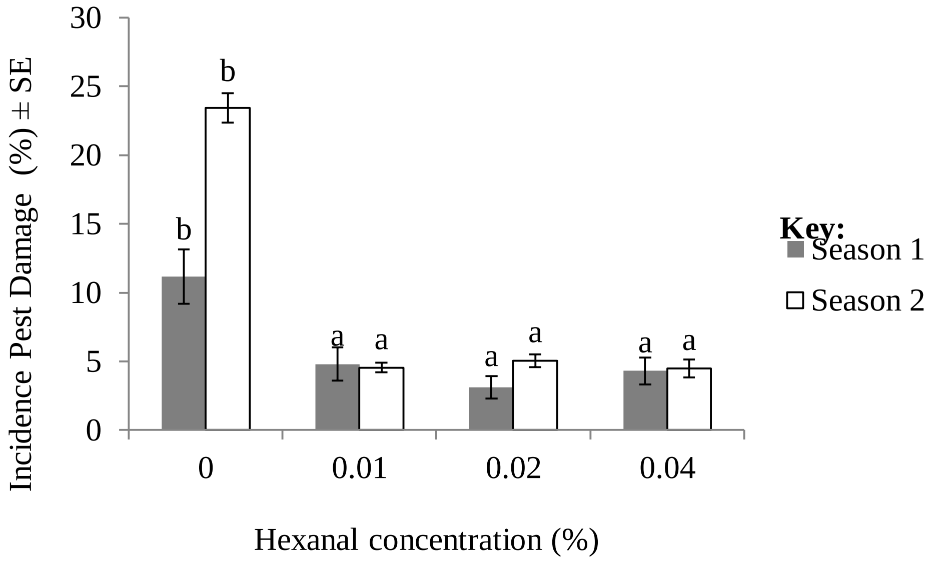


**Figure 7.6: Mean incidences of pest damage of fruits of Apple mango variety during first season ($F_{(3, 36)}$ = 7.39, $P < 0.001$) and second season ($F_{(3, 36)}$ = 187.05, $P < 0.001$), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

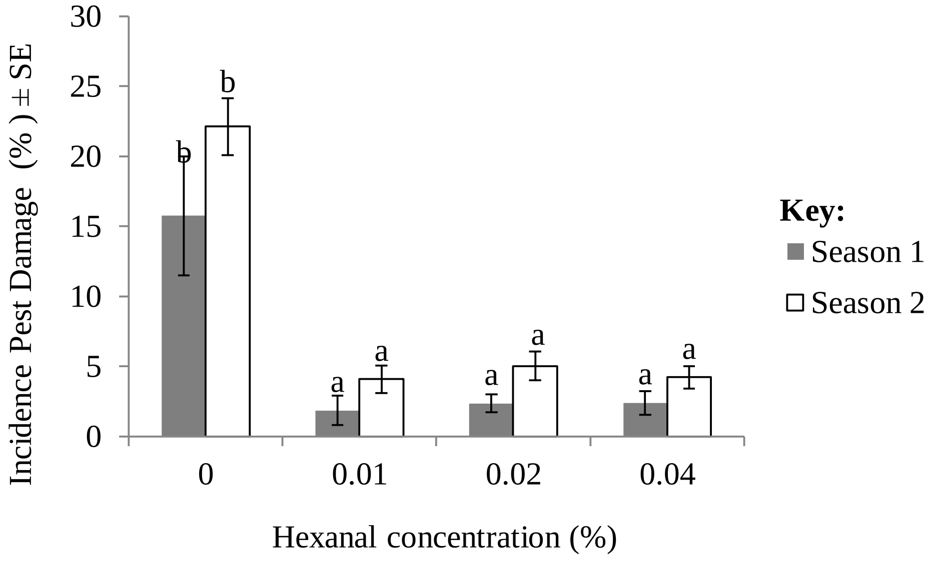


**Figure 7.7: Mean incidences of pest damage of fruits of Palmer mango variety during first season ($F_{(3, 36)}$ = 9.02, $P < 0.001$) and second season ($F_{(3, 23)}$ = 43.92, $P < 0.001$), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

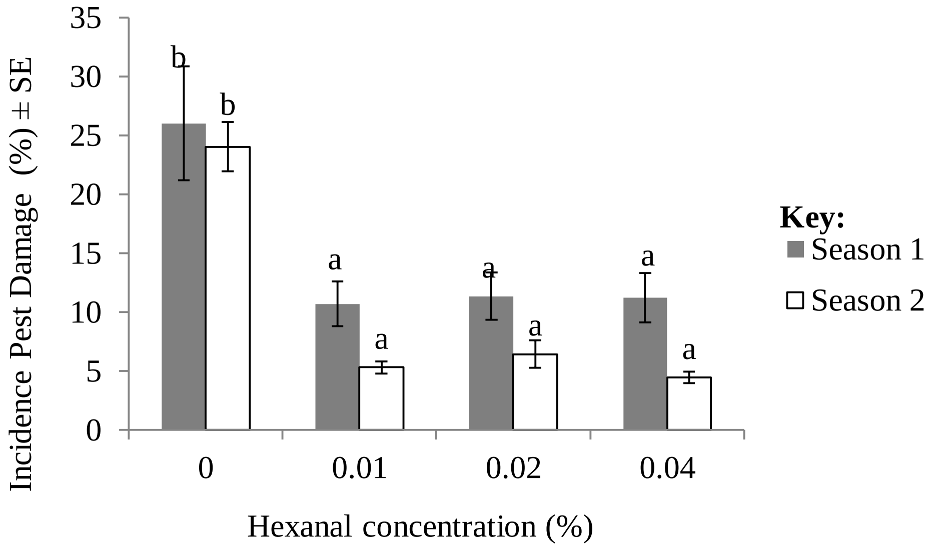


**Figure 7.8: Mean incidences of pest damage of fruits of Keitt mango variety during first season ($F_{(3, 36)}$ = 9.02, $P < 0.001$) and second season ($F_{(3, 20)}$ =55.39, $P$ <0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means in the same bars bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

## 7.4 Discussion

The present study show that the various concentrations significantly reduced fruit drops in all three tested mango varieties of Apple, Palmer and Keitt. However the time of hexanal application had no significant effects on fruit retention. Previous studies linked fruit retention on trees to reduced fruit abscission by hexanal. During abscission, a layer of separation cells is formed on fruit stalk. Subsequently, the substance bonding the cells of the separation layer dissolves, and the cells separate from each other. At this stage the fruit is only attached on the plant by a vascular bundle. During this process there is high accumulation of peroxidase, RNA and protein in the abscission zone (Shen *et al.*, 2014; Anusuya *et al.*, 2016). Hexanal slows down the synthesis of peroxidise (Baggio *et al.*, 2014), RNA and protein in fruit stalk abscission zone (Shen *et al.*, 2014; Anusuya *et al.*, 2016). The slowdown of these physiological processes in the abscission zone extends the fruit retention in the hexanal-sprayed trees. Hexanal also slows down respiration and depletion of ascorbic acid an important substrate for respiration, and consequently improves retention of fruits on trees (Preethi *et al*., 2018). Retention of fruits in hexanal sprayed trees may be closely associated with the dilution of abscission.

Several others studied reported improved retention of fruits on trees due to hexanal application. Anusuya *et al*. (2016) reported that hexanal sprayed trees retained 20% more fruits of Alphonso mango variety even after 33 days in Alphonso variety while almost all fruits dropped from unsprayed trees. Karthika *et al.* (2015) reported that hexanal reduced premature drop of sprayed fruits of mango Apple variety. Furthermore hexanal enhanced retention of mango fruits in the field for three weeks reduced premature fruit drop and prolonging the harvest window (Karthika *et al.,* 2015). Yumbya *et al*. (2018) reported that Hexanal applied twice as a spray significantly improved fruit retention by 12 days and 18 days in Machakos and Meru Counties, respectively in Kenya. Therefore, our results further confirmed that hexanal assists in retention of fruits in the fruits orchard, and its application is highly beneficial for the farmers.

The current results also show that hexanal application at 0.01% reduced non marketable fruit yield of Apple, Palmer and Keitt varieties. However time of hexanal application had non-significant effects on number of non-marketable fruits of all three mango varieties. Specifically hexanal application reduced incidences of diseases and insect pest damage and consequently reduced non marketable yield. Spreer *et al*. (2013) reported that non -marketable yield of mango and longan fruits are caused by pests especially fungi. According to Onyeani *et al*. (2012) non-marketable yield of mango fruits is caused by anthracnose and fungal defects. According to OECD (2010) slight defects could make fruits non-marketable. Some diseases cause superficial blemishes that do not affect yield or juice quality but may affect market appeal (Whiteside *et al*., 1988). Previous studies showed that hexanal application reduced insect pest and disease defects on mango, apple and pear fruits (Sholberg and Randall, 2007; Anusuya *et al*., 2016). For example, hexanal application inhibited anthracnose, stem end rot, mould and bacteria in mango varieties (Anusuya *et al*., 2016). According to Sholberg and Randall (2007), hexanal possess antifungal properties via its lipoxygenase pathway. Moreover, hexanal strengthens the fruit cell wall structures and thus drastically reduces pathogen penetration and infections (Ahemad and Kibret, 2014; Wang *et al*., 2014). Hexanal also increases maximum defence related enzymes such as peroxide, polyphenol oxidase, phenylalanine ammonia-lyase, superoxide dismutase and catalase in mango fruits against pathogens (Seethapathy *et al*., 2016).

Hexanal remarkably reduced number of dropped fruit, number of non-marketable yield and incidences of pest damage of mango varieties Apple, Palmer and Keitt. Hexanal is a naturally occurring compound in plants and applying hexanal formulations as preharvest sprays have been known to increase fruit firmness, soluble solids, and antioxidant activity (Paliyath and Murr, 2007; Sharma *et al*., 2010). It has also been proven that pre and postharvest application of hexanal containing formulations extended the shelf life of climacteric and non-climacteric fruits such as apple, banana, cherry, strawberry, blueberry and tomato (Paliyath *et al*., 2003; Paliyath and Subramanian, 2008).

## 7.5 Conclusions and Recommendations

The objective of this study was to determine the effects of field application of hexanal on pre-harvest yield losses of mango fruits. Hexanal remarkably improves mango marketable yield by reducing number of dropped fruit, number of non-marketable yield and incidences of pest damage of mango varieties Apple, Palmer and Keitt. It is recommended that mango producers should apply hexanal at concentration of 0.01% in order to reduce number of dropped fruit, number of non-marketable yield and incidences of pest damage in mango Apple, Palmer and Keitt varieties.

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# CHAPTER EIGHT

## EFFECTS OF PRE-HARVEST FIELD APPLICATION OF HEXANAL ON LOSSES OF TOMATO FRUIT GROWN IN EASTERN ZONE OF TANZANIA

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**ABSTRACT**

The study was to determine the effects of field application of hexanal on pre-harvest losses on pest defects on fruits and non-marketable yield of Tomato (*Lycopersion esculentum* Mill.) cultivars grown in Tanzania. The experiment was laid out in Completely Randomized Design in a 4 x 4 factorial arrangement using well established and supervised experimental plot. The factor A consisted of hexanal concentrations (0.01, 0.02, 0.04% m/v and control - untreated fruits) and factor B consisted time of hexanal application prior to fruit harvest (7, 14, 21 and 28 days to prior harvest) assessed in Mwanga, Rio Grande and Tanya. A plot of 12 tomato plants constituted a treatment for hexanal application and time of its application prior to fruit harvest. The results show that pre-harvest application of hexanal at 0.01% reduced non-marketable yield and pest defects on tomato fruits of Mwanga, Rio Grande and Tanya cultivars. The application of hexanal at 0.01% reduced tomato non-marketable yield by 23.24, 23.27 and 28.39% for Mwanga, Rio Grande and

Tanya, respectively and pest defects by 22.53, 22.00 and 23.02% for Mwanga, Rio Grande and Tanya, respectively over the control (untreated fruits). The time of hexanal application prior to fruit harvest as well as the interactions between hexanal concentrations and its time of application did not significantly affect non-marketable yield and pest defects on tomato fruits of Mwanga, Rio Grande and Tanya. It is recommended that farmers should apply hexanal at 0.01% from 42 to 21 prior to fruit harvest in order to reduce pre-harvest fruit yield losses of Mwanga, Rio Grande and Tanya tomato cultivars.

**Key word:** Hexanal, Pre-harvest, Hexanal, Non-marketable yield, Pest defects, Tomato, Mwanga, Rio Grande and Tanya.

## 8.1 Introduction

Tomato (*Lycopersion esculentum* Mill.) is one of the most important vegetables grown in Tanzania (Mushobozi, 2010) with a total annual production of more than 962 684 tons in an area of 26 612 ha (MMA, 2017). Total production of tomato in Tanzania is 51% of the ttotal fruit vegetables prodused in the country (NBS, 2008). Tomato provides income to growers and is a good source of vitamin A, B and C, iron and phosphorus (Yilmaz, 2001; Sowley and Damba, 2013). The productivity of tomato in Tanzania is far below the world average of 27.5 t $ha^{-1}$ (FAO, 2005). The major causes of low productivity include of fruit defects due to competition for photo-assimilates, unfavourable climatic conditions, especially drought stress and high incidences of diseases like late blight powdery mildew and anthracnose, and insect pests such as mealy bugs (Roberts *et al.*, 2002; Normand *et al.*, 2009; Roemer, 2011). Tomato yield losses due to pests and diseases during the rainy season range from 80 to 100% (BCSL, 2009).

The most popular techniques to control pre-harvest fruit defects include application of fungicide, fertilizers and irrigation during flowering and fruit development (Mertely *et al.*, 2002; Bulletin, 2009). However, application of fungicides to control pre-harvest fruit losses is limited by consumers' desire for the reduced fungicide residues in fruits (Song *et al*., 2010; Moser *et al*., 2011; McCluskey, 2015). Hexanal composition is relatively a new technology which has been successfully used for pre-harvest treatment of fruit and vegetables. Hexanal inhibits phospholipase D, which is a key enzyme involved in membrane deterioration that occurs during fruit ripening and senescence (Cheema *et al*., 2014). Field application of hexanal has been reported to be the most effective in increasing fruit firmness, freshness and fruit retention on trees in several fruit species like apple, cherry, longan, guava and mango (Subramanian *et al*., 2014; Karthika *et al*., 2015). Moreover, field application of hexanal was earlier reported to reduce premature fruit drop, pest and disease infections in various fruits such as mangoes, straw berry, apple, cherry, guava and tomato (Subramanian *et al*., 2014; Karthika *et al*., 2015). However, there is limited information on the effect of field application of hexanal on pre-harvest pest defects on fruits and non-marketable yield of tomato cultivars grown in Tanzania. Therefore, the objective of this study was to determine the effects of field application of hexanal on pre-harvest fruit losses of tomato fruits in the eastern zone of Tanzania.

## 8.2 Materials and Methods

### 8.2.1 Description of study area and tomato cultivars

The study was carried out at Horticulture unit of Sokoine University of Agriculture in Morogoro region from October to December, 2017. Horticulture unit is located at altitude, latitude and longitude of 523.40 m asl, $6^o$50'41.478"S and $37^o$39'43.476"E, respectively. There are two rain seasons with short rains from October to January, and long rains from March to May. Annual precipitation ranges from 700 to 2 300 mm and temperatures from 18 to $30^o$ C (ZP, 2016).

Three tomato cultivars were selected for the study namely ‘Mwanga’, ‘Rio Grande’ and ‘Tanya’. Rio Grande is an early maturing cultivar (75 – 85 days) and produces high yield with excellent keeping quality fruits and withstand hard transport conditions (Ahmad *et al*., 2007; Jonathan, 2017). Tanya cultivar is characterized by early ripening, resistance against diseases (i.e. brown rot, alternationsis cancer and verticillium wilt) and tolerant to bumpy road transportation (NTIF, 2018). Mwanga cultivar is early maturing, high yielding and is susceptible to early blight disease and insect pest (Testen *et al*., 2016).

### 8.2.2 Experimental design

The experiment was laid out in a Completely Randomized Design in a 4 x 4 factorial arrangement. The factor A consisted of hexanal concentrations (0.01, 0.02, 0.04% m/v and control - untreated fruits) and factor B consisted of time of hexanal application prior to fruit harvest (7, 14, 21 and 28 days). A plot with 11 tomato plant cultivar was taken as a treatment for hexanal concentration and its time of its application prior to fruit harvest. A treatment was repeated three times. The spacing per plot was 1 m and per replicate 1.5 m, plot size was 2.1 m x 2.8 m with 11 plants. Seedlings planted three weeks after sowing followed with other manegment practices of gap filling, application of pestsides, fungalsides, ferlitilizer and weeding. Hexanal was manually sprayed on tomato fruits until the solution dripped off using a knapsack sprayer. Untreated tomato fruits for each cultivar were used as controls.

### 8.2.3 Data collection and analysis

Fifteen hexanal treated and untreated fruits per replicate were randomly harvested at ripening stage. Harvested tomato fruits in each plot or treatment were sorted into marketable and non marketable fruits. Data were collected immediately after fruit harvest based on number of pest defects on fruit peel and number of non-marketable fruits yield. Data on pest defects were obtained by sorting and counting fruits with pest defects. Non marketable fruits includes affected by with pest defects and physilogical defects (scars, clacks, sunbun).

Data in percentage were transformed by using arcsine scale prior to their analysis. Two way ANOVA was used to analyse data using R statistical package version 3:3:2 2016 (R CoreTeam, 2013) and the treatment means were post- hoc separated based on Tukey test at 5% probability. Independent analysis was carried out for each cultivar.

## 8.3 Results

Two - way ANOVA results on effects of hexanal concentration, its time of application and their interactions on losses of tomato are presented below. Independent analyses were performed for each variety and during season. Results are conveniently reported together in the same sections.

### 8.3.1 Effects of hexanal concetrationand time of application on tomato non marketable yield per plot

Results show that hexanal concentration significantly reduced fruit non marketable yield for Mwanga, Rio Grande and Tanya cultivars. The effects of time of hexanal application prior to tomato fruit harvest and interaction between hexanal concentrations x its time of application prior to fruit harvest no significantly affect fruit non-marketable yield for Mwanga Rio Grande and Tanya cultivars (Table 8.1). The study showed main effects means significant of hexanal concentration on fruit non-marketable yield for Mwanga, Rio Grande and Tanya cultivars regardless of time application. The number of non-marketable yield of Mwanga cultivars were reduced by 23.24%, 23.27% and 28.39% respectively when treated with different hexanal concentration (Figures 8.1, 8.2 and 8.3).

**Table 8.1: Effect of hexanal concentration and time of application on non marketable yield of tomato cultivars**

| **Effects** | ***F* - ratio** | ***P*** |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ =40.28 | <0.001 |
| Time | $F_{3, 32}$ =1.02 | 0.399 |
| Conc. x Time | $F_{9, 32}$ =0.32 | 0.964 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =80.62 | <0.001 |
| Time | $F_{3, 32}$ =0.47 | 0.707 |
| Conc. x Time | $F_{9, 32}$ =0.57 | 0.812 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ =48.26 | <0.001 |
| Time | $F_{3, 32}$ =0.77 | 0.518 |
| Conc. x Time | $F_{9, 32}$ =0.98 | 0.477 |

Note: Conc. = Concentration

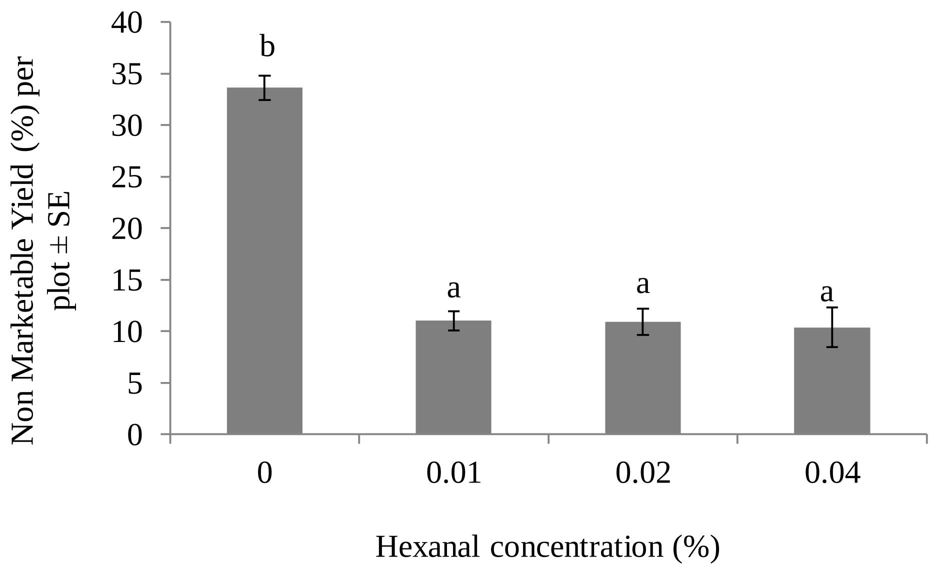


**Figure 8.1: Mean of number non marketable yield of Mwanga tomato cultivar ($F_{(3, 8)}$ = 69.08, $P$ < 0.001), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

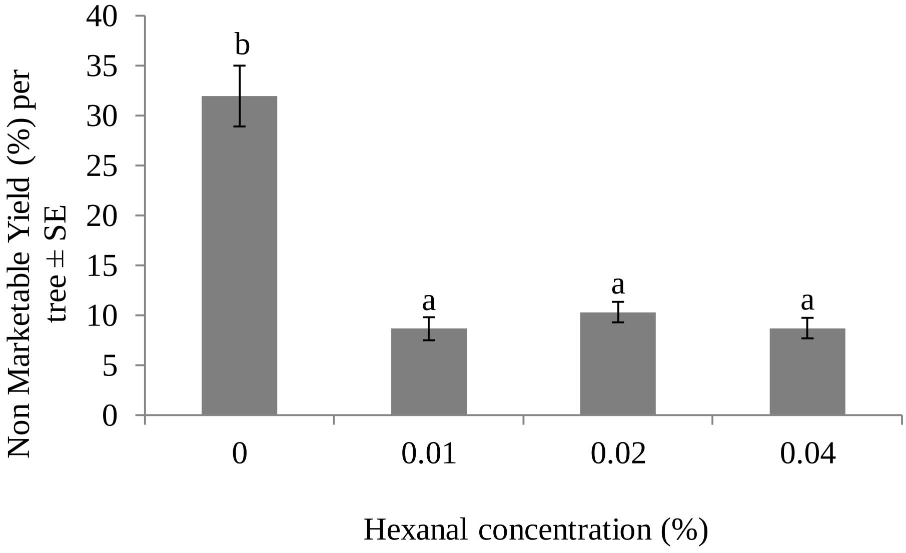


**Figure 8.2: Mean of number of non marketable yield of Rio Grande tomato cultivar (*F* $_{(3,8)}$ = 41.57, *P* <0 .001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

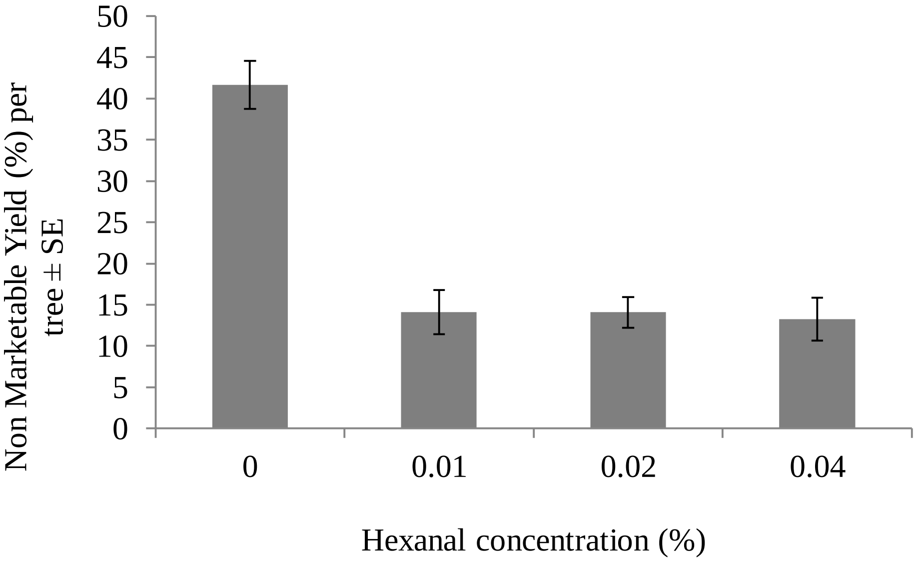


**Figure 8.3: Figure 4: Mean of number of non marketable yield of Tanya tomato cultivar (*F* $_{(3, 8)}$ = 30.29, *P* < 0.001), Post Hoc Tukey test = HSD** $_{(p=0.05)}$**.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

### 8.3.2 Effects of hexanal concentration and time of application on tomato pest defects on fruits

Results in Table 8.2 show hexanal concentration significantly reduced incidences of pest defects on fruits of Mwanga, Rio Grande and Tanya cultivars compared to control. The time of application and hexanal concentration x time of application had no significant effects on incidences of pests on tested varieties. Analysis of the main means showed significant differences on pest defects on fruits of Mwanga, Rio Grande and Tanya cultivars. The incidences of pest damage for Mwanga, Rio Grande and Tanya cultivars fruits significantly decreased by 22.53% , 22.00% and 23.02% respectively when exposed to various concentrations of hexanal compared to the control (Figures 8.4, 8.5 and 8.6).

**Table 8.2: Effect of hexanal concentration and time of application on pest defects of tomato cultivars**

| Effects | ***F*** **- ratio** | ***P*** |
|---|---|---|
| **Mwanga** | | |
| Conc. | $F_{3, 32}$ =44.64 | <0.001 |
| Time | $F_{3, 32}$ =1.00 | 0.407 |
| Conc. x Time | $F_{9, 32}$ =0.62 | 0.771 |
| **Rio Grande** | | |
| Conc. | $F_{3, 32}$ =87.87 | <0.001 |
| Time | $F_{3, 32}$ =0.78 | 0.516 |
| Conc. x Time | $F_{9, 32}$ =0.69 | 0.710 |
| **Tanya** | | |
| Conc. | $F_{3, 32}$ =43.27 | <0.001 |
| Time | $F_{3, 32}$ =0.31 | 0.817 |
| Conc. x Time | $F_{9, 32}$ =0.58 | 0.804 |

Note: Conc. = Concentration

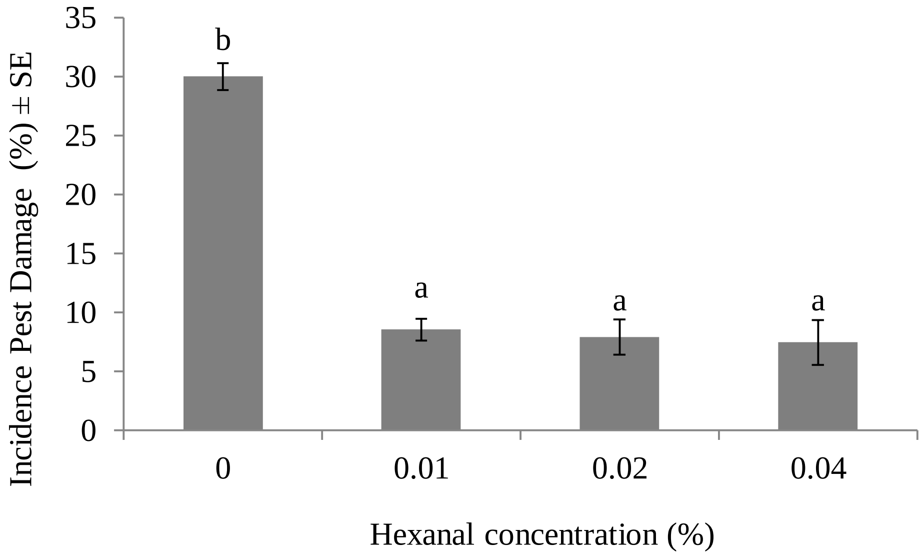


**Figure 8.5: Mean of incidences of pest defects of Mwanga tomato cultivar ($F_{(3, 8)} = 61.24$, $p < .001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

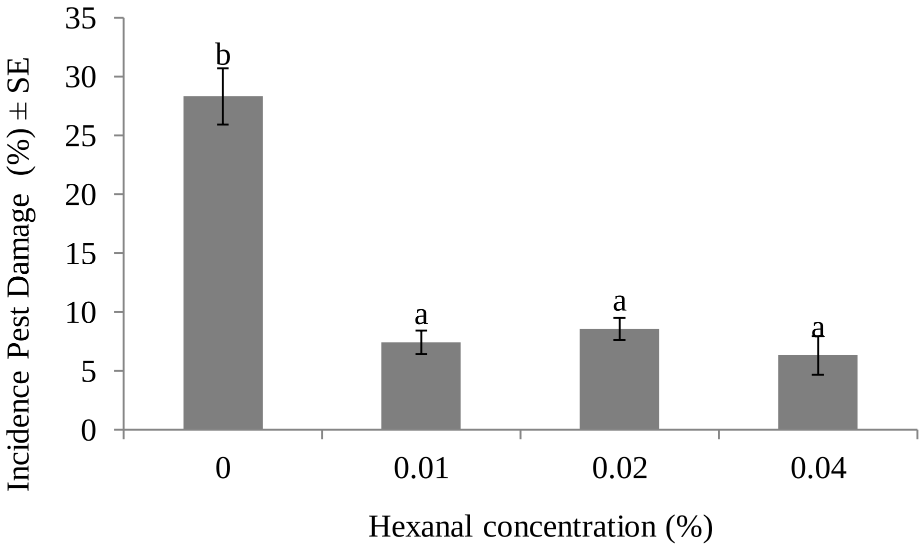


**Figure 8.6: Mean of incidences of pest defects of Rio Grande tomato cultivar ($F_{(3, 8)} = 43.27$, $P < .001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

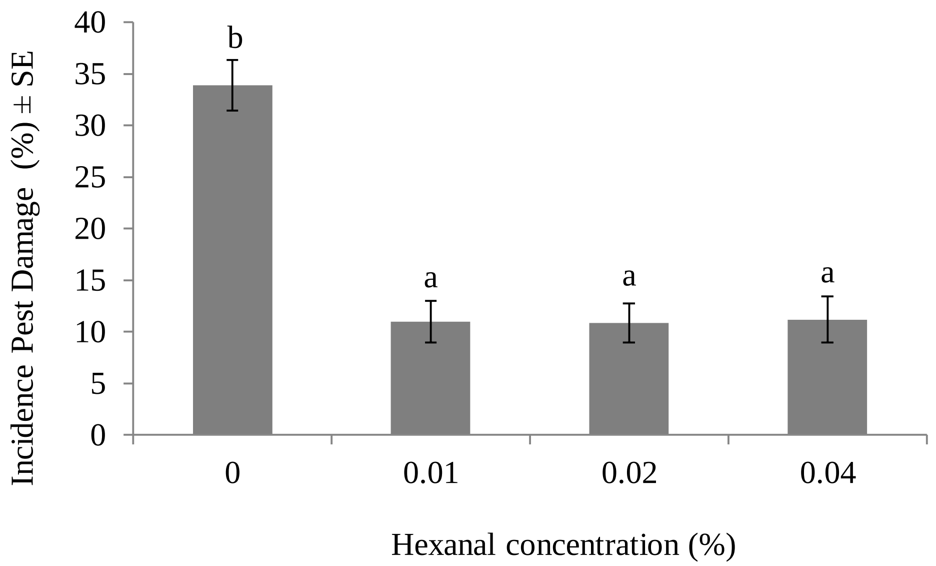


**Figure 8.7: Mean of incidences of pest defects of Tanya tomato fruits cultivar ($F_{(3, 8)}$ = 23.23, $P < .001$), Post Hoc Tukey test = HSD $_{(p=0.05)}$.** Means bearing the same letter(s) are not significantly different. Error bars represents ± 5% standard error around sample means

## 8.4 Discussion

The results of the present study indicate the application of various concentrations of hexanal significantly reduced number of non-marketable yield on tomato cultivars (Mwanga, Rio Grande and Tanya). However time of hexanal application had non-significant effects on number of non-marketable fruits of all three tomato cultivar. Specifically, the application of hexanl reduced non marketable fruits by decreasing the incidences of diseases (early and late bright and stem cancer), insect pests (tuta abusoluta (*tomato leafminer*) and aphids) and physiological disorders (fruit blossom end rot and cracking). These results are supported by previous studies where pre-harvest hexanal application decreased the incidences of pest defects on mango, apple and pear fruits (Sholberg and Randall, 2007; Anusuya *et al*., 2016) particularly anthracnose, stem end rot, mould and bacteria in mango varieties (Anusuya *et al*., 2016). According to Bojan *et al*. (2016), hexanal reduces fungal pathogens of *Colletotrichum glaeosporioides* and *Lasiodipladia theobromae* which cause anthracnose and stem end rot on mango.

Moreover, hexanal effectively controls both blue and gray moldsin peach and lesion development of *P. expansum* in apple (Sholberg and Randall, 2007). Hexanal has antifungal properties and thus reduces fungal infections (Karthika *et al*., 2015). Hexanal also increases maximum defence related enzymes such as peroxide, polyphenol oxidase, phenylalanine ammonia-lyase, superoxide dismutase and catalase in mango fruits against pathogens (Seethapathy *et al.*, 2016). According to Sholberg and Randall (2007), hexanal can exhibit antifungal properties by altering the lipoxygenase pathway. Lipoxygenase are key enzymes that play an important role in the response of plants to wounding and pathogen attack (Gobel *et al*., 2001). Aldehydes including hexanal derived from the lipoxygenase pathway induce a subset of defence related genes (Kuo and Gadner, 2005). Also, Cheema *et al*. (2014) reported that when tomatoes treated with hexanal solution increased their resistance to pathogens simply because hexanal strengthens the fruit cell wall structures and thus drastically reduces pathogen penetration and infections (Ahemad and Kibret, 2014; Wang *et al*., 2014). Hexanal also increases maximum defence related enzymes such as peroxide, polyphenol oxidase, phenylalanine ammonia-lyase, superoxide dismutase and catalase in mango fruits against pathogens (Seethapathy *et al*., 2016).

## 8.5 Conclusions and Recommendations

The objective of this study was to determine the effects of application of hexanal on pre-harvest tomato losses. Field application of hexanal at 0.01% remarkably improves Pre-harvest tomato marketable yield by reducing non-marketable yield and pest defects for Mwanga, Rio Grande and Tanya cultivars. It is recommended that farmers should apply hexanal at 0.01% from 21 to 7 days prior to fruit harvest in order to reduce non-marketable yield and pest defects of tomato in Mwanga, Rio Grande and Tanya cultivars. Further studies are required to evaluate the effect of pre-havest hexanal application on keeping quality of tomato fruits after harvest. Further studies also required to determine the effect of hexanal application on non-marketable yield and pest defects of tomato cultivars during the dry season.

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# CHAPTER NINE

# GENERAL CONCLUSIONS AND RECOMMENDATIONS

## 9.1 Conclusions

The objectives of the present study were to (1) investigate relative contribution of individual market attributes used by buyers in selecting fruits, (2) determine the effects of pre-harvest hexanal application on fruit market attributes, and (3) determine the effects of field application of hexanal on pre-harvest fruit losses.The main fruit attributes which enhance marketing, longevity and endurance of mango and orange are fruit freshness, colour, spots free on fruit peel and firmness. Pre-harvest hexanal application at 0.01% can improve fruit attributes namely firmness and marketable yield of orange varieties (Early Valencia, Jaffa and Late Valencia), mango varieties (Apple, Palmer and Keitt) and tomato cultivars (Mwanga, Rio Grande and Tanya). Moreover, pre-harvest hexanal application at 0.01% can increase marketable yield of mango, oranges and tomato (Early Valencia, Jaffa, Late Valencia Apple, Palmer and Keitt) by reducing fruit drops from plants and pest infestation. And reduced pest infestation for Mwanga, Rio Grande and Tanya .The pest infestation reduced by hexanal are anthracnose, fruit flies, aphids, stem end rot, black spots, early and late bright, stem cancer and tuta abusoluta. Pre-harvest hexanal application also reduced physiological fruit damage namely blossom end rot and cracking in mango, orange and tomato.

## 9.2 Recommendations

### 9.2.1 Recommendation for application of hexanal concentration

It is recommended that farmers should use hexanal at 0.01% to reduces pre-harvest fruit losses, and increase quality and marketable yields of of orange (Early Valencia, Jaffa and

Late Valencia), mango (Apple, Palmer and Keitt) and tomato (Mwanga, Rio Grande and Tanya).

### 9.2.2 Recommendation for further studies

Further studies are required on the following:

1) Hexanal research should be extended to other horticultural crops grown in Tanzania like pawpaw, grapes and avocado.
2) Determinate effects of hexanal on postharvest fruit quality and fruit losses of orange, mango and tomato.
3) Determine if there are residue effects of hexanal in next season.

# APPENDIX

## Appendix 1: PhD research questionnaire

# Sokoine University of Agriculture

## PhD RESEARCH QUESTIONNAIRE

**Instructions:**

1) Please make sure you introduce yourself and explain the purpose of the study as per introduction presented after these instructions
2) Ensure that you adequately complete the questionnaire at the time of interview
3) Record answers appropriately in the space provided before asking the next question, where necessary use extra writing materials (empty of this questionnaire)
4) Use pencils
5) Remember to thank the respondent after the interview
6) Options of ‘’other’’ need to be followed by the details.
7) Throughout use **-9** for ‘Don’t know” and **-8** for Information, which is missing’ information’

Good morning/afternoon/evening, my name is __________I am working for a Project at Sokoine University of Agriculture, which is implemented in this place. The project aims at improvement of livelihood, especially increasing income and creating opportunities for employment. Also the project intends to assess differences in terms of other benefits and cost for males and females in fruit production. As the implementation of the Project it is going on, it is important to collect market attribute information as a basis for evaluating the impact of the project in the future. You have been randomly chosen to participate in this project to give detailed information. I would like to assure you that the information provided will be used for the intended purpose only and your identity will never be disclosed when such information is presented. Please feel free to answer the questions that will be asked.

| | | |
|---|---|---|
| Q1 | Enumerator’s name ______________________________ | |
| Q2 | Date of interview ________________________________ | |
| Q3 | District _______________________________________ | |

| | | |
|---|---|---|
| Q4 | Ward ________________________________________ | |
| Q5 | Village _______________________________________ | |
| Q6 | Name of Household head _______________________ | |
| Q7 | Name of respondent _________________________ | |
| Q8 | Sex of interviewee: _____________<br>0=Male<br>1=Female | **Fill in the value**<br>**( 0 or 1)** |
| Q9 | Age of interviewee (**in years**) | ___________ |
| Q10 | Interviewee category<br>1=Farmer<br>2=Trader<br>3=Consumer | _____ |
| Q11 | Type of fruit crop produced/marketed/purchased<br>1 = Orange<br>2 = Mango | _____ |
| Q12 | Experience in production/marketing/purchasing the fruit | _____ (Years) |
| Q13 | How important are the following fruit attributes in enhancing **marketing**<br>1 Colour intensity ______________<br>2 Firmness ______________<br>3 Small-sized fruits ______________<br>4 Medium-sized fruits _____________<br>5 Big-sized fruits ______________<br>6 Sports free ______________<br>7 Freshness ______________ | **Rank the attributes**<br>1=Not important<br>2= Important |
| Q14 | How important are the following fruit attributes in enhancing fruit **longevity**<br>1 Colour intensity ______________<br>2 Firmness ______________<br>3 Small-sized fruits ______________<br>4 Medium-sized fruits ______________<br>5 Big-sized fruits ______________<br>6 Sports free ______________<br>7 Freshness ______________ | **Rank the attributes**<br>1=Not important<br>2= Important |
| Q15 | How important are the following fruit attributes in | |

| | | | |
|---|---|---|---|
| | enhancing fruit **endurance** | | **Rank the attributes**<br><br>1=Not important<br>2= Important |
| | 1 | Colour intensity ______________ | |
| | 2 | Firmness ______________ | |
| | 3 | Small-sized fruits ______________ | |
| | 4 | Medium-sized fruits ______________ | |
| | 5 | Big-sized fruits ______________ | |
| | 6 | Sports free ______________ | |
| | 7 | Freshness______________ | |
| Q16 | Is there anything else about your farm or your work that you would like to talk about today? | | |