NUTRITIONAL AND POSTHARVEST QUALITY ATTRIBUTES OF COMMERCIAL TOMATO VARIETIES

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MASTER OF SCIENCE

(Food science and nutrition)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

2016

Nutritional and postharvest quality attributes of commercial tomato varieties

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A thesis submitted in partial fulfillment for the degree of Master of Science in Food Science and Nutrition in the Jomo Kenyatta University of Agriculture and Technology

2016

DECLARATION

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

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DEDICATION

This thesis is dedicated to my late parents Mr. and Mrs. Kubai with love.

ACKNOWLEDGEMENT

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ABBREVIATIONS AND ACRONYMS

USDA   United States Department of Agriculture

AVRDC   The World Vegetable Center

HCDA   Horticulture Crops Development Authority

FAO   Food and Agriculture Organization

AOAC   Association of Official Analytical Chemists

TSS   Total Soluble Solids

TTA   Total Titratable Acidity

CRBD   Completely randomized block design

HCDA   Horticultural Crops Development Authority

KARI   Kenya Agricultural Research Institute

GC   Gas Chromatography

HPLC   High Performance Liquid Chromatography

^{o}C   Degree centigrade

FID   Flame ionization detector

TCD   Thermal conductivity detector

DPPH   2, 2-Diphenyl-1-picryl hydrazyl

ABSTRACT

Tomato (*Lycopersicon esculentum* Mill) is the leading vegetable in terms of production in Kenya. The Kenyan local market has a wide variety of tomato cultivars with a wide range of morphological and sensorial characteristics but information on the nutritional and postharvest quality of these varieties is limited. The objective of this study was to investigate and identify tomato varieties of superior postharvest and nutritional quality. The study was conducted over two seasons in 2014. In the first season, thirteen tomato varieties were grown in a greenhouse. The tomatoes were harvested at three maturity stage (mature green, turning and red ripe) and stored at ambient room conditions (Temperature: 25^0C). For each variety and maturity stage, analysis of postharvest characteristics including cumulative weight loss, skin color changes, and ethylene production and respiration rates was done. The fruits were also analyzed for phytochemical and nutritional quality attribute including lycopene content, antioxidant capacity, total soluble solid content and total titratable acid. In the second season, eight varieties were grown for confirmatory studies on respiration and ethylene production rates. Significant differences ($p< 0.05$) was then determined for the data. The percentage weight loss of the tomato fruits relative to the initial was lowest in the Anna F1 (0.16%) at the mature green stage and highest in Nuru F1 (3.80%) at the turning stage. The respiration rate peaks in the first season ranged between 82.82-23.67 ml $CO_2 Kg^{-1} h^{-1}$ compared to 43.34-9.82 ml $CO_2 Kg^{-1} h^{-1}$ in the second season while the ethylene peaks in the first season ranged between 8.30-0.34 µl $C_2H_4 kg^{-1}h^{-1}$ compared to 5.51-0.97 µl C_2H_4 $kg^{-1}h^{-1}$ in the second season. The lycopene content was highest in Rambo (27.53 mg/100g) and the lowest in Cal J (0.41mg/100g). The lycopene content and antioxidant capacity were highest at the red ripe stage. Generally, the Anna F1 and Chonto F1 varieties displayed better postharvest quality that can prolong the shelf life of the fruits while for better phytochemical properties, harvesting at red ripe stage is recommended. In turn the turning stage of maturity proved to be a better stage to harvest tomatoes.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tomato (*Lycopersicon esculentum Mill*) belongs to the Solanaceae family that has about 3,000 species of economic importance such as potatoes, eggplant and pepper. It is one of the most popular vegetable in the world with a world production of about 160 million tons from an estimated 4.8 million ha (FAO, 2014). China is the largest producer accounting for about a fourth of global output followed by India and the United States. Tomato production in Kenya in 2014 was 400,204 Mt with a production area of 24,074 Ha, valued at Kshs 11.8 Billion. In Kenya, the three leading tomato producing counties are Kirinyaga, Kajiado and Bungoma (HCDA, 2015). The production volumes have steadily increased over the years to meet the rising demand in tomato due to its health promoting benefits.

Tomato production in Kenya has been mainly done under open field conditions until the adoption of modified high tunnels popularly known as 'greenhouses' (GOK, 2012). Green house production creates an ideal production environment that includes ideal relative humidity, temperature and light. These results in high yields, efficient water utilization, high fruit quality, prolonged production, shortened maturity period, low pest and disease incidences, reduced use of land to achieve the same results i.e. ratio of about 1:10, low labor input and timing of market. It takes a shorter period, two months, for greenhouse-produced tomatoes to mature, while it takes a minimum of three months with outdoor (field) farming (Dobson *et al.,* 2002). Due to controlled irrigation and temperatures, the crop sports a continuous output of flowers and fruits, all at different stages and hence year-round supply of tomatoes.

There is significant evidence that regular tomato consumption decreases the incidence of chronic degenerative diseases such as certain types of cancer and cardiovascular diseases

and improvement of the immune system (Wang, 2012). The beneficial effects of tomato consumption are generally attributed to carotenoids, particularly lycopene which have antioxidant activity (Fiedor & Burda, 2014; Amorim-Carrilho *et al.,* 2014). The tomato fruit is also a reservoir of potentially healthy molecules, such as ascorbic acid, vitamin E and phenolic compounds (Böhm, 2012; Abdul-Hammed *et al.,* 2014) .

Despite increased production, postharvest losses occur between harvest and consumption (estimated to be between 15-40% in fruits and vegetables in developing countries) (James & James, 2010). The losses in tomato are aggravated by the continuous year-round supply. Tomatoes are highly perishable with a very short shelf life of 3 – 7 days depending on the harvest maturity (Gould, 2013). Appropriate harvesting, storage, transportation and distribution are therefore important in maintaining fruit and vegetable quality and minimizing the losses. Tomatoes can be harvested at the mature green stage or the breaker stage to minimize their losses caused by handling and during transport (Moneruzzaman *et al.*, 2008; Tigist *et al.,* 2013) . Postharvest losses of tomatoes (qualitative and quantitative) result from poor postharvest handling practices and lack of appropriate postharvest technologies.

There are new tomatoes varieties which have been developed over the years and have superior nutritional and postharvest qualities. Some of these varieties have been adopted by farmers. However indiscriminate adoption of varieties by farmers without proper consideration of the end use remains a major challenge in meeting the market demand.

1.2 Problem Statement

The Kenyan local market has a wide variety of tomato cultivars with a wide range of morphological and sensorial characteristics which determine their use. To maximize yields most of the Kenya tomato farmers grow imported hybrid tomato varieties. However, these varieties are bred under a different agro ecological conditions and information on their nutritional and postharvest characteristics under local conditions is lacking. The various tomato varieties have different characteristics suited for different

uses/markets such as fresh market (cooking), dessert or processing. However farmers are not sure which variety to grow for which target market. This lack of knowledge contributes to seasonal postharvest losses during period of glut on one hand and insufficient supply on the other hand during low seasons. When selecting tomatoes to grow, farmers base their choice on varieties that are high yielding, resistant to disease and pest and also bring in good returns.

1.3 Justification

Most of the high yielding hybrid tomato varieties grown by Kenyan farmers are imported from either Europe or South Africa. The varieties vary in terms of their physical, nutritional and shelf life characteristics (Owino *et al.,* 2015). Imported hybrid tomato varieties are more preferred in Kenya because they have better growth characteristics such as high yields, resistant to disease and pest, as opposed to local tomato varieties. In the last three years, consumer quality demands have been changing towards high quality produce (Grade 1 tomatoes). Some of the imported hybrid varieties also have a longer shelf life and are therefore preferred by the farmers (GOK, 2012). However the nutritional composition and shelf life characteristics of these tomato varieties grown under local environmental conditions are largely unknown. Characterization of their nutritional value and postharvest characteristic will generate information that will enable farmers, traders and processors to make informed choices on which varieties to suit the target market and end use. Production of the right variety for the specific market will help in minimizing postharvest losses and guard against low returns experienced by farmers.

1.4 Objectives

1.4.1 Main objective

To characterize the nutritional and postharvest qualities of selected commercial tomato varieties grown in Kenya

1.4.2 Specific Objectives

1. To determine the physical characteristics (weight loss and color) of thirteen tomato varieties harvested at three stages of maturity
2. To analyze the physiological properties (ethylene and respiration rates) of these tomato varieties harvested at three stage of maturity
3. To determine the phytochemical and nutritional composition (lycopene content, antioxidant capacity, soluble solids and titratable acidity) of these tomato varieties harvested at three stages of maturity.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and botanical classification

Tomato (*Lycopersicon esculentum* Mill) (from the Solanaceae family) originated from the South American Andes and spread to Europe by the Spanish conquistadors in the 16th century and later to the southern and eastern Asia, Africa and the Middle East (Rick, 1976; Taylor, 1986).

2.2 Production in the World and Kenya

Tomato fruits are an important source of nourishment for the whole world with a world production of about 160m tons fresh fruits from 4.8 million Ha in 2013 (FAO, 2014). China is the largest producer accounting for about a fourth of global output followed by India and the United States. Tomato production in Kenya in 2013 was 400,204 Mt with a production area of 24,074 Ha, valued at Kshs 11.8 Billion.

Table 2.1: Tomato production in Kenya, 2010-2013

Year	2010	2011	2012	2013
Area (ha)	17,529	18115.9	18612.98	24,074
Production (tons)	378756	395297.8	397008.1	400204
Value Kshs (million)	10.4	11.2	12.8	11.8

Source: HCDA validated report, 2014

Tomato is among the most promising commodities for horticultural expansion and development in Kenya, accounting 14% of the total vegetable produce and 6.72% of the horticultural crops (GOK, 2012). In Africa, Kenya is the sixth country in terms of tomato production. The three leading tomato producing counties are Bungoma (50,399

Mt), Kirinyaga (48,560 Mt) and Kajiado (47,368 Mt) (HCDA, 2015). The tomato produced is locally marketed within Kenya and around East Africa countries.

Table 2.2: Tomato production in selected counties, 2010-2012

COUNTY	2010			2011			2012		
	Area (Ha)	Quantity (Ton)	Value Kshs (million)	Area (Ha)	Quantity (Ton)	Value Kshs (million)	Area (Ha)	Quantity (Ton)	Value Kshs (million)
Kirinyaga	1890	43612	927.2	1638.8	44290	623.7	1917.8	54524	1070.2
Taita Taveta	1690	70328	1507.9	477	22896	572.4	548	27400	959.0
Kajiado	1024	25706	573.6	934.5	42920	1021.5	1551	36460	989.7
Bungoma	837	11793	340.3	571	13133	528.8	1022	21720	887.0
Meru	761	19304	578.8	895.7	6658	99.2	420	22214	468.4
Migori	628	12300	538.0	920	17779	789.6	1068	18429	910.1
Homa Bay	618	7681	247.3	1713	14754	688.6	803	13120	637.9
Nakuru	491	7986	308.8	670.7	13484	311.9	580.5	10990	257.0
Machakos	202	6284	125.6	350	8317.72	263.9	314	10240	357.2
Makueni	172	3795	121.2	380.4	16219	616.2	407.7	17551	681.5
Kilifi	167	5980	149.5	313	10280	235.5	280.4	8403.5	242.2
Kiambu	142	1155	30.9	1136	28836	1170.8	930	20972	883.5

Source: HCDA validated report, 2013

Greenhouse production of tomatoes in Kenya started to increase as from 2007 (Makunike, 2007). This was through promotion by stakeholders such as Horticultural Crops Development Authority (HCDA, 2015) through the Kenya Horticulture Development Program (KHDP) in collaboration with the Ministry of Agriculture and agricultural input suppliers like Seminis seeds, Osho chemical industries and Amiran Kenya ltd.

Previously most of the tomato production in Kenya was mainly under field conditions and this greatly affected the supply of tomatoes in the market with shortage during off seasons and glut during in season. Use of greenhouses ensured constant supply of fresh

market tomatoes throughout the year. Tomato under open field production is grown in two main seasons, November to February and from April to June with peak production in May. Use of greenhouse is one of the cores areas the agricultural sector development strategies of 2010-2020, that seeks to boost agricultural production in rural areas, create employment and improve food security (GOK, 2010).

Tomato production in Kenya plays a great role in the generation of income, creating employment, foreign exchange and improving food security. However production is hindered by a number of factors such as pests and disease, poor postharvest technologies, poor market, poor road infrastructure, price fluctuations, poor quality open pollinated varieties and expensive hybrid varieties. In addition, tomato production is labor and water intensive which drives up production costs (Kennedy, 2008; Kitinoja *et al.,* 2011) . Tomato consumption has further increased since tomato supply both fresh market and processing market for products such as sauces, juices, soups and purees (Mungai *et al.,* 2000).

2.3 Cultivation of tomatoes
2.3.1 Breeding tomatoes

Seed is the most important input for increasing agricultural production in Africa. Use of hybrid seeds is a great option to increase yield of the tomato crop (Afari-Sefa *et al.,* 2012). Hybrids are produced by controlled hand pollination of male and female plant lines. Throughout the world there has been a considerable increase in use of hybrid tomato varieties since they have more advantages than the open pollinated varieties. Hybrids have high yields, are disease resistant and therefore expensive. Many farmers in Kenya are going for the hybrid tomato varieties though they are expensive. But since they are disease resistant they require less use of pesticides and also with high yields they give good returns to the farmer.

When developing new hybrids, the breeder puts into consideration the farmers, consumer and processors requirement. Some associated needs of farmers may be a

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variety with high yields and with low costs of production and the breeder meets these needs by breeding varieties with a high number of fruits and weight and resistant to pest and disease (Schroeder, 1993). Consumers may need tomatoes with high nutritional value and having better culinary appeal while processors may require varieties that give high product yield and high % of usable fruits.

2.3.2 Varieties of tomatoes

Tomato varieties can be broadly classified as determinate and indeterminate. Indeterminate varieties are usually trellised and pruned to 2-3 shoots per plant to achieve better plant health and quality while the determinate varieties are mostly left untrellised (Dobson *et al.,* 2002). Trellising involves supporting plants with sturdy material to keep the fruits and foliage off the ground. Pruning of tomatoes involves selective removal of side shoots to limit plant growth and to divert nutrients to flower clusters on the main stem (Amati *et al.,* 2002).

The indeterminate or tall type varieties are mainly for long harvest period. They keep growing after flowering but under tropical conditions, disease and pest attacks stop the growth. The variety has generally more foliage and this keeps the temperature lower within the crop and the fruit grows in the shade of the leaves. The fruits are therefore not damaged by the sun and ripen slowly. Slower ripening and a high leaf to fruit ratio helps in improving the taste of the fruit especially the sweetness (Tigist *et al.,* 2013). These varieties also require trellising, staking or caging. Determinate varieties normally stop growing after flowering and require no support or staking. They require less labor and therefore very popular for commercial cultivation. They also have a relatively concentrated fruit set which lasts two or three weeks and the fruits ripen much faster (Nasrin *et al.,* 2008).

Common determinate varieties in Kenya include; Kilele F1, Cal J, Assila, Oxyl, Faulu, Onyx F1, Rambo F1, Sandokan f1, Strike F1, Moneymaker, Fortune maker, Eden, Nuru

F1,Rio grande, Rio tinto, Libra F1 while the indeterminate varieties include Chonto F1, bravo F1, Samantha F1, Anna F1, Monalisa F2, harmony F1, Tylka F1, Proster F1.

Tomatoes can be divided into two groups depending on their use: for fresh consumption and for processing. Within each of these groups, specific cropping systems exist that require adapted varietal types (indeterminate or determinate). Varieties for fresh consumption can be cultivated in greenhouses and in the open air, while varieties for processing are only cultivated in the open air. Tomato varieties for fresh consumption should have open growth habit, high yield, earliness, external quality of fruits (shape, color, homogeneity), internal quality of fruits (flavor, sweetness, juiciness), long shelf life, adaptation to growing systems and resistance to biotic and abiotic stresses (Prohens-Tomás & Nuez, 2007. The characteristics needed in the tomato for processing include, compact growth habit of the plant, grouped flowering and ripening, presence of the recessive jointless gene which facilitates the detachment of the fruit without the peduncle, homogeneity of fruit shape and size, high consistence, resistance to cracking, lack of scar at the point of insertion with the calyx, lack of puffiness, flexible skin to facilitate peeling, thick and firm pericarp, round, smooth plumb- or pear-shaped fruits and red, uniform color (Causse *et al.,* 2003). The fruits must also have other internal characteristics related to processing quality such as high viscosity and dry extract, pH values between 4.2 and 4.4 and high values of total soluble solids.

2.3.3 Harvesting of tomatoes

Tomatoes are harvested at stages of maturity ranging from physiological maturity (mature-green stage) through full-ripe depending on the market and area of production. Immature tomatoes are also harvested for certain regional dishes (Teka, 2013). Tomato maturity can either be determined by either using the red color index classification or depending on the seed maturity and juice of the tomato. According to Kader & Morris (1976), tomato maturity can be classified in terms of seed and juice (internal appearance) as follows;

M-1: seeds are white in color (immature) and can be cut up when the tomato is sliced.

M-2: seeds have a tan color (mature) and some juice present.

M-3: seeds are pushed aside when cut and juice is still green.

M-4: the juice is red in color.

Tomatoes harvested at the M-2 stage will ripen to moderate quality, while those harvested at M-1 stage will not ripen to acceptable levels of quality. Ripeness stages as defined for red-fleshed tomatoes according to the external color (USDA, 2007):

1. Mature green stage: fruit surface is completely green and can range from light to dark green.
2. Breaker stage: break in color from green to tan yellow, pink or red on not more than 10% of the tomato skin.
3. Turning stage: over 10% but not more than 30% tomato skin is yellow, pink or red.
4. Pink stage: over 30% but not more than 60% of the tomato skin is pink or red.
5. Light red stage: over 60% is pinkish red or red but the red color covers not more than 90% of the tomato skin.
6. Red stage: more 90% of the tomato skin is red.

2.4 Postharvest quality changes

2.4.1 Pre-harvest and post-harvest factors affecting tomato quality

Distribution of tomatoes to the domestic and international market is greatly affected by the fruits short postharvest life, high susceptibility to chilling injury, mechanical damage and pathogens (Mutari & Debbie, 2011). After harvest tomatoes are still living tissues and therefore show sensory, microbial and nutritional quality changes with time and hence it is important to maintain their quality to reduce postharvest losses (Gonzalez-Aguilar *et al.,* 2010). Quality management starts in the field and continues until produce

reaches the consumer. Postharvest qualities in tomatoes depend on pre-harvest factors such as cultural practices, genetics and environmental conditions (Radzevičius *et al.,* 2009). Understanding and managing roles that pre- harvest factors play on quality of tomatoes is therefore important in order to achieve maximum harvest and post-harvest quality.

Quality of harvested tomato fruits is of major concern to growers because traders grade them according to external attractiveness like color, size, shape and skin defects or internal characteristics like taste and texture (Guichard *et al.,* 2005). Consumers judge fresh tomato quality in-terms of firmness, color, and taste which are related to ripeness and shelf life. Losses in quality and quantity of fresh vegetables and fruits occur between the harvest and consumption of the produce (Brooks *et al.,* 2008). These depend on three factors which are; reduction in desiccation, reduction in the physiological process of maturation and senescence and a reduction in the onset of microbial growth (González-Aguilar *et al.,* 2009).

2.4.2 Textural changes in tomatoes

Major changes in the texture of tomatoes occurs during ripening and is mainly associated with softening that considerably influences postharvest performance such as transportation, storage, shelf life and pathogen resistance (Brummell & Harpster, 2001). The ripening of fruits is complex and genetically programmed process that results in several changes such as texture, aroma, color and flavor of the fruit.

Maturation of tomato is accompanied with alterations in the texture of the fruit, more specifically the loss of firmness, due to structural changes in the principle cell wall components like cellulose, hemicellulose and pectin as they are modified and partially disassembled by enzymes. The decline in fruit firmness coincides with dissolution of the middle lamella, resulting in a reduction in intercellular adhesion, depolymerization, and solubilization of hemicellulosic and pectic cell wall polysaccharides and, in some cases, wall swelling (Brummell, 2006). The ripening is accompanied by the increased

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expression of numerous cell wall degrading enzymes, including polysaccharide hydrolases, transglycosylases, lyases, and other wall loosening proteins, such as expansin (Artés *et al.,* 2007). During storage, tomatoes soften as a result of the enzymes Pectin Methyl Esterase (PME) and Polygalacturonase (PG) activities which are associated with pectin modification. PME action leads to softening of the cell wall by disassembly of the primary cell wall and middle lamella through the process of de-esterification of pectin. According to Bennett & Labavitch (2008) these two enzymes are regulated by ethylene. Therefore it is recommended that tomatoes be harvested before ripening and ethylene burst, to prolong the short shelf life of the fruits after harvest.

Tomato fruits are harvested at various stages of ripeness and therefore the storage conditions depends on each stage (Harold *et al*., 2007). Ideal conditions for ripening are 19 to 21 °C with 90 to 95% RH. Fruits harvested at mature green stage or at the turning stage or breaker stage should not be stored at temperature lower than 12 ^{0}C as chilling injury may occur and hence affect ripening and quality of the tomatoes. Since tomatoes are prone to chill injury especially during the early stages of ripening, use of low temperature for storage of tomatoes is restricted. Fully ripe tomatoes can be stored at 2-5 ^{0}C for few days before consumption since color loss and softening may occur if they are held for a longer period (Maul *et al.,* 2000). The conversion of tomato fruit from mature green to red ripe stage involves changes in color, composition, aroma, flavor and texture.

2.4.2 Respiration in tomatoes

Respiration, transpiration and ethylene production are three main factors that contribute to deterioration of fruits and vegetables quality after harvest (Gonzalez-Aguilaret *et al.,* 2010). Tomato is a climacteric fruit and therefore its ripening is accompanied by a peak in respiration and a concomitant burst of ethylene (Alexander & Grierson, 2002). There exist an inverse relationship between respiration rate and shelf life of fresh produce and

therefore respiration is important in determining the shelf life of fresh fruits and vegetables (Mangaraj & Goswami, 2011).

The respiration rate is usually expressed as rate of oxygen consumption or carbon dioxide production per unit weight of the commodity. Respiration rate in tomatoes reflects the metabolic activity of the fruit tissue in the form of biochemical changes associated with ripening. Temperature and respiration quotient (ratio of volume of carbon dioxide released to the volume of oxygen consumed by a fruit tissue in a given period) are the two main factors that influence the rate of respiration (Rai & Paul, 2007). Accurate measurement of respiration is important in designing storage system for horticultural produce like tomatoes (Iqbal *et al.,* 2005). Respiration continues after harvest and this leads to major deterioration in both quality and quantity. Therefore a commodity with a lower rate of respiration is desired to contribute to extension of the products consumable period.

The tomato fruit may suffer damage of varying degrees during harvest, classification, packaging, transportation, loading and unloading and storage which in turn leads to the change in respiration and ethylene production rates, decline in quality and decrease in the storage time. Therefore, studying and forecasting the fruits respiration rate is not only essential for the fruit storage and preservation but also to have a directive significant to the fruit packaging design (Shoujiang & Dejing, 2006).

Respiration is a very important metabolic process in living cells including harvested fruits and vegetables and is responsible for energy production needed in growth and maintenance of cellular organization.

Respiration rate determination helps in investing the physiology of many fresh commodities such as tomatoes. This is because the storage life of fresh produce is inversely proportion to the rate of respiration (Valero & Serrano, 2010). Respiration provides the energy required to drive other metabolic processes that are related to quality parameters such as sugar content, flavor, aroma firmness, acidity and color and hence

the relationship. Therefore, for extended shelf life the rate of respiration has to be at the lowest level that is just enough to maintain the essential living activity in the harvested tomato fruit. Respiration brings about changes in chemical composition of a produce such as carbohydrates, proteins, lipids and organic acids substrates.

Several approaches are used in the determination of the rate of respiration such as the static system approach, flow through system approach, permeable system approach and model approaches. The static system is commonly used since it's easy and fast to set up and use. The system involves lacing the produce of known weight in an air tight container of known volume. Changes in the CO_2 and O_2 concentration (using gas chromatography) over time are determined and used to calculate the rate of respiration (Saltveit, 2005). Flow through system is also often used and the system involves enclosing the produce in an impermeable container ventilated with a known flow rate of air. The rate of respiration is calculated from the changes in gas concentration between the inlet and outlet of the container (Lencki *et al.,* 2004).

2.4.3 Ethylene production in tomatoes

Ethylene is a diffusible hormone that has an important role in plant growth and development, seed germination, leaf and flower senescence and abscission, root growth and development, somatic embryogenesis inhibition of stem and root elongation, flower formation, root hair development and root nodulation, leaf expansion, abscission, senescence and fruit ripening (Abeles *et al.,* 1992; Mattoo & Suttle, 1991) Plants show a great diversity of physiological responses to ethylene depending on the stage of development and organ or tissue. The diversity and amplitude of these responses shows existence of several molecular mechanisms of regulation by ethylene. For complete ripeness, tomato requires synthesis, perception and signal transduction of the plant hormone ethylene.

Ethylene production rate of fruits and vegetables is an important physiological activity in postharvest and also affects the storage lifetime of the produce (Lixin, 2005; Tiejin,

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2001). Ethylene biosynthesis is regulated by developmental processes as well as by numerous external stresses, such as wounding, very low and very high temperatures, drought, treatment with other hormones and attack by pathogens (Wang *et al.,* 2002; Pech *et al.,* 2002). The pathway of ethylene synthesis is well established in higher plants (Bleecker & Kende, 2002). Ripening in tomato consists of two phases of ethylene synthesis; system I (immature) and system II (mature). In System I ethylene is auto-inhibitory, functions during normal vegetative growth, and is responsible for basal levels of ethylene present in all tissues. In System 2, ethylene is auto stimulatory and operates in climacteric fruit and during petal senescence (Vrebalov et al., 2002). Ripening in tomatoes proceeds toward external tissue progressing from the blossom end toward the calyx as ethylene diffuses freely from cell to cell and integrates the ripening process throughout the fruit.

Tomato fruits produce moderate amounts of ethylene at 1 to 10 $\mu L\ kg^{-1}\ h^{-1}$ at 20 °C and are sensitive to ethylene exposure. Ethylene levels as low as 0.5 $\mu L\ L^{-1}$ is sufficient to trigger ripening and other associated metabolic processes (Abeles *et al.,* 1992). For commercial ripening, green tomatoes are held at 20 to 21 °C with 90% RH and 50 $\mu L\ L^{-1}$ ethylene to promote uniform ripening. Upon reaching breaker stage, tomatoes produce sufficient ethylene and no longer require use of commercial ethylene for ripening. Tomatoes harvested at the mature green stage will have high quality ripeness if they get to the breaker stage after 3 days of exposure to ethylene.

2.4.4 Color and lycopene

Tomato fruit color is an important attribute of fruit quality that helps assess ripeness and maturity, postharvest life and consumer decision of purchase. Its uniformity is also a principal requirement as a quality standard for tomato export. Color is usually the first characteristic that consumers look at in evaluating the quality the tomato fruit. Color also serves as a measure of total quality for tomato and tomato products. The color is due to the presence of diverse carotenoid pigment system with appearance conditioned

by pigment types and concentrations and affected by genetic and environmental regulation (Arias *et al.,* 2000; López Camelo & Gómez, 2004). The red color results from chlorophyll degradation and synthesis of lycopene and other carotenoids, as chloroplast are converted into chromoplasts (Brandt *et al.,* 2006). During fruit ripening maximum concentration of α and β – carotene occur at the turning and breaker stages while lycopene accumulates in the later stages.

After separation from the plant the tomato fruit has continued metabolic activities that cause color change after harvest (Vigneault *et al.,* 2012). The tomato color changes from green to red when harvested at the mature green stage. The process of color change is accelerated by ethylene induction. Chlorophyll degrades rapidly as the fruit ripens while lycopene accumulates at the later stage of ripening to give the tomato the intense red color. In case of a delay in ripening, there may be a period between chlorophyll degradation and lycopene accumulation presenting a yellow – orange hue of β-carotene.

The characteristic red color of ripe tomato fruits and tomato products is mainly due to lycopene and serves as a measure of quality. Lycopene in tomatoes is an important contributor of carotenoids to the human diet (Luna-Guevara *et al.,* 2014). Lycopene is the most abundant carotenoid in ripe tomatoes, comprising approximately 80 to 90% of the pigments present. Other carotenoids such as α-carotene, β-carotene, lutein, and β-cryptoxanthin are negligible. At least 85% of our dietary lycopene comes from tomato fruits and tomato based products, the remainder is obtained from water melons, pink grapefruit, guava and papaya. The lycopene content in fresh tomato fruits depends on variety, maturity, and the environmental conditions under which the fruit matured (Moneruzzaman *et al,* 2008; Brandt *et al.,* 2006). The content of lycopene usually increases as the fruit ripens from the mature green to the red ripe stages.
Chlorophyll is the dominant pigment in the early stages of tomato fruit maturation. As the maturation continues, the chlorophyll degrades and the color change from green to white. When chlorophyll is reduced, lycopene is biosynthesized with concomitant changes in the ultrastructure of the fruit, which results in the color change from white to

red. The largest concentrations of lycopene are found in the pericarp. The typical bright red color in ripe tomatoes is due to the elongated and needlelike crystals of lycopene. Lycopene is very sensitive to light, heat, oxygen and acids in degradation and some metallic ions such as Cu^{2+}, Fe^{3+} catalyze its oxidation.

Lycopene is among the most efficient singlet oxygen quenchers of the natural carotenoids (Luna-Guevara et al., 2014) The antioxidant activity of lycopene is highlighted by its singlet oxygen ($O_2\ ^{\cdot-}$) quenching property and ability to trap peroxyl radicals (ROO.) .The potential reduction is related to the formation of the superoxide radical anion (Fiedor & Burda, 2014).

Since lycopene is the most efficient singlet oxygen quencher among biological carotenoids, its presence in the human diet has become of considerable interest (Holzapfel *et al.,* 2013). The ability of lycopene to function as an antioxidant may contribute to reduction in risk of some diseases. Increasing clinical evidence supports the role of lycopene as an important micronutrient, as it appears to provide protection against prostate cancer, lung cancer, and a broad range of epithelial cancers (Böhm, 2012; Wei & Giovannucci, 2012).

The absorption and bioavailability of lycopene in the human diet is reported to be highly variable and can be affected by a number of dietary factors and food properties. These factors include molecular linkage, amount of lycopene consumed in a meal, food matrix in which the lycopene is incorporated, co-ingestion of high amounts of dietary fiber, co-ingestion of fat as a delivery medium, effects of absorption and bioconversion, interaction of lycopene with other carotenoids and nutrient components, chlorophyll and xanthophyll contents, particle size of the material, dietary protein content and genetic factors (Shi & Maguer, 2000; Taber *et al.,* 2008; Willcox *et al.,* 2003).

Lycopene is particularly important due to its influence on production and quality as a natural color and nutrient for the food and pharmaceutical industries. Lycopene and other carotenoids are used as natural colorants for food use without toxicological evidence in the same manner as vegetable and fruit products. Consumers, researchers, and the food industry have also dramatically increased their interest and awareness of

the health benefits of lycopene from tomatoes. At present, lycopene content is not a critical factor in tomato production. More efforts are required to produce lycopene-rich tomato varieties and improve lycopene content through proper management and cultural practices. The lycopene content in tomato fruits could be enhanced by improved techniques in fertilizer, harvest time, and variety selection research (Shi & Maguer, 2000).

2.5 Tomato processing

Tomatoes are perishable and must either be consumed rapidly or preserved for later consumption. Tomatoes are consumed either fresh or processed into tomato paste, sauce or juice. More than 80% of processed tomatoes are consumed in the form of tomato juice, paste, puree, catsup, sauce, and salsa (Gould, 2013). Because not all fresh tomatoes can be consumed after harvest, preserved tomato products provide a larger market, allowing consumers to buy the product all year-round.

There are several parameters both external and internal considered when choosing tomatoes for processing. For the external aspects they have to be uniform in size and shape, uniform and intense red color, no cracking, small pedicel scar and flexible skin that easily peels off. The outer and radial pericarp should be heavy and firm in order to reduce losses during harvest and transport, with the central pericarp column firm and thick, locules lacking puffiness and with an optimum number of three. Internal attributes desired include an intense red color and a range of between 4 and 6° brix (Yousef & Juvik, 2001). The soluble solids content is also important especially for the processing of tomato concentrate. Viscosity of the tomato pulp depends on the quantity of soluble pectin and this in turn affects the consistency of different processed products such as ketchup, sauces and juices. The pH must be below 4.4 and this directly affects the preservation of the final product. The sugar/acid ratio is very important in determining the flavor and aroma of tomato and consequently the processed product. In addition, volatile compounds also affect the aroma. Industrial processes normally help in

optimizing and maintaining the flavor and aroma (YILMAZ, 2001). Depending on the desired end product, the tomato varieties must have different quality characteristics.

Interaction between sugars and acid in tomatoes is important in determining sweetness, sourness and flavor intensity. The major organic acids in tomatoes are citric acid and malic acid. Tomatoes are not low acid food and therefore require less drastic thermal treatments than foods classified as low acid (pH >4.6), so as to destroy spoilage micro-organisms to ensure food safety. The ratio of soluble solids and acid is used as a criterion for ripening index and degree of fruit acceptance (Saltveit, 2005).

Lycopene is an important ingredient as a natural color in food formulations. There is widespread use of tomato paste as a colorant in commercial processing. However, lycopene undergoes degradation via isomerization and oxidation during tomato processing, which affects the final product sensory quality and health benefit (Klee & Giovannoni, 2011).

2.6 Nutritional importance of tomatoes

Tomato fruit forms an important constituent of the human diet, being a low energy dense food that provides essential vitamins and antioxidants. Tomatoes contain about 5 to 10% dry matter, of which 75% is soluble, and 1 to 3% is skin and seed. A half of the total dry matter is reducing sugars and 10% organic acid, principally citric and malic acids. Compositionally, the tomato has a unique nutritional and phytochemical profile. They are a rich source of beta carotene, folate, potassium, vitamin C, vitamin E, flavonoids and lycopene (Southon, 2000; USDA, 2015). In addition they also contain several trace elements, including iron, phosphorus, magnesium, niacin, potassium, thiamine, riboflavin and folate (Crozier *et al.,* 2000). The pericarp tissue provides a source of fiber (cellulose and lignin). During the process of fruit ripening, changes in texture, color, flavor and aroma occur in addition to alteration in levels of vitamins and antioxidants.

Tomato fruits are an important source of substances with known health beneficial effects on health including vitamins, minerals and antioxidants (Frusciante *et al.,* 2007). Tomatoes are rich in antioxidants, such as lycopene, vitamins E and C, *β*-carotene which serves as a provitamin A, and phenolics, such as *ρ*-coumaric and chlorogenic acids. The major phytochemicals in tomato are the carotenoids consisting of 60% to 64% lycopene, 10% to 12% phytoene, 7% to 9% neurosporene, and 10% to 15% carotenes.

Many factors such as environment (temperature, light, and air composition), cultural practices (ripening stage and irrigation system) and genetics (cultivar and variety) affects the chemical composition of tomatoes (Jesús Periago *et al.,* 2009). Fruit consumption has been associated with reduced risk of inflammatory processes, cancer and chronic non-communicable diseases (Canene-Adams *et al.,* 2005). Antioxidants are important in disease prevention in human beings. The activity of antioxidants is based on inhibiting or delaying the oxidation of biomolecules by preventing the initiation or propagation of the oxidizing chain reaction.

Tomato fruits are consumed fresh in salads or cooked in sauces and soup. They can also be processed into purées, juices, ketchup, canned and dried tomatoes.

2.6.1 Antioxidant capacity of tomatoes

Apart from having nutritional value and adding flavor and color to food, tomatoes are a valuable source of antioxidants compounds and thus referred to as a "functional food" (Wang, 2012).The health stimulating effect of tomatoes is due to their antioxidant properties. Antioxidants are important in disease prevention in animals and human beings. The antioxidants in tomatoes and tomato products provide cardio-protective effect, antiplatelet activities and reducing blood lipid levels (Fuentes *et al.,* 2012; Hsu *et al.,* 2008).

Antioxidant biomolecules are present in tomatoes include lycopene, ascorbic acid, phenolic compounds, flavonoids and vitamin E. Carotene are the major antioxidants in

tomatoes with lycopene being the dominate carotene (Radzevičius *et al.,* 2009). β-carotene is the second most important carotenoid in tomatoes. Carotene amounts in tomatoes as well as their antioxidant activity are influenced by tomato variety, maturity stage and the growth conditions (Arias *et al.,* 2000). Antioxidant functions are associated with lowering DNA damage, malignant transformation, and reducing biological oxidative damage of proteins, lipids, and other cell components *in vitro.*

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study material

The imported hybrid varieties were bought from a leading Agro- vet in Thika town (**Table 3.1**).

Table 3.1: Varieties, seed producer and growth behavior of the tomatoes grown

Variety abbrev.	Variety name	Seed producer	Growth behavior
A	Anna F1	Monsanto Kenya Ltd	Indeterminate
B	Bravo F1	Kenya Highland Seed	Indeterminate
C	Chonto F1	Kenya Highland Seed	Indeterminate
E	Eden F1	Monsanto Kenya Ltd	Determinate
F	Fortune maker	Simlaw seeds	Determinate
K	Kilele F1	Syngenta	Determinate
N	Nuru F1	East Africa Seed Co.	Determinate
R	Rambo F1	Kenya Highland Seed	Determinate
AS	Assila F1	Monsanto Kenya Ltd	Determinate
CJ	Cal J Supreme	Simlaw seeds	Determinate
L	Libra F1	Simlaw seeds	Determinate
RG	Rio Grande	Kenya Highland Seed	Determinate
RT	Rio Tinto	VetAgro Ltd	Determinate

The seeds were planted directly in paper pots (two seeds per pot) (10 X 12 x 150g LD Perforated). The pots were filled with sterilized soil and organic manure mixed in a ratio of 2:1. Support was provided to the tomatoes 50 days after planting. Crops were maintained by weeding, watering twice a day and pruning regularly.

3.2 Study site

The seeds were grown at JKUAT experimental research farm under greenhouse conditions and adequate water. Thirteen tomato varieties were grown. The tomatoes were grown in the first season in the month of April to June and a second season from October to December. All the analysis was carried out in the JKUAT, Food Science Laboratory.

3.3 Study design

A completely randomized block design (CRBD) was used as the experimental design. The samples for analysis were picked for analysis at 3 different maturity stages; mature green (Stage 1), turning (Stage 3) and red ripe (Stage 6) based on the "Color Classification Requirement in United States Standards for Grades of Fresh Tomatoes" chart, published by (USDA, 2007). Six fruits at each maturity stage were hand picked randomly from the twenty plants of each of the varieties, 40 days after flowering. The tomatoes were harvested in crates and taken to the laboratory where they were washed and sorted into the different stages of maturity and those with defects were discarded. This was done separately for each of the tomato variety. The fruits were then washed in distilled water, dried thoroughly with a cotton cloth to remove surface moisture and stored separately according to variety and stage of maturity at room temperature (25° C). Analysis was done in three replicates, for color changes, weight loss, soluble solids, titratable acidity, antioxidant capacity, lycopene content, respiration and ethylene production rates were done on day 0, 2, 4 and 6 in three replicates. Eight tomato varieties were selected based on good color development, lower rates of weight loss, respiration and ethylene production, from among those grown in the first season and grown for a second season and their rates of respiration and ethylene production determined for days 0,1,2,3,4,5,6 and 7.

3.5 Analytical methods

3.5.1Determination of the physical characteristics

3.5.1.1 Determination of the weight loss

The tomato fruits were weighed using Shimadzu weighing machine (Shimadzu, model Libror AEG 220).Weight loss was determined by subtracting sample weights from their previous recorded weights and presented as % of weight loss compared to initial weights.

3.5.1.2 Determination of color

Tomato fruit color was measured using Minolta Chromameter (Minolta, model CR-200 R Japan/75043055) which provided CIE L*, a* and b*. A Chromameter describes color in three coordinates :L*,lightness from 0(black) to 100 (white);a*,from-60(green)to+60(red)and b*,from -60(blue) to +60 (yellow).The instrument was calibrated with Minolta Calibration standard white reflector plate before sampling of the tomato fruits. Color readings were taken from four points of the fruit (2 readings from equatorial region and 2 readings from the blossom end of the fruit). The L*, a* and b* readings were transformed to hue angle. The hue angle (h*) which describes the visual sensation according to area which appears to be similar to one or proportion of two of the perceived colors ,red, yellow, green, and blue was calculated according to the formula given below.

$Hue\ angle\ (h^*) = \tan^{-1}(b*/a*)$ - Equation 3.1

Where L*, a*and b* are values

3.5.2 Determination of the physiological properties

3.5.2.1 Determination of ethylene production and respiration rate

Tomatoes of known weight were separately placed in plastic jars of 1000 ml. The jar covers were fitted with a self-sealing rubber septum for gas sampling. The fruits were then incubated for two hours at room temperature (25°C). Gas samples from the

headspace gas was taken using an airtight syringe and injected into gas chromatographs (Models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan for respiration and ethylene production rates, respectively). The gas chromatograph for carbon dioxide determination was fitted with a thermal conductivity detector and a Poropak N column and that for ethylene determination was fitted with an activated alumina column and a flame ionization detector. Rate of carbon dioxide production was expressed as ml per kg per hr at standard atmospheric pressure while ethylene production was expressed as µL per kg per hr.

3.5.3 Determination of phytochemical and nutritional composition

3.5.3.1 Determination of Antioxidant capacity

Sample extraction

Sample extraction for analysis of antioxidant activity was done as described by Harborne, (1998). About 5 g of dried and crushed samples were weighed into a 250 mL conical flask and about 100 mL methanol added. The flask was closed securely using Parafilm and covered with aluminum foil. The samples were put in a shaker and shaken for about 3 hours. They were then kept in the dark and left to extract for 72 hours.

After 72 hours, the samples were filtered through Whatman No. 4 filter paper, and then the filtrate concentrated in a vacuum evaporator to a volume of 20 mL. The extract was transferred into vial bottles and securely stoppered.

Determination of free radical scavenging activity

The radical scavenging activities of the pulp extracts against 2, 2-Diphenyl-1-picryl hydrazyl (DPPH) radical (Sigma-Aldrich) were determined by UV spectrophotometer at 517 nm (Molyneux, 2004). The following concentrations of the extracts were prepared, 0.01, 0.1, 1.0, 2.0 and 5 mg/mL in methanol (Analar grade). Vitamin C was used as the antioxidant standard at concentrations of same as the extract concentrations. One mL of the extract was placed in a test tube, and 3 mL of methanol was added followed by 0.5

mL of 1 mM DPPH in methanol. A blank solution was prepared containing the same amount of methanol and DPPH. Methanol was used to zero the spectrophotometer and the absorbance was read at 517 nm after 5 minutes in UV-Vis spectrophotometer (Shimadzu model UV – 1601 PC, Kyoto, Japan). The radical scavenging activity was calculated using the following formula:

$$\% \; Inhibition \; of \; DPPH = \{(A_B - A_A)/A_B\} \times 100$$ - Equation 3.2

Where A_B is the absorption of blank sample and A_A is the absorption of tested extract solution.

The results were expressed as percentage inhibition of DPPH and mean inhibitory concentrations (IC_{50}) determined from a plot of % inhibition of DPPH versus concentration of extract.

3.5.3.2 *Determination of lycopene content*

Lycopene extraction was based on the method of Fish *et al.,* (2002) with slight modifications. Tomato fruit were finely ground using a pestle and mortar for 1 min to puree. Ground tissues were kept on ice and out of light after preparation and until assayed. An approximate 1 g of the puree (without seeds) was put in 50mL PTFE aluminum wrapped test tubes while they were on ice.20 ml Lycopene extraction solution consisting of hexane, 0.05% (w/v) butylated hydroxytoluene (BHT) in acetone and 95% ethanol in a ratio of 2:1:1 was added to the tubes and shaken for 10 min at 180 rpm using table top shaker while they were on ice. To each tube 3ml of cold double distilled water was added and agitated for an additional 5 min for better separation of polar and non-polar compounds. Tubes were then removed from the shaker and left for 15 min in room temperature for separation into polar and non-polar layers. Supernatant was put into new 15ml aluminum wrapped test tubes. The absorbance of supernatant (hexane layer) containing lycopene was read three times using Shimadzu UV-1800 model UV

spectrophotometer at the wavelength of 503 nm VIS lamp. Absolute hexane was used as blank. The amounts of lycopene in tissues were then estimated by the following formula:

$Lycopene\ content\ (mg/kg) = (x/y) \times A503 \times 3.12$ -Equation 3.3

Where;

x = amount of hexanes (ml)

y = weight of fruit tissue (g)

A503 = absorbance at 503 nm

3.12 = Extinction coefficient.

3.5.3.3 Determination of total soluble solids

Total soluble solids (TSS) content was determined using an Atago hand refractometer (Model 500, Atago, and Tokyo, Japan) and expressed as o Brix. Juice was extracted from three different fruits and the TSS level determined using the refractometer. The TSS level was expressed as °brix.

3.5.3.4 Determination of total titratable acidity

Total titratable acidity (TTA) analysis was done according to AOAC, (1995) methods.

The sample was homogenized using a pestle and mortar and about 25g of the sample weighed. Pipette 10ml of sample into a conical flask and add 2 drops of phenolphthalein indicator. Titration was done using 0.1N NaOH to a faint pink color which persisted for at least one minute compared against a white background. The titre volume was noted and used for calculation of TTA.

Calculations:

Titratable acidity % $= \dfrac{Vol.of\ 0.1\ NaOH\ used \times conversion\ factor \times 100}{Volume\ of\ sample\ used}$ -Equation 3.4

Where the conversion factor is the principal acid in tomato is citric acid = 0.064

3.6 Statistical analysis

All experiments were carried out in triplicate. The data was presented as means of three replicates. The results were analyzed using one-way analysis of variance (ANOVA) followed by Duncan multiple range test of significance at $\alpha = 0.05$. This treatment was carried out using GenStat Release 12.1 software. A probability of 5% or less was considered statistically significant.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical characteristics

4.1.1 Percentage weight loss

There was a significant difference (P< 0.05) in the percentage weight loss between the determinate and indeterminate tomato varieties with the determinate exhibiting higher percentage weight loss. Weight loss of tomatoes at the red ripe stage was significantly higher than at the turning and mature green stage as shown in figures 4.1 – 4.3. At the mature green stage, the Cal J Supreme variety had the highest percentage weight loss (3.7%), while the Anna F1 variety had the lowest percentage weight loss (0.16%). At the turning stage, the Nuru F1 variety had the highest percentage weight loss (3.80%), while the Chonto F1 variety had the lowest percentage weight loss (0.93%). At the red ripe stage, the Cal J Supreme variety had the highest percentage weight loss (3.50%), while the Chonto F1 variety had the lowest percentage weight loss (1.34%). From the graphs of percentage weight loss the weight loss increased with the advancement of storage time and maturity and varied depending on variety. In studies where treatment such as 1-MCP was used to extend the shelf life of tomatoes, weight loss of between 3.8%-4.4% was observed after storage for 10 days at 20°C (Wills & Ku, 2002).The indeterminate varieties Anna F1, Chonto F1 and Bravo F1 had lower percent weight loss compared to the determinate varieties. It has been shown that the rate of weight loss in tomatoes is affected by storage period, storage temperature and treatment on the tomato surface. The internal atmosphere of the fruit is assumed to be saturated and therefore water is prone to evaporate from the harvested tomatoes to the surrounding atmosphere. The rate of the water loss is dependent on the factors such as maturity, amount of solutes in the produce, size, shape and surface area (Seymour *et al.,* 2013). From the results it clear that at advanced stage of ripening the fruit the more water it loses as it has more soluble solids that creates the internal saturation (Nasrin *et al.,* 2008). The low % weight loss in the

indeterminate varieties could be associated to their big size, skin thickness and glossiness that gives a small volume to surface ratio for water to transpire and a firm surface. According to Ball (1997), postharvest weight loss in vegetables is usually due to the loss of water through transpiration. Weight loss can lead to wilting and shriveling which both reduce market value and consumer acceptability (De Castro *et al.,* 2006). Plant tissues are usually in equilibrium with an atmosphere at the same temperature and relative humidity of 99.0-99.5% and therefore any storage conditions having a lower atmospheric water vapor pressure will cause water loss from produce exposed to that condition (Badami & Ramankutty, 2015).
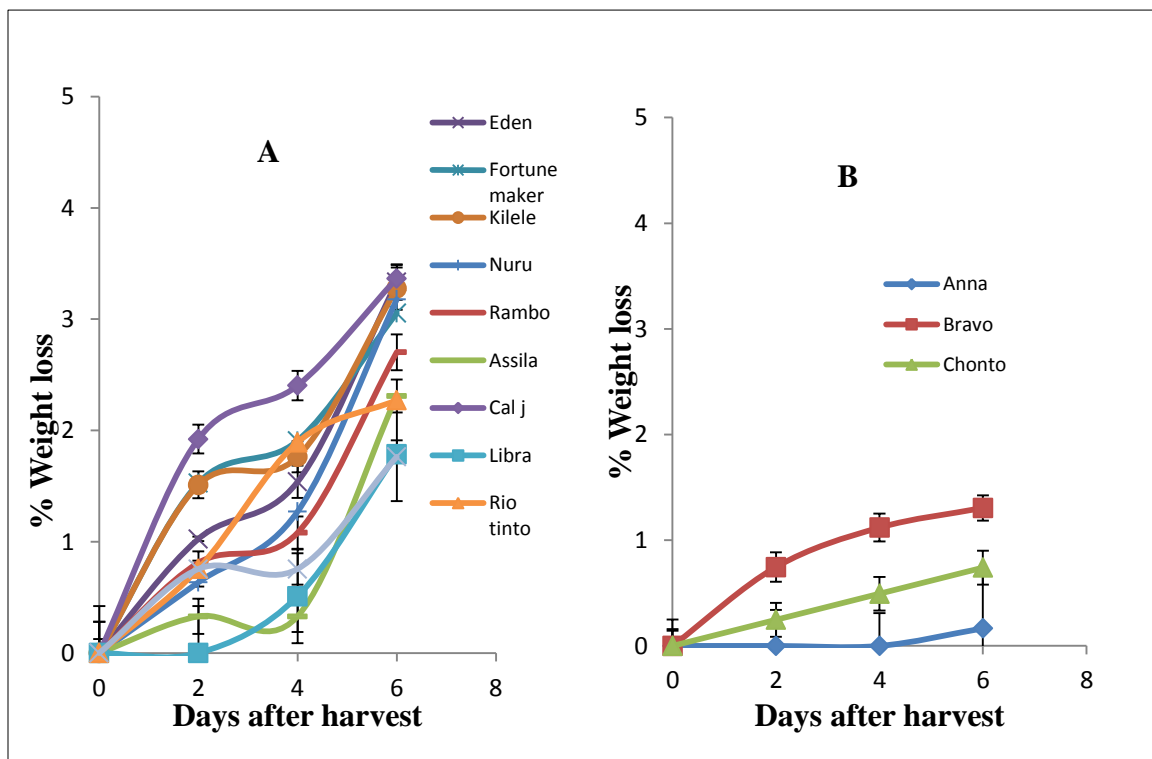
Figure 4.1: Weight loss (%) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at mature green stage. Values are presented as means of three replicates

30
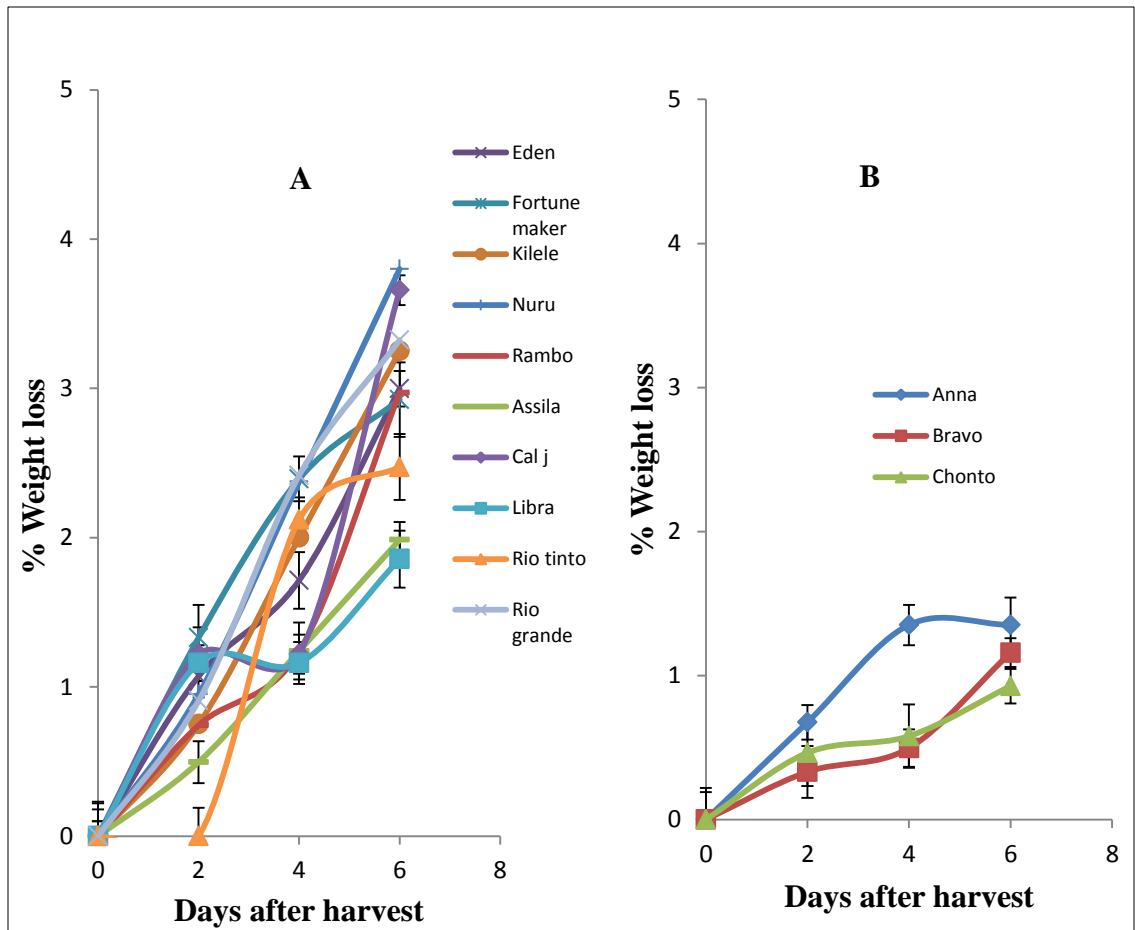
Figure 4.2: Weight loss (%) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at turning stage. Values are presented as means of three replicates
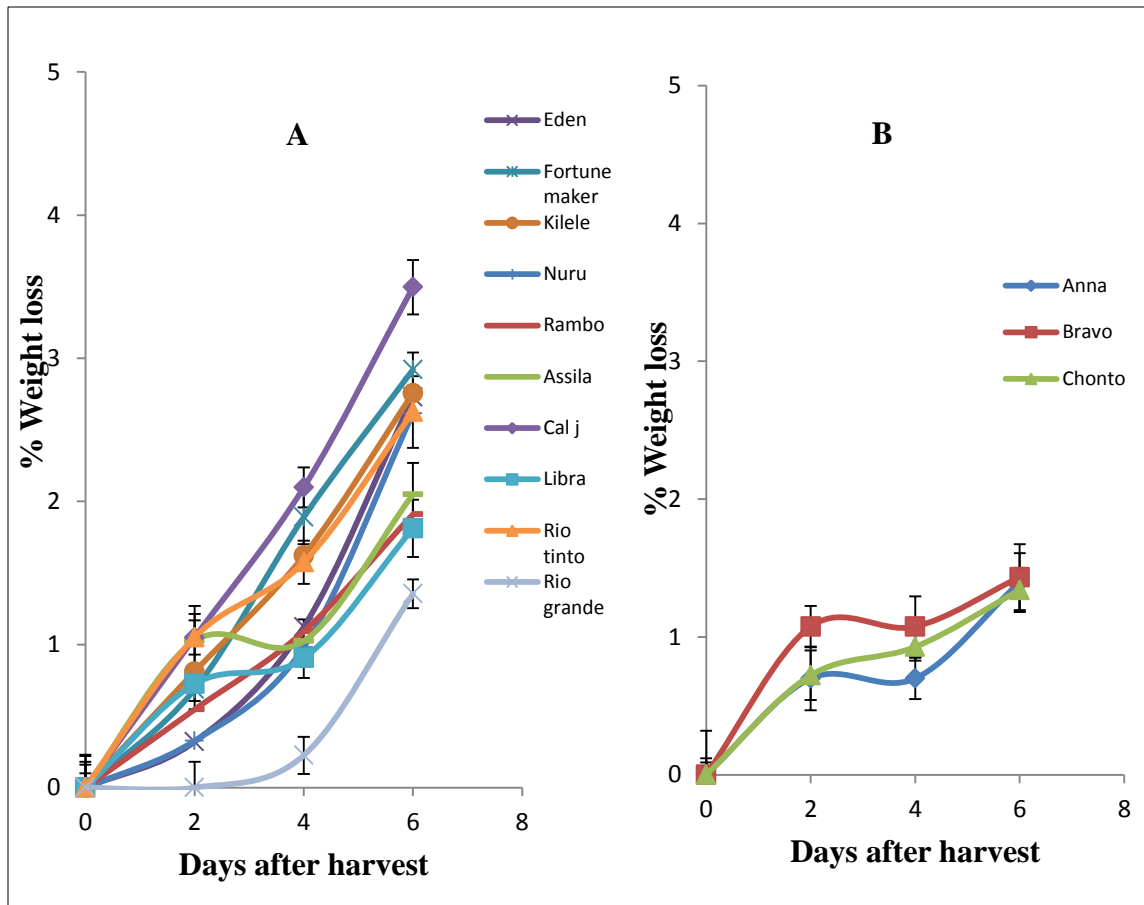
Figure 4.3: Weight loss (%) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage. Values are presented as means of three replicates

4.1.3 Color changes

The external color was expressed in terms of hue angle, which is the most important measure in the perception of tomato quality (Klee & Giovannoni, 2011), due to the fact that external fruit color relates better to perception of color by the human eye. The color changes during storage are indicated in Tables 4.2-4.4 and in general it indicates that hue angle of 130° to 65° indicates different intensities of green color, while 65° to 45° is

yellow while 45° to -15° is red coloration (Saltveit, 2005). As expected, all the varieties had significant change in color as the storage period increased. A greater change in color was observed after storage in the Cal J Supreme variety (80.08^{o} to 50.07^{o}), Rambo F1 (70.17^{o} to 43.66^{o}) and Libra F1 (48.05^{o} to 40.78^{o}) at the mature green, turning and red ripe stages respectively. Small changes in color were observed in Bravo F1 (74.70^{o} to 61.35^{o}), Bravo F1 (53.86^{o} to 50.22^{o}) and Fortune Maker (47.52^{o} to 46.19^{o}) in the mature green, turning and red ripe tomatoes respectively (Tables 4.2-4.4). The color of tomato fruit is an important quality factor of fresh tomatoes for consumers' preference and is also used to indicate the stage of ripeness (López Camelo & Gómez, 2004). In order to prolong shelf life in tomatoes, it is desirable that the color changes take place as slowly as possible. Fruits harvested at the mature green stage tended to be less red than the fruits harvested at the red ripe stage by the 6th day. The Anna F1 variety achieved the lowest hue angle value of 36.99^{o} by the 6th day when harvested at the red ripe stage while the Chonto F1 variety had the highest value of 61.34^{o} on day six when harvested at the mature green stage. There was no significant difference between the indeterminate and determinate varieties. There was a greater change in color when the tomato fruits were harvested at the mature green as compared to the tomatoes harvested at the turning or red ripe stage. These could be attributed to the fact that color development rate of fruits increases with ripening as the fruit changes color from green to red (Žnidarčič & Požrl, 2006). Chlorophyll degrades rapidly as the fruit ripens while lycopene accumulates at the later stage of ripening to give the tomato the intense red color. In case of a delay in ripening, there may be a period between chlorophyll degradation and lycopene accumulation presenting a yellow – orange hue of β-carotene (Saltveit, 2005). This phenomenon is displayed by some tomato varieties tomatoes that were harvested at the mature green stage like assila F1, cal j, bravo F1 and rio grande varieties. The process of color change is accelerated by ethylene induction.

Table 4.1: Hue angles (^{o}) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at mature green stage

		Days			
	Variety	**0**	**2**	**4**	**6**
A	**Anna F1**	75.60^d	68.73^d	63.16^i	47.75^c
	Bravo F1	74.70^c	77.04^g	71.55^l	61.34^l
	Chonto F1	72.20^b	67.86^{cd}	68.09^k	51.29^{fg}
B	**Eden F1**	74.80^c	72.96^f	55.36^d	47.48^b
	Fortune Maker	75.20^{cd}	73.62^f	63.07^i	55.74^j
	Kilele F1	80.00^e	71.16^e	58.8^f	51.53^h
	Nuru F1	72.50^b	78.67^g	51.51^b	45.69^a
	Rambo F1	74.80^c	69.20^d	55.18^c	49.26^d
	Assila	82.32^g	78.49^g	66.19^j	54.77^i
	Cal J	80.08^e	72.19^{ef}	50.35^a	50.07^e
	Libra	81.08^f	67.68^b	58.19^e	58.73^k
	Rio Grande	65.59^a	63.36^a	61.04^g	51.17^f
	Rio Tinto	75.78^d	66.48^{bc}	62.28^i	51.44^{gh}
	Grand Mean	**75.72**	**71.19**	**60.35**	**52.02**
	LSD (5%)	**0.60**	**1.67**	**0.17**	**0.16**

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

Table 4.2 : Hue angles (^{o}) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at turning stage

	Variety	Days 0	2	4	6
A	Anna F1	60.75[c]	68.09[j]	46.25[c]	44.49[e]
	Bravo F1	53.86[a]	54.58[e]	52.79[k]	50.22[j]
	Chonto F1	55.94[b]	60.05[i]	49.48[i]	46.88[h]
B	Eden F1	57.88[b]	51.93[c]	46.43[d]	44.48[e]
	Fortune Maker	66.17[de]	56.61[g]	44.75[b]	46.96[h]
	Kilele F1	70.92[f]	55.35[f]	48.56[h]	47.48[i]
	Nuru F1	67.39[e]	49.00[a]	49.50[i]	42.46[b]
	Rambo F1	70.17[f]	53.30[d]	47.01[f]	43.66[d]
	Assila	64.23[d]	55.87[f]	52.43[j]	42.77[c]
	Cal J	60.97[c]	50.74[b]	44.25[a]	42.28[a]
	Libra	65.61[de]	59.25[h]	48.22[g]	43.59[d]
	Rio Grande	59.52[b]	56.74[g]	48.49[h]	45.53[g]
	Rio Tinto	64.49[d]	53.40[d]	46.61[e]	44.76[f]
	Mean	**62.74**	**55.77**	**48.06**	**45.04**
	LSD (5%)	**1.87**	**0.59**	**0.17**	**0.13**

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

Table 4.3: Hue angles (^{o}) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at red ripe stage

	Variety	Days 0	2	4	6
A	Anna F1	42.02^a	40.91^b	39.75^b	36.99^b
	Bravo F1	45.54^g	43.71^g	42.87^e	39.94^a
	Chonto F1	45.74^h	46.11^j	43.89^g	41.38^{fg}
	Eden F1	43.79^c	42.56^e	41.09^d	41.77^{gh}
	Fortune Maker	47.52^j	47.22^k	46.33^j	46.19^k
	Kilele F1	44.71^f	44.93^h	44.52^h	42.65^i
B	Nuru F1	45.64^{gh}	43.77^g	43.63^g	42.01^h
	Rambo F1	46.16^i	45.91^i	45.5^i	44.77^j
	Assila	44.50^e	43.51^f	43.27^f	41.19^f
	Cal J	43.56^b	41.02^b	40.11^c	39.73^d
	Libra	48.05^k	41.73^d	40.79^d	40.78^e
	Rio Grande	46.27^i	41.49^c	40.74^d	39.89^d
	Rio Tinto	44.22^d	40.50^a	38.30^a	38.68^c
	Mean	45.21	43.34	42.37	40.51
	LSD	0.17	0.16	0.35	0.40

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

4. 2 Physiological properties

4.2.1 Ethylene production and respiration rates

There was a significant difference ($p < 0.05$) in the respiration rate and ethylene production rates of the tomatoes between the varieties and storage days of the tomatoes in the three maturity stages. The highest respiration rate peak was observed in Cal J Supreme variety with 82.82 ml CO_2 $Kg^{-1} h^{-1}$, Rio Grande 80.56 ml CO_2 $Kg^{-1} h^{-1}$ and Rio Grande 54.22 ml $CO_2 Kg^{-1} h^{-1}$ for the mature green, turning and red ripe stages of ripening respectively. The lowest respiration rate peaks were in Nuru F1 38.64 ml CO_2 $Kg^{-1} h^{-1}$, Eden F1 30.51 ml $CO_2 Kg^{-1} h^{-1}$ and Kilele F1 23.76 ml CO_2 $Kg^{-1} h^{-1}$ for the mature green, turning and red ripe tomatoes respectively (Figures 4.4-4.6). All the tomato varieties in the three stages of maturity showed an increased respiration and ethylene production rate for the early days of storage and then had a peak which was followed by a steady decline as the storage period prolonged. This is a characteristic behavior of climacteric fruits which have a peak in respiration and a burst of autocatalytic ethylene to help the ripening process (Alexander & Grierson, 2002). Tomatoes can either increase or decrease their respiration rates in response to external stresses which is dependent on factors such as variety, maturity stage, surrounding gas composition and temperature (Fonseca *et al.,* 2002).

Ethylene production was highest in day 2 in Rio Tinto variety (8.30 µl C_2H_4 $kg^{-1}h^{-1}$) after harvest at the turning stage while the lowest ethylene production peak was observed on day 6 in Kilele F1 variety (0.34 µl C_2H_4 $kg^{-1}h^{-1}$) after harvest at red ripe stage of maturity (figures 4.7-4.8). According to Kader (2002), tomato fruits generally produce moderate amounts of ethylene of between1 and 10µl C_2H_4 $kg^{-1}h^{-1}$ at 20 ^{o} C, which is the range that most varieties in this study fell thou there some which had low values below 1 µl C_2H_4 $kg^{-1}h^{-1}$. The low ethylene rates could be associated to the temperature the experiment was done (25^oC), the difference in varieties and maturity stages. The low rates are not issue the ripening process as tomatoes are very sensitive to ethylene and as little as 0.5µL L^{-1} ethylene is enough to trigger the ripening process (Abeles *et al.,* 1992).

In addition the low rates are desirable in prolonging the shelf life of tomatoes. It was observed that the determinate tomato varieties had relatively higher rates of respiration at all the three stages of maturity in comparison to the indeterminate varieties.
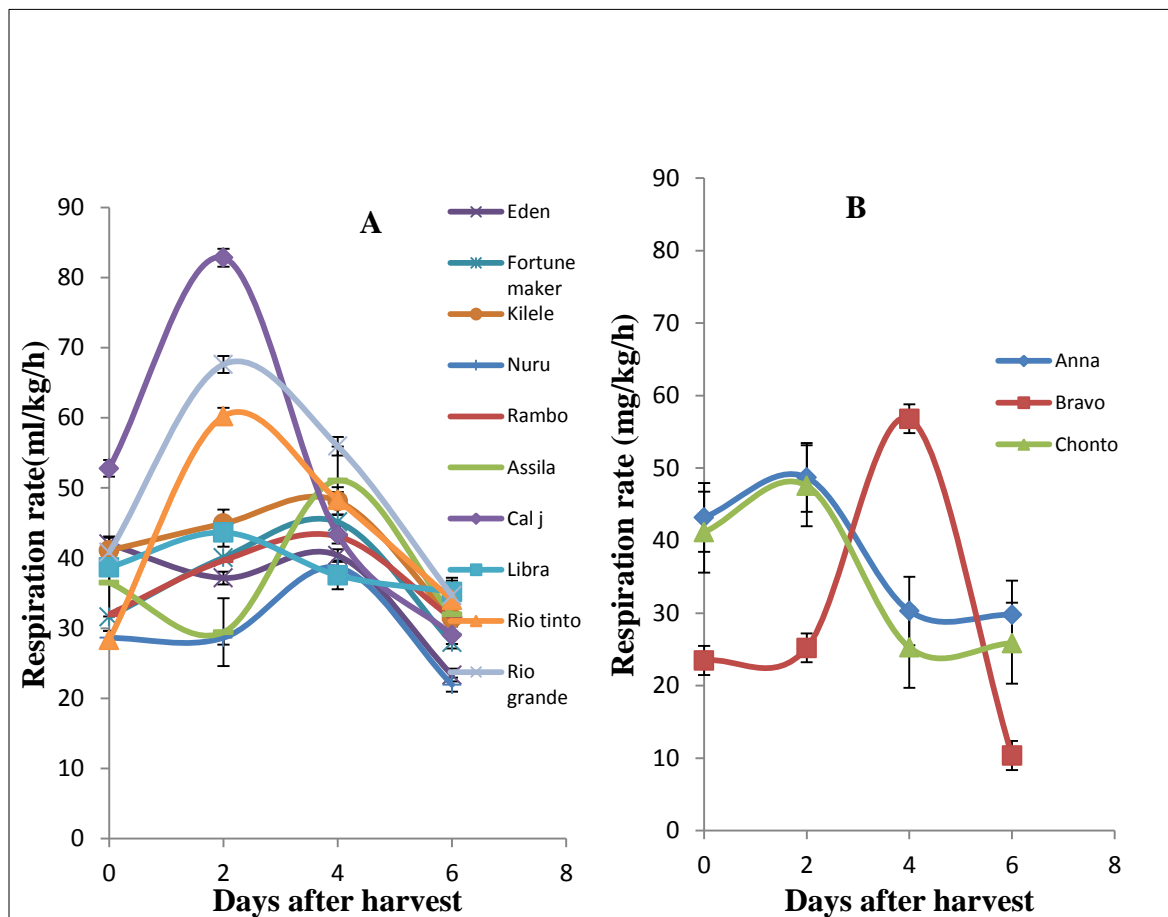

Figure 4.4: Respiration rate (ml/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage. Values are presented as mean of three replicates

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Figure 4.5: Respiration rate (ml/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the turning stage. **Values are presented as mean of three replicates**
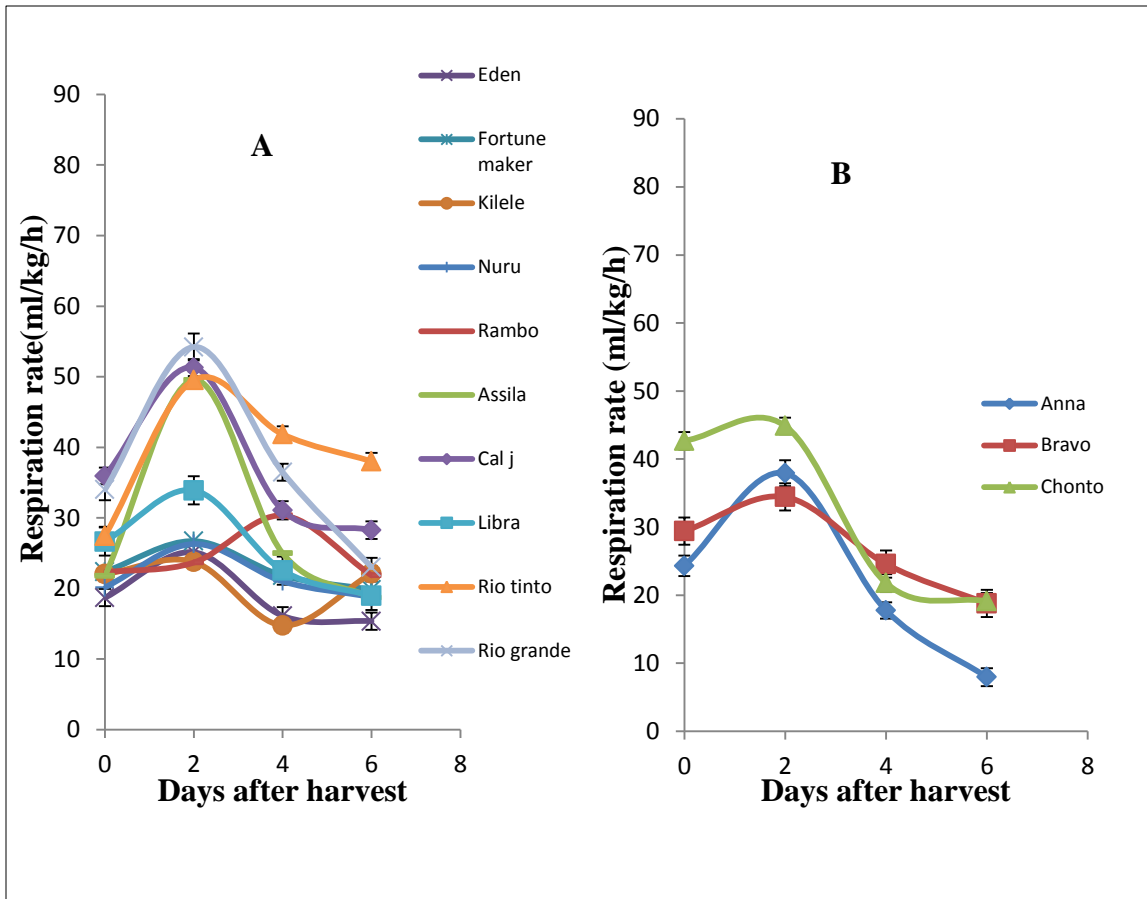
Figure 4.6: **Respiration rate (ml/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage. Values are presented as mean of three replicates**
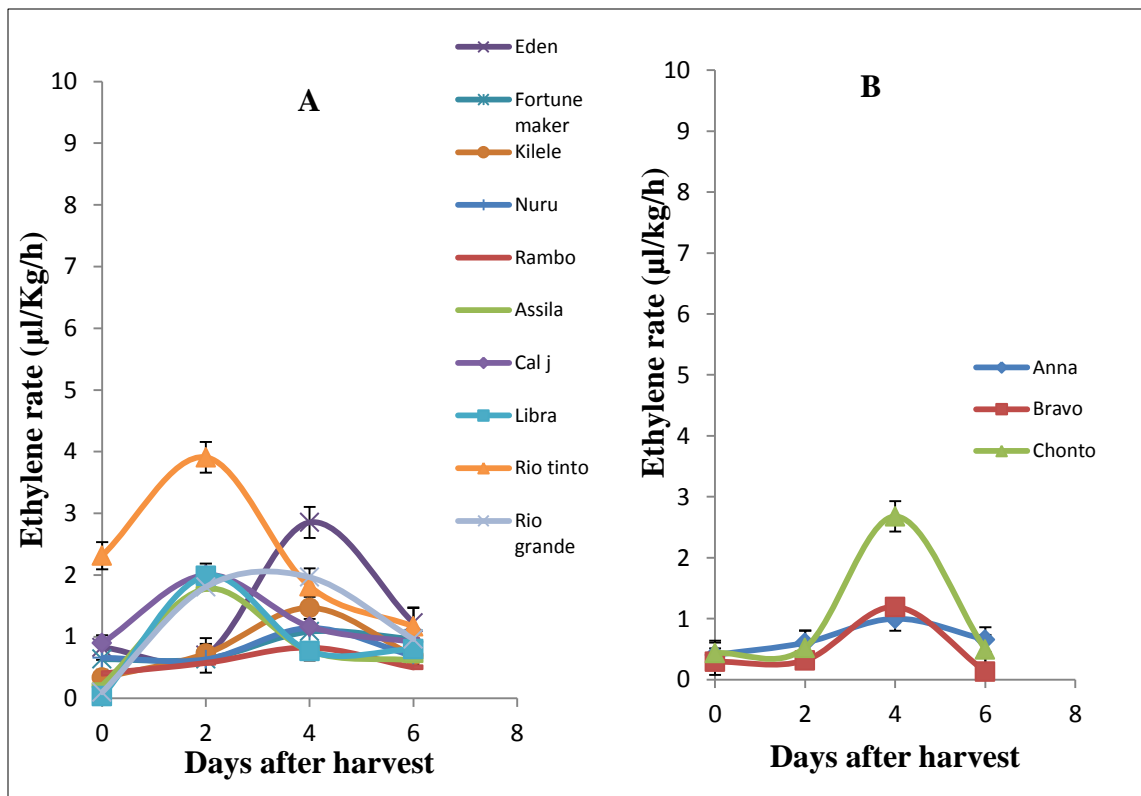
Figure 4.7: Ethylene production rate (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage. Values are presented as mean of three replicates
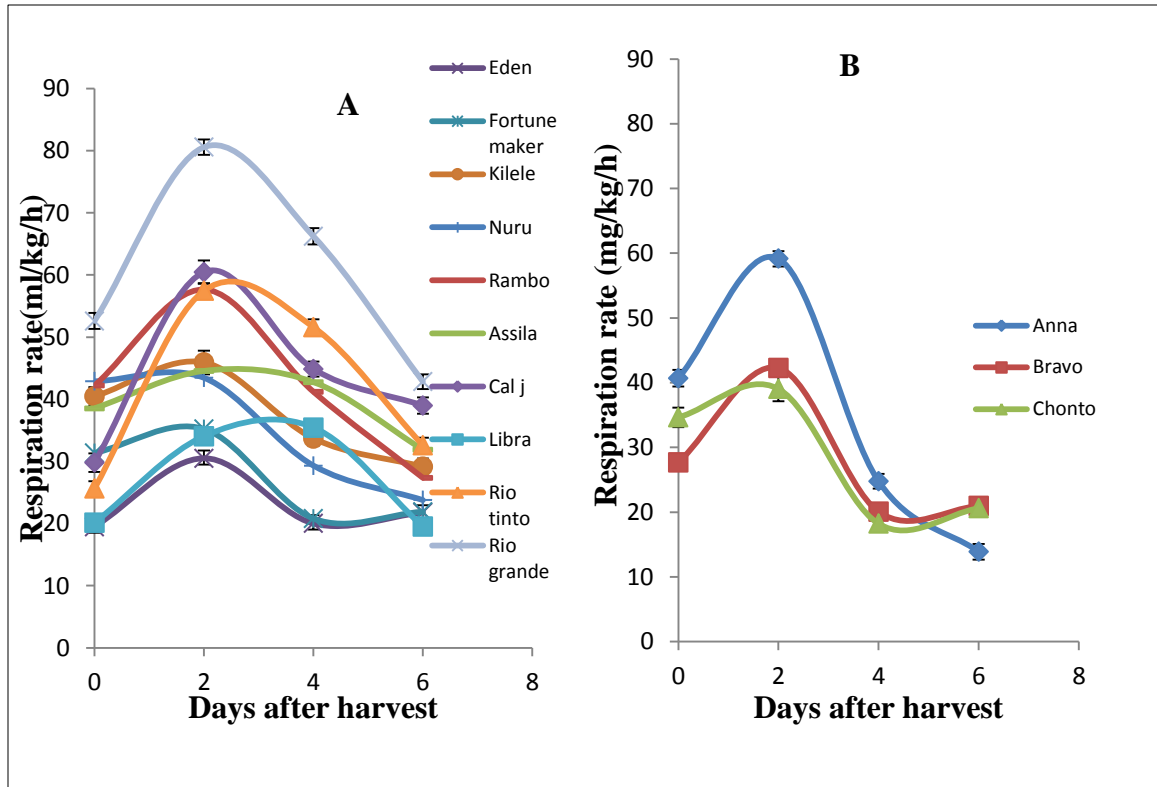
Figure 4.8: Ethylene production rate (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the turning stage. Values are presented as mean of three replicates

Figure 4.9: Ethylene production rate (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage. Values are presented as mean of three replicates
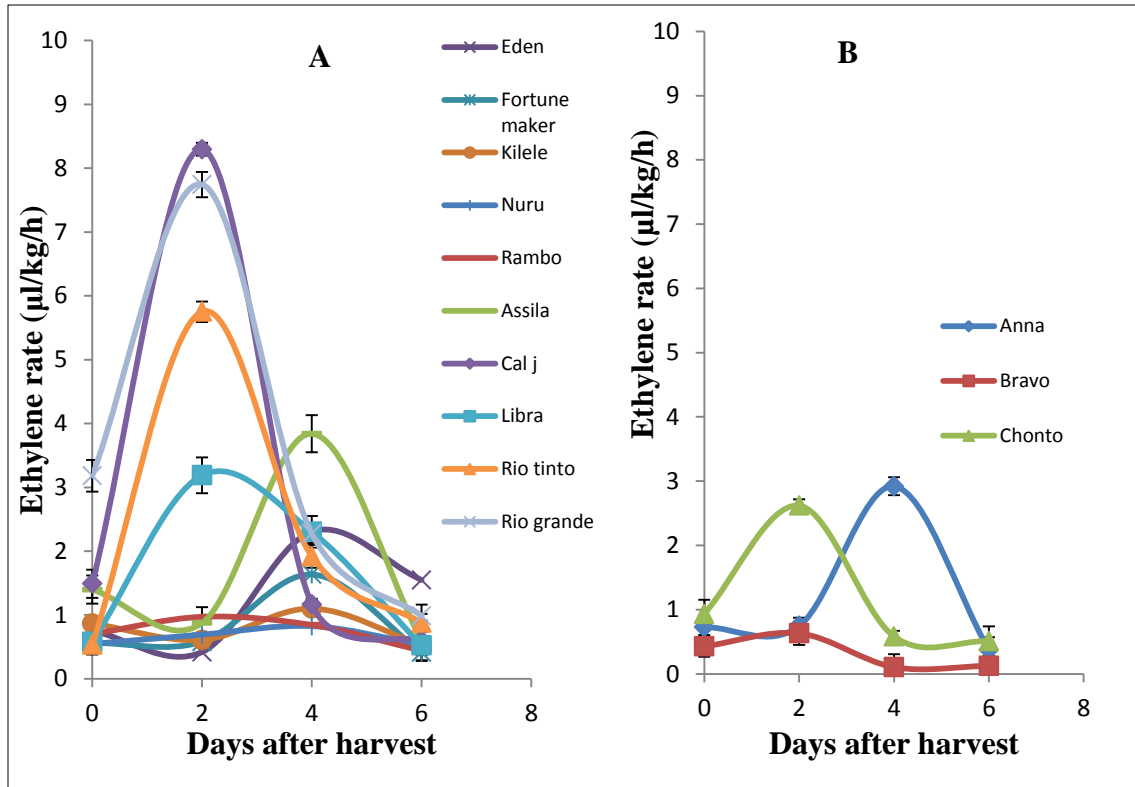
There was a significant difference ($p<0.05$) between the two harvest season. The respiration rates and ethylene production rates were higher in the first season than in the second season as shown in figures 4.10 to 4.15. In the second season the highest respiration rate peak was observed in Eden F1 variety with 42.39 ml CO_2 Kg^{-1} h^{-1}, Fortune maker 43.34 ml CO_2 Kg^{-1} h^{-1} and Rambo 39.64ml $CO_2 Kg^{-1}$ h^{-1} for the mature green, turning and red ripe stages of ripening respectively. The lowest respiration rate

peaks were in Bravo F1 17.80 ml CO_2 Kg^{-1} h^{-1}, Bravo F1 19.96ml Kg^{-1} h^{-1} and Anna F1 9.82 ml CO_2 Kg^{-1} h^{-1} for the mature green, turning and red ripe tomatoes respectively. Highest peaks in ethylene production were observed in Nuru F1 variety (3.15 μl C_2H_4 $kg^{-1}h^{-1}$), Chonto F1 (5.51 μl C_2H_4 $kg^{-1}h^{-1}$), and Chonto F1 (4.75 μl C_2H_4 $kg^{-1}h^{-1}$), for the mature green, turning and red ripe stages of ripening respectively. Even though there was a big difference in the rates in the two seasons (which could be attributed to weather condition variation), the days in which the peak appeared were all in the early days after harvest (days 1 to 4). A decline in respiration and ethylene rates is observed after the maximum peaks as the energy reserves get exhausted and respiration shifts from aerobic to anaerobic (Goyette et al., 2012; Mangaraj & Goswami, 2011). In a study by Adam et al., (2014) to determine the effect of gamma radiation on tomato quality during storage, respiration results obtained from untreated samples showed similar range at peaks (47.43-56.19mg/kg/h) as in the first season. Treatment of the same cultivars with different does of gamma radiation did not affect the rates significantly.
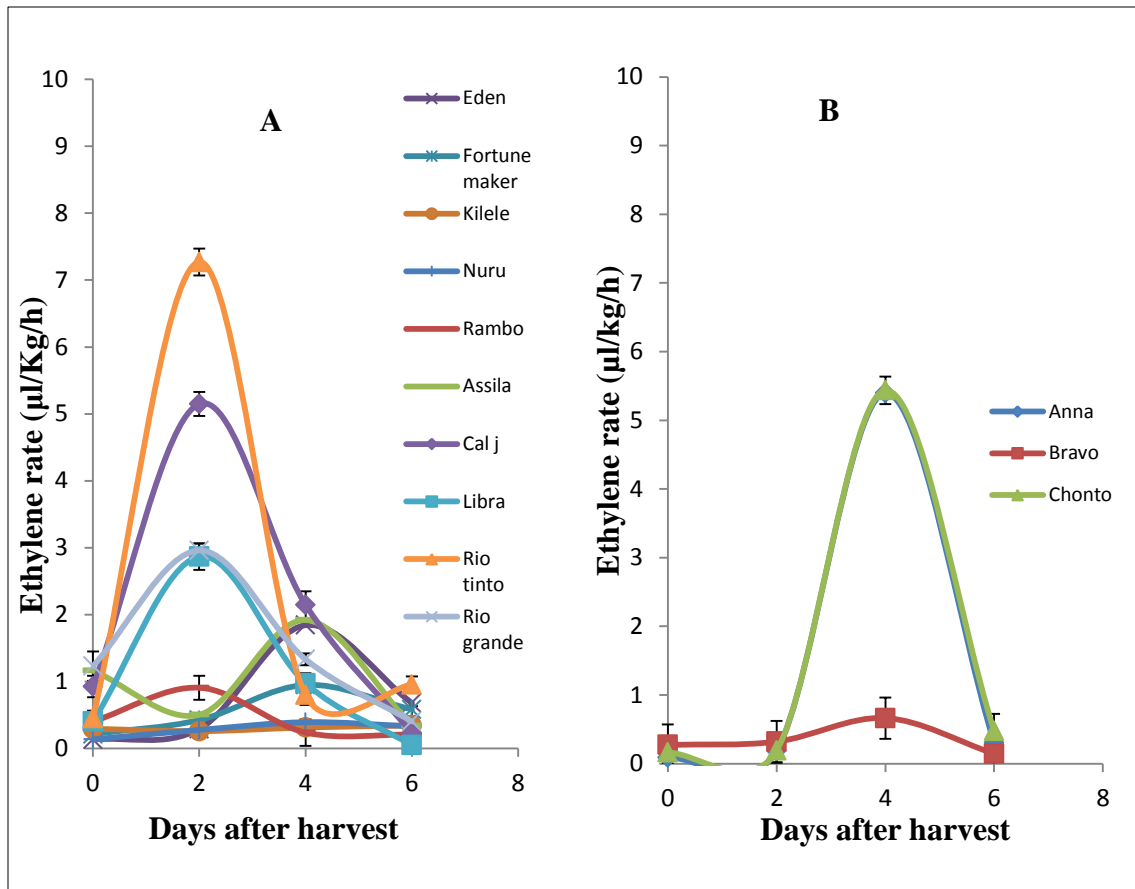
Figure 4.10: Respiration rate (ml/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage in the second season. Values are presented as mean of three replicates

Figure 4.11: Respiration rate (ml/kg/h) of the eight tomato varieties after harvest at the turning stage in the second season. Values are presented as mean of three replicates

Figure 4.12: Respiration rate (ml/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage in the second season. Values are presented as mean of three replicates

Figure 4.13: Ethylene production rates (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage in the second season. Values are presented as mean of three replicates

Figure 4.14: Ethylene production rates (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the turning stage in the second season. Values are presented as mean of three replicates
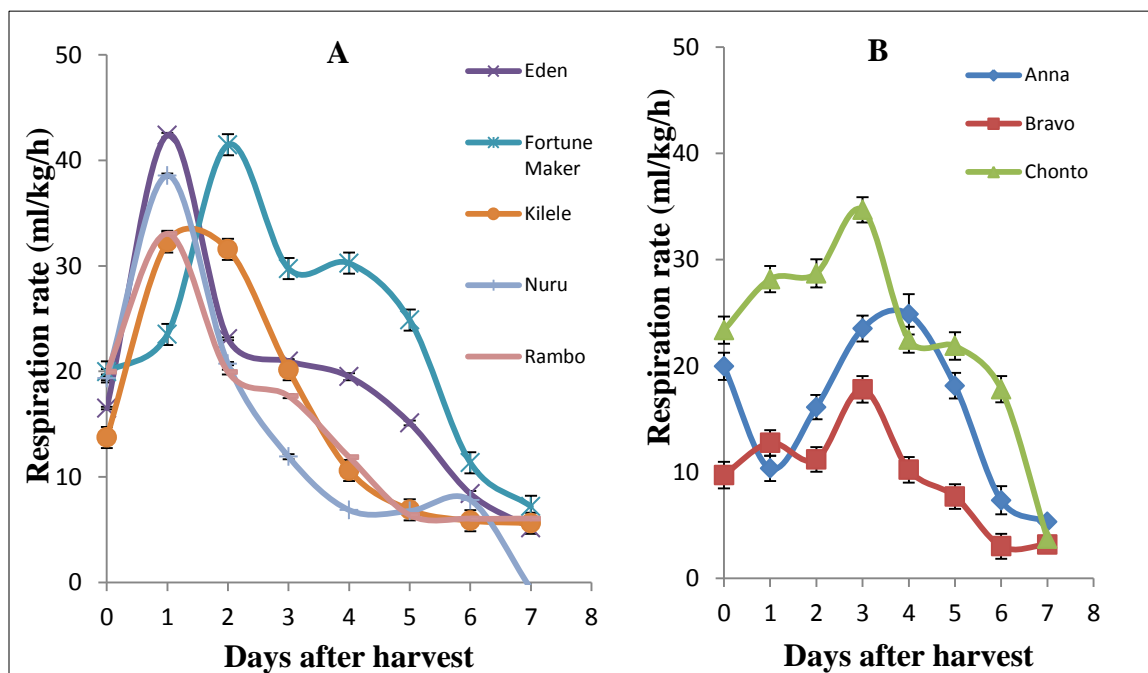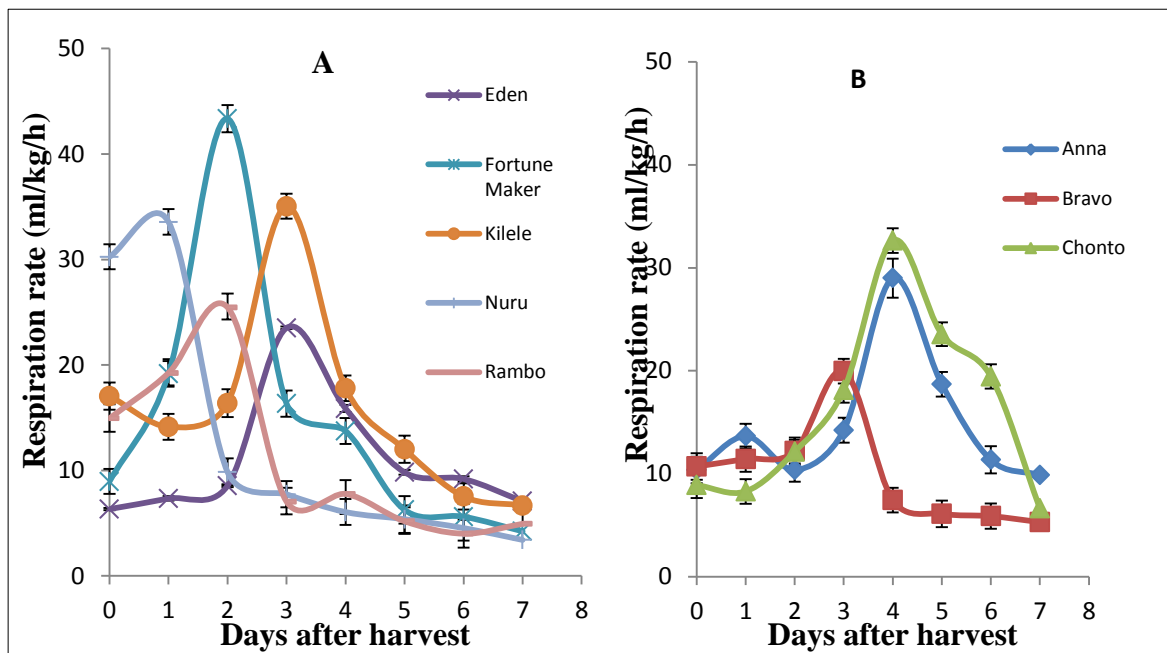
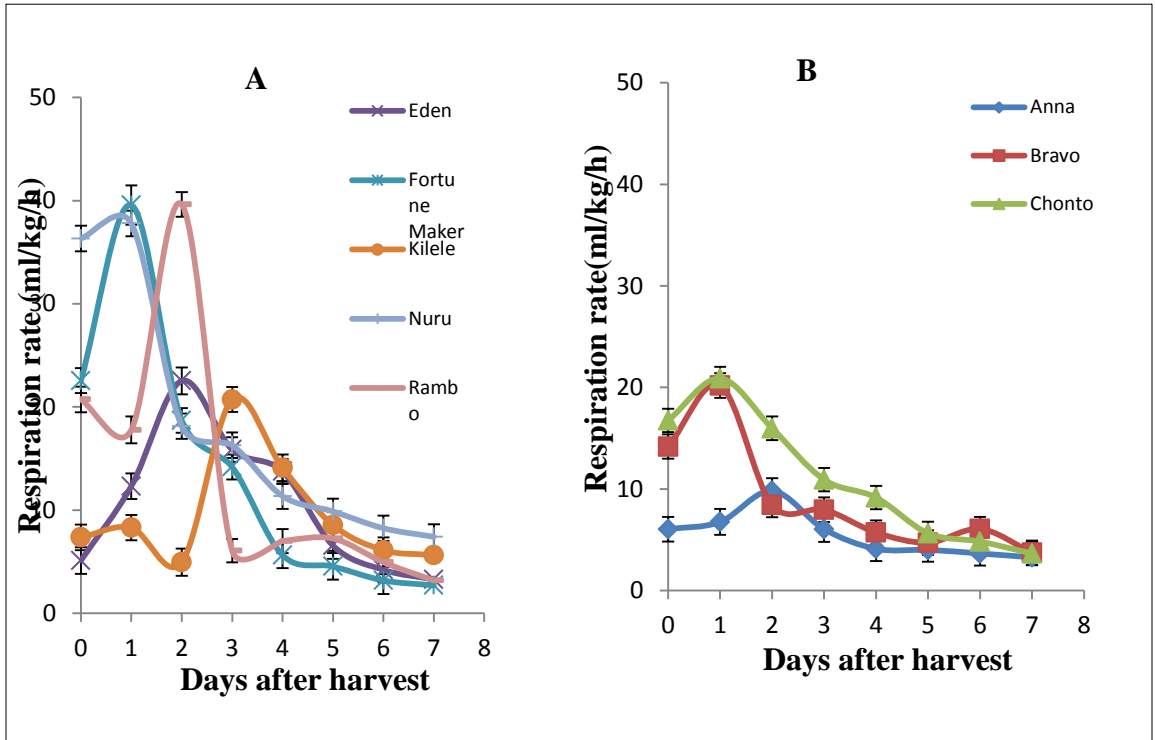**Figure 4.15: Ethylene production rates (µL/kg/h) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage in the second season. Values are presented as mean of three replicates**

4.3 Phytochemical and Nutritional composition

4.3.1 Antioxidant capacity

The antioxidant capacity is expressed in terms of IC_{50} which the antioxidant concentration required to obtain a 50% radical inhibition. A Lower IC_{50} value is an indication of higher antioxidant activity of the sample. There was significant difference (P<0.05) (figures 4.16-4.18) in the antioxidant activity at the three maturity stages. At the mature green stage, the antioxidant activity ranged from IC_{50} 1.02 to 1.23 mg/mL while at the turning stage, the values ranged from IC_{50} 0.85 to 1.02 mg/mL and at the

red ripe stage, the values ranged from IC_{50} 0.83 to 0.99 mg/mL (figures 4.16-4.18). There was no significant difference (P<0.05) in the antioxidant activity of the 13 varieties. Tomatoes harvested at the red ripe stage had significantly higher values of IC_{50} compared to fruits harvested at turning and mature green stages. This difference in the stages could be attributed to high levels of lycopene, which is a good scavenger of free radicals in the red ripe tomatoes. The differences observed in the antioxidant contents of tomato varieties could also be related to genotype and other factors such as the ripening stage, cultivation practices (water availability, mineral nutrients), and climatic environment such as light and temperature (Dumas *et al.,* 2003). From the results tomato exhibited a good potential to act as a free radical scavenger. However it's IC_{50} for DPPH inhibition was comparably lower to that of Vitamin C (0.004 mg/mL) which is a known free radical scavenger. The antioxidant activity is contributed to by the various phytochemicals with antioxidant activity such as phenolics, flavonols, anthocyanins, β-carotene, lycopene, β-tocopherol and α-tocopherol.
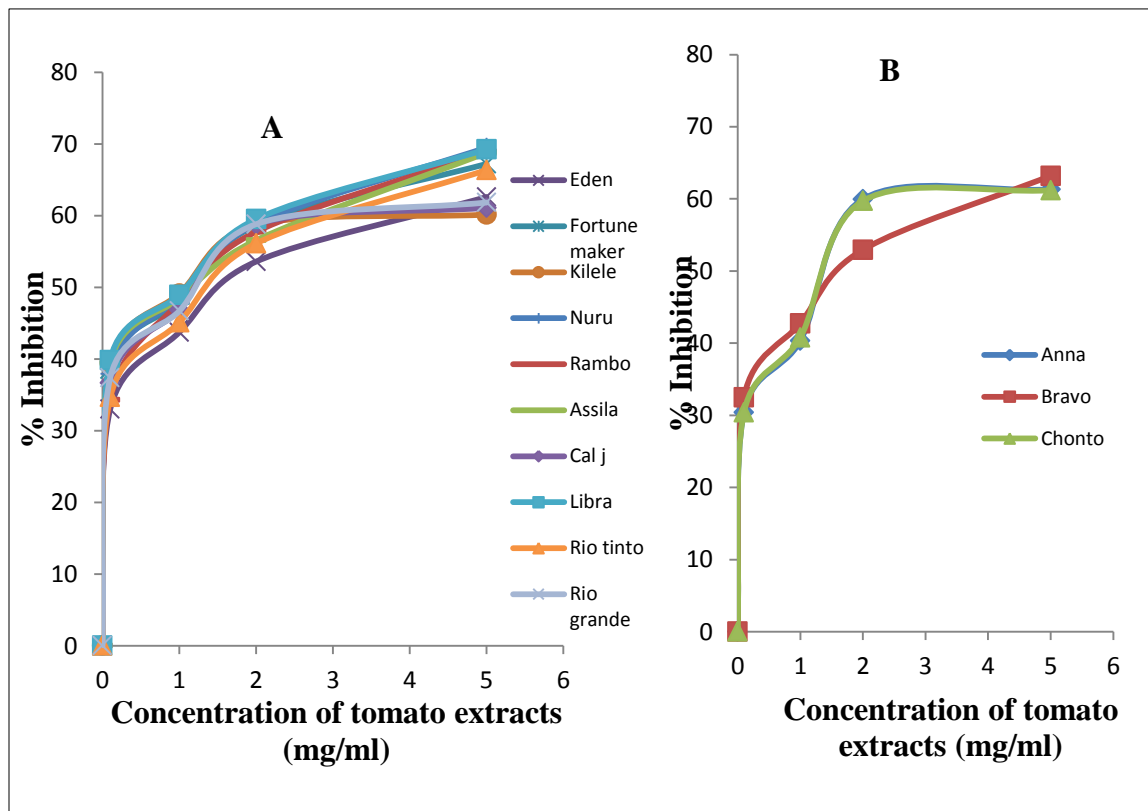
Figure 4.16: Inhibition (%) of DPPH against concentration of extracts of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage. Values are presented as mean of three replicates
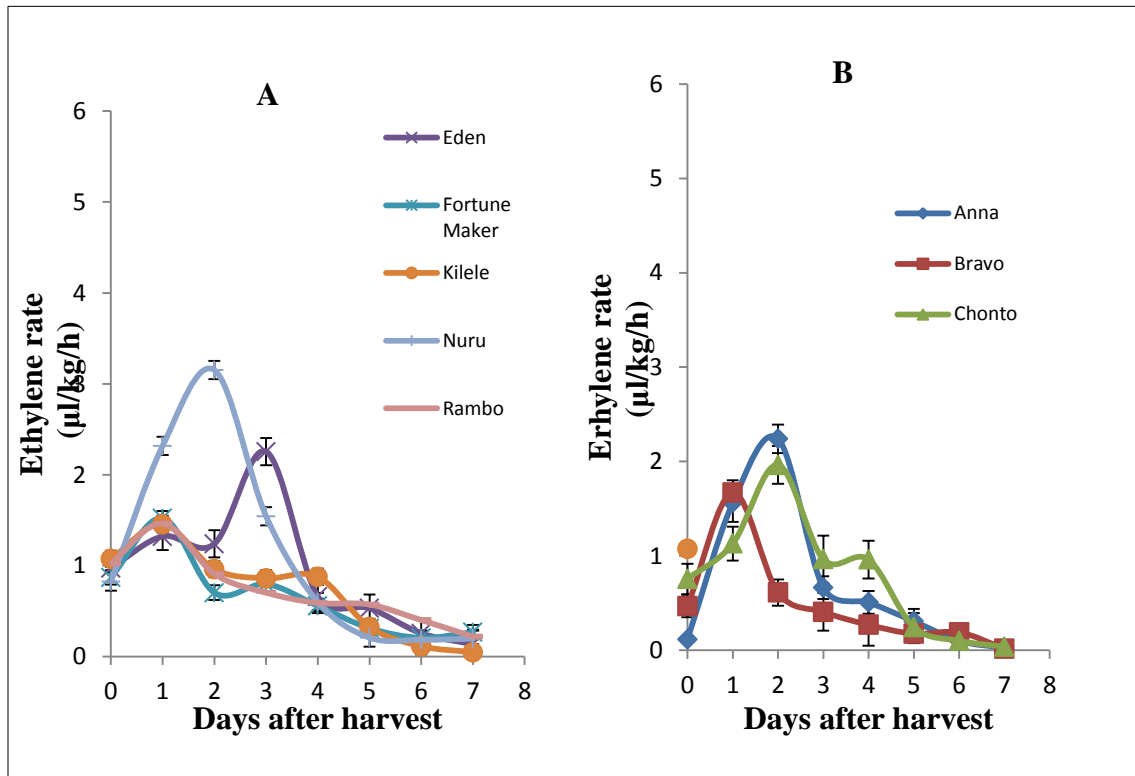

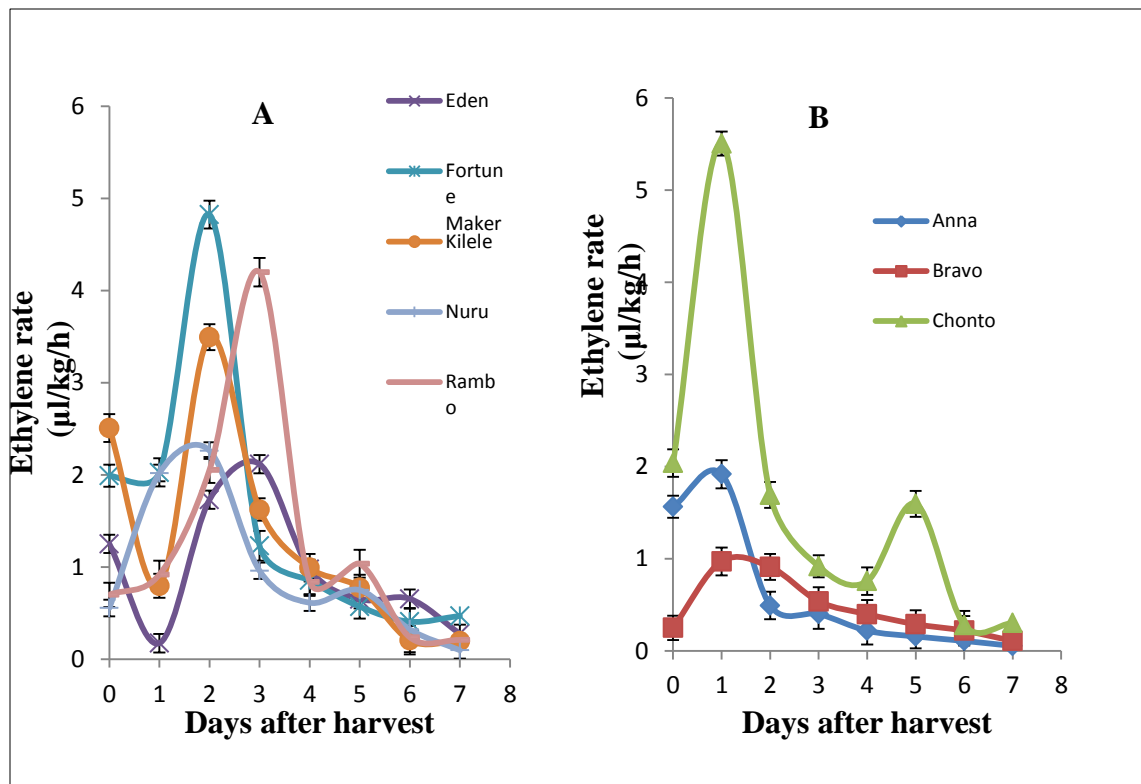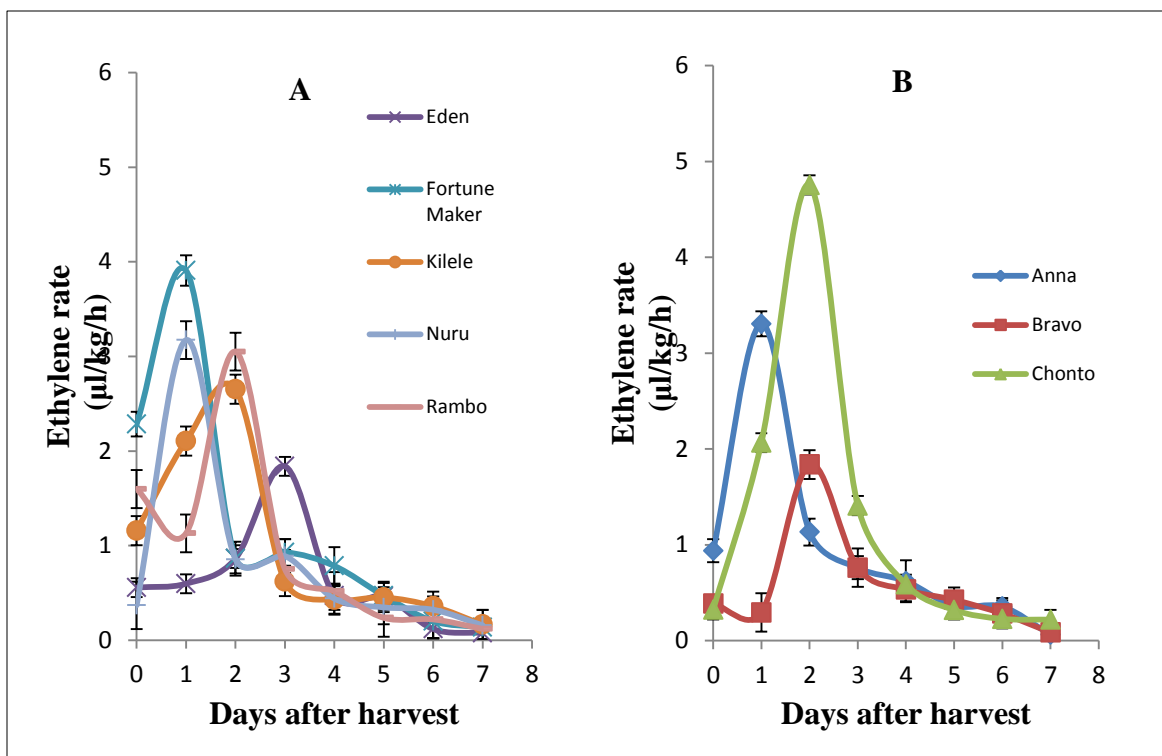**Figure 4.17: Inhibition (%) of DPPH against concentration of extracts of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the turning stage. Values are presented as mean of three replicates**

Figure 4.18: Inhibition (%) of DPPH against concentration of extracts of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage. Values are presented as mean of three replicates

4.3.2 Lycopene content

From the results in figures 4.22-4.24, the lycopene content of the tomatoes changes significantly during the ripening process. Overall the lycopene content increased with the storage period after harvest at the three maturity stages. Based on the averages of all the varieties, the lycopene content on the sixth day of storage ranged from 4.95 to 9.53mg/100g at the mature green stage, from 8.85 to13.95mg/100g at the turning stage and from 9.03 to 27.53mg/100g at the red ripe stage. This result shows that there was a greater significant difference ($p < 0.05$) in the lycopene content at the red ripe stage than

at the turning and mature green stages (Figure 4.22-4.24). The Rambo F1 variety achieved the highest content (27.53mg/100g) on day 6 at the red ripe stage while the Rio Grande variety achieved the lowest content (4.95mg/100g) at the mature green stage on day 6. Low lycopene content was observed at the mature green stage, with the Cal J Supreme variety having the lowest (0.41mg/100g) on day zero.

The lycopene content in the Kenyan varieties studied is relatively higher than those reported for tomato cultivars grown in southwestern Romania (1.2-4.9mg/100g) (Nour *et al.,* 2013), those obtained for tomato varieties cultivated in Italy (2.33-16.9mg/100g) (Frusciante *et al.,* 2007) and for Portuguese farmer varieties cultivated in homegardens (10.9-18.6mg/100g), (Pinela *et al.,* 2012).

According to Gould (2013), tomato fruits picked green and ripened in storage are substantially lower in lycopene than vine- ripened fruits. Lycopene content is dependent on the cultivar, maturity stage, and environment (Sharma & Le Maguer, 1996).

After harvest, most of the varieties achieved a more than 50% increase in the lycopene content by the 6th day at the stages of maturity. This is in agreement to a study by Fraser *et al.,* (1994) which showed that there can be a 10-14 fold increase in the concentration of carotenoids during maturation of red tomato cultivars.
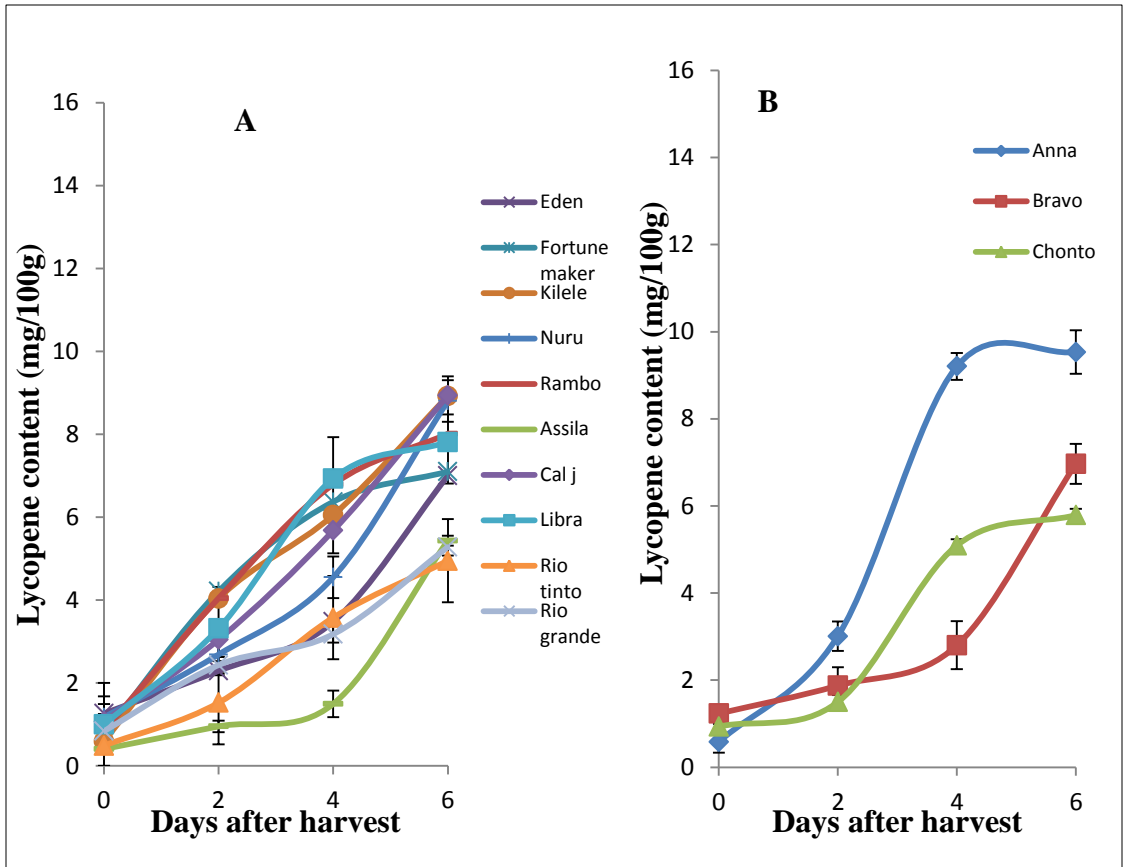
Figure 4.19: Lycopene content (mg/100g) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at mature green stage. Values are presented as mean of three replicates

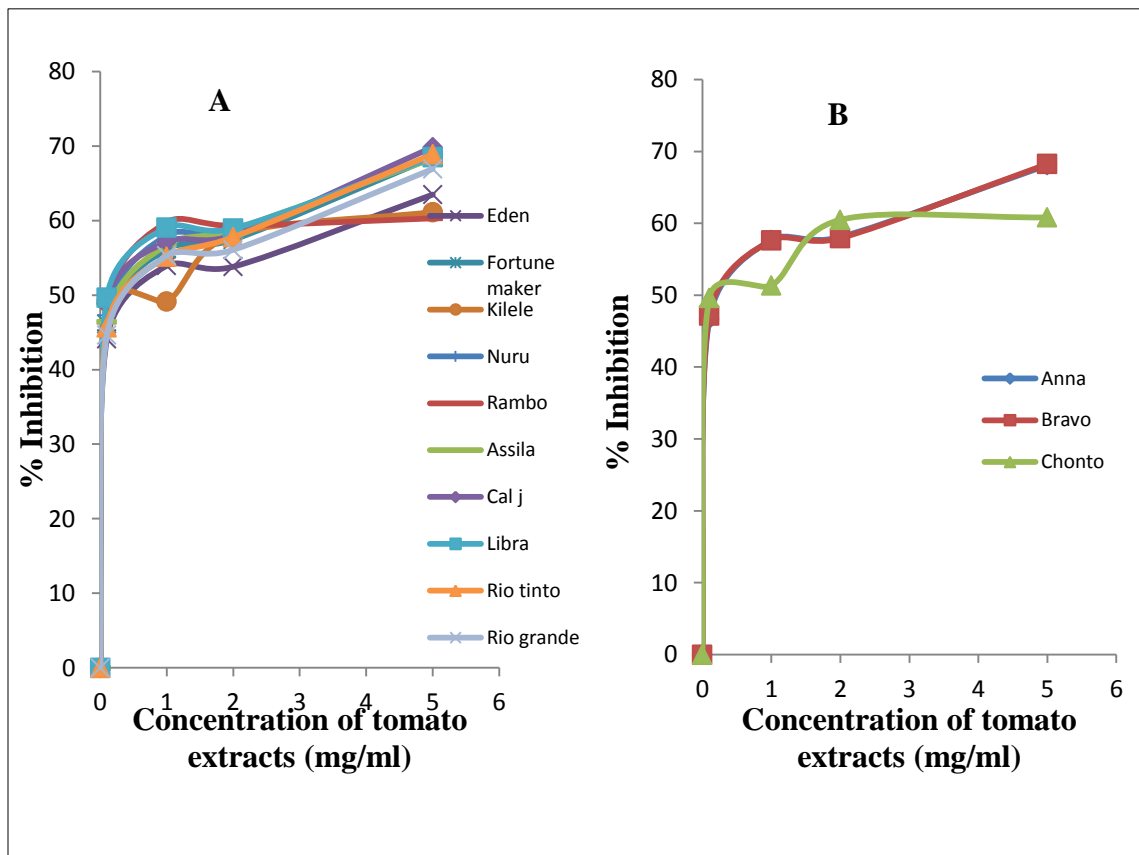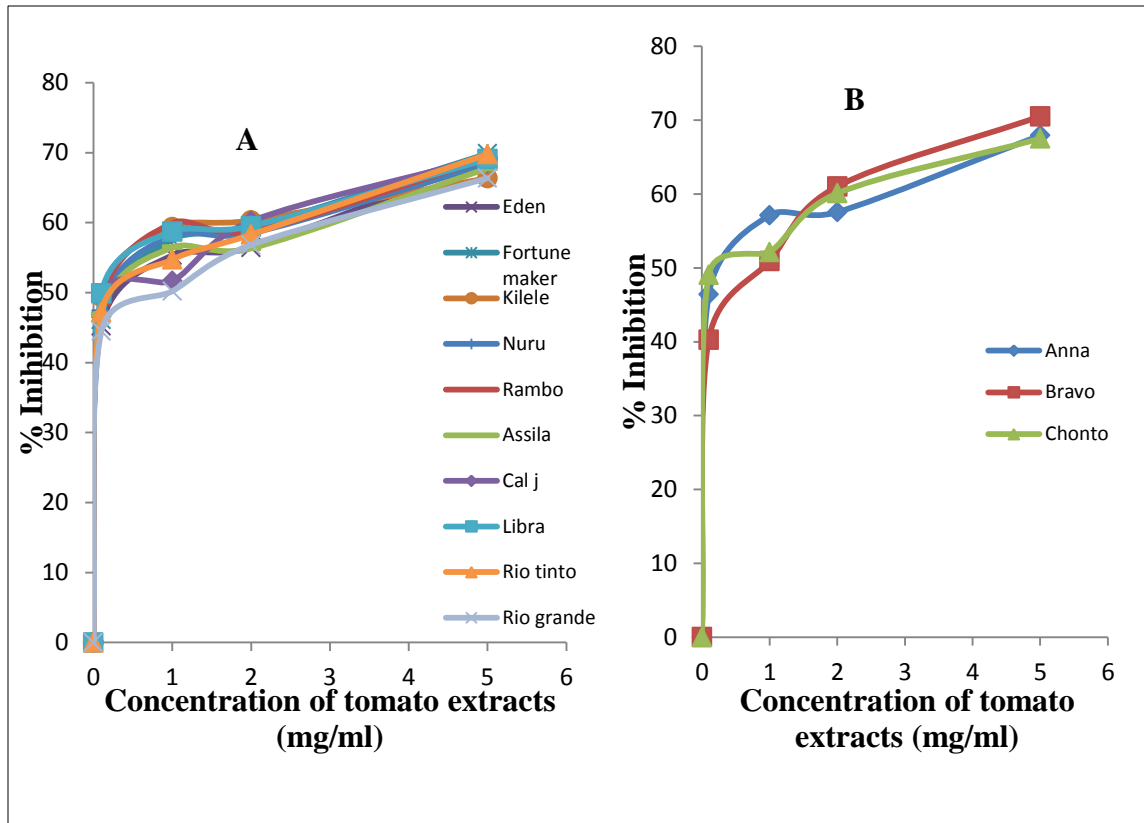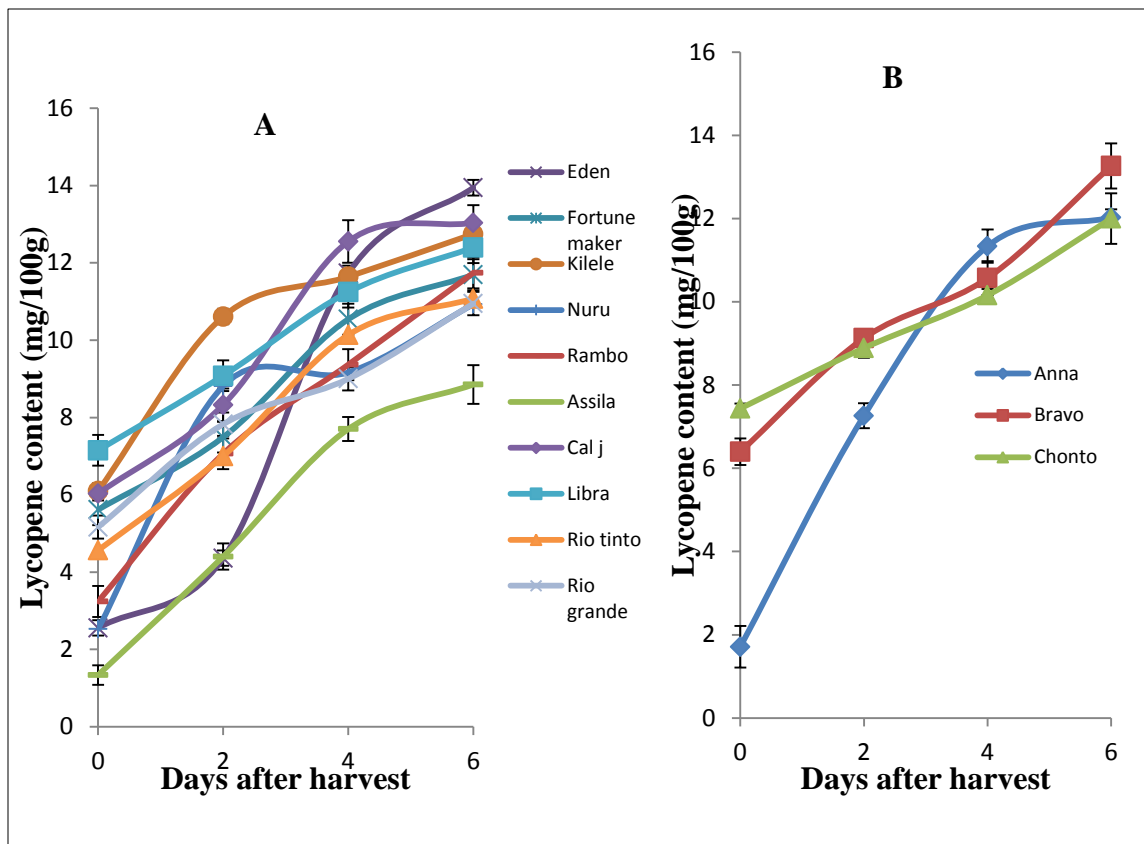**Figure 4.20: Lycopene content (mg/100g) of A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at turning stage. Values are presented as mean of three replicates**
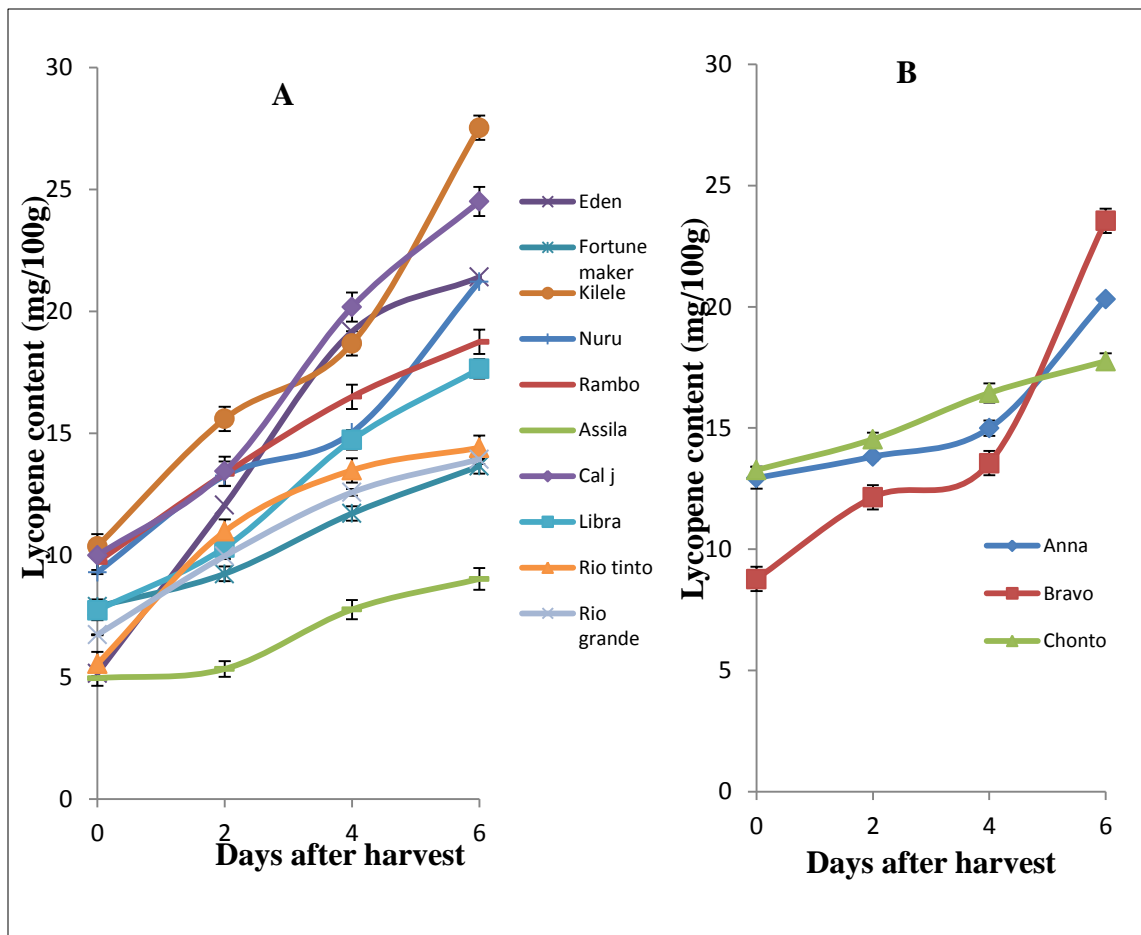
Figure 4.21: Lycopene content (mg/100) of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at red ripe stage. Values are presented as mean of three replicates

4.3.3 Total soluble solids (TSS)

There was significant difference ($p < 0.05$) (Tables 4.4 - 4.6) in the soluble solid content of the thirteen tomato varieties at each of the three maturity stages. Tomatoes harvested at the mature green stage had the highest change in the soluble solid content by the 6th day after harvest. After harvest the mature green tomatoes had soluble solid content between 1.9 – 3.0^{o}Brix and achieved a range between 3.2- 4.0^{o}Brix by the 6th day (Tables 4.4). There was little or no change in the soluble solid content in the tomatoes

harvested (4.1-4.8 $^\circ$ Brix) at the red ripe stage by the 6th day after storage (4.8-5.7 $^\circ$ Brix). These could be attributed to changes in constituents of TSS such as ratio of glucose/fructose and organic acids during storage. The Rio Tinto variety had the highest content (5.7 $^\circ$ Brix), Kilele (4.4 $^\circ$ Brix) and Rambo (4.0 $^\circ$ Brix) at the red ripe, turning and mature green stages respectively.

Table 4.4: Total soluble solid content (^{o} Brix) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at the mature green stage

	Variety	Days 0	2	4	6
A	Anna F1	2.60^d	2.60^b	3.60^{cd}	3.60^{bc}
	Bravo F1	2.40^c	2.80^c	3.70^d	3.90^d
	Chonto F1	1.90^a	2.30^a	3.50^{bc}	3.50^b
B	Eden F1	2.20^b	2.90^{cd}	3.40^b	3.70^c
	Fortune Maker	2.80^{ef}	3.00^{de}	3.10^a	3.30^a
	Kilele	2.20^b	3.70^i	3.70^d	3.90^d
	Nuru F1	2.90^{fg}	3.60^{hi}	3.50^{bc}	3.70^c
	Rambo F1	3.00^g	3.40^g	3.50^{bc}	4.00^d
	Assila F1	2.70^{de}	2.90^{cd}	3.00^a	3.20^a
	Cal Supreme J	3.00^g	3.50^{gh}	3.70^d	3.90^d
	Libra	2.60^d	3.10^{ef}	4.00^e	3.50^b
	Rio Tinto	2.80^{ef}	3.20^f	3.90^e	3.90^d
	Rio Grande	3.00^g	3.40^g	3.40^b	3.50^b
	Grand mean	2.623	3.108	3.538	3.662
	LSD (%)	0.1749	0.1685	0.1749	0.1749

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

Table 4.5: Total soluble solid content (^{o} Brix) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at the turning stage

	Variety	Days 0	2	4	6
		0	**2**	**4**	**6**
A	**Anna F1**	2.70^b	2.90^{ab}	3.50^{ab}	3.60^b
	Bravo F1	2.70^b	3.00^b	3.80^{efg}	3.80^c
	Chonto F1	2.50^a	2.80^a	3.40^a	3.40^a
	Eden F1	2.90^c	2.90^{ab}	3.80^{efg}	3.80^c
	Fortune Maker	3.00^c	3.20^c	3.90^g	4.00^{de}
	Kilele	2.90^c	3.80^f	3.90^g	4.40^f
B	**Nuru F1**	3.50^f	3.50^e	3.80^{efg}	3.80^c
	Rambo F1	3.20^d	3.70^f	3.70^{cde}	4.10^e
	Assila F1	3.30^{de}	3.30^{cd}	3.60^{bc}	3.60^b
	Cal J Supreme	3.40^{ef}	3.70^f	3.60^{bcd}	3.90^{cd}
	Libra	3.00^c	3.30^{cd}	4.10^h	4.30^f
	Rio Tinto	3.00^c	3.50^e	3.70^{cde}	4.10^e
	Rio Grande	3.30^{de}	3.40^{de}	3.80^{efg}	4.00^{de}
	Grand mean	**3.031**	**3.308**	**3.738**	**3.908**
	LSD (%)	**0.1749**	**0.1707**	**0.1749**	**0.1619**

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

Table 4.6: Total soluble solid content (^{o} Brix) of A (Determinate) and B (Indeterminate) tomato varieties after harvest at the red ripe stage

		Days			
	Variety	**0**	**2**	**4**	**6**
A	**Anna F1**	3.20^{ab}	3.50^b	3.70^b	3.80^a
	Bravo F1	3.60^e	3.70^e	3.70^{bc}	3.90^{ab}
	Chonto F1	3.60^e	3.50^{bc}	3.80^{bcd}	3.80^a
B	**Eden F1**	3.10^a	3.10^a	3.90^{de}	4.00^{bc}
	Fortune Maker	3.80^f	3.90^f	4.30^g	4.50^d
	Kilele	3.30^{bc}	3.00^a	3.90^{de}	4.50^d
	Nuru F1	3.60^e	3.70^e	3.90^{de}	4.00^{bc}
	Rambo F1	3.50^{de}	3.70^e	4.10^f	4.50^d
	Assila F1	3.50^{de}	3.70^e	3.80^{bcd}	4.10^c
	Cal J Supreme	3.50^{de}	3.70^e	3.50^a	4.60^{de}
	Libra	3.30^{bc}	3.60^{bce}	4.10^f	4.60^{de}
	Rio Tinto	3.10^a	3.50^{bc}	3.90^{de}	4.70^e
	Rio Grande	3.40^{cd}	3.70^e	4.00^{ef}	4.10^c
	Grand mean	**3.423**	**3.562**	**3.892**	**4.238**
	LSD (%)	**0.1707**	**0.1738**	**0.1749**	**0.1478**

Values are presented as mean of three replicates. In each column different letters mean significant differences ($p < 0.05$).

4.3.4 Total Titratable Acidity

The changes in TTA (Figures 4.22 4.24) indicates that acid concentrations in the fruit declined with maturity. The predominant acid in tomatoes is citric acid. Citric acid levels declined with maturity in all 13 tomato varieties at the three maturity stages. The titratable acidity after harvest ranged from 1.79% (Nuru F1) to 0.90% (Libra F1), 1.12% (Kilele F1) to 0.70% (Libra F1) and 0.69% (Kilele F1) to 0.41% Rambo) at the mature green, turning and red ripe stages respectively. There was no significant difference (p< 0.05) observed at the red ripe stage at which tomatoes are popularly consumed. Carbohydrates, acids (citric and malic) and their interactions play an important role in the sweetness, sourness, and flavor intensity in tomatoes. For best flavor, ratio of high sugars and high acids are required (Maul *et al.,* 2000). High acids and low sugars produces a tart tomato; high sugars and low acids result in a lard taste and low sugars with low acids give a tasteless, insipid tomato. The 'off- flavor' character found in tomatoes of certain cultivars when picked green and ripened off the plant appears to be related to higher concentration of some volatiles as the acid-sugar balance is altered (Pagliarinp *et al.,* 2001; Beckles, 2012). The titratable acidity and total soluble are very important in determining the peculiar sensory profile of tomatoes.

Figure 4.22: % Titratable acidity of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the mature green stage. Values are presented as mean of three replicates

Figure 4.23: % Titratable acidity of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the turning stage. Values are presented as mean of three replicates

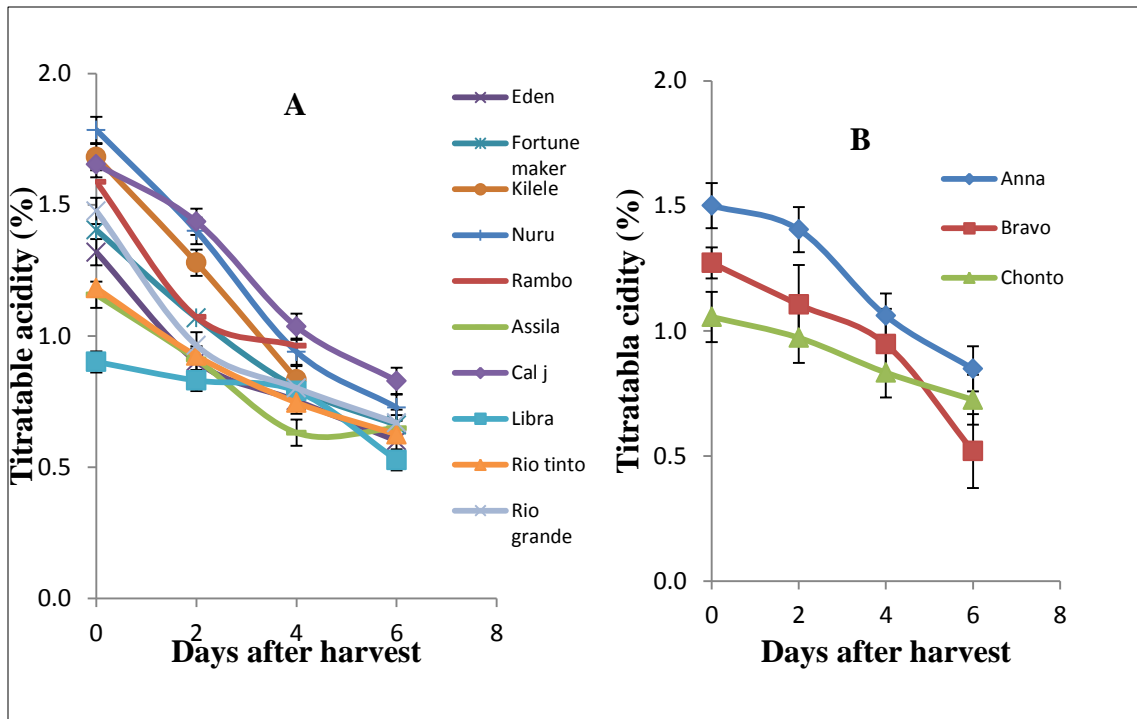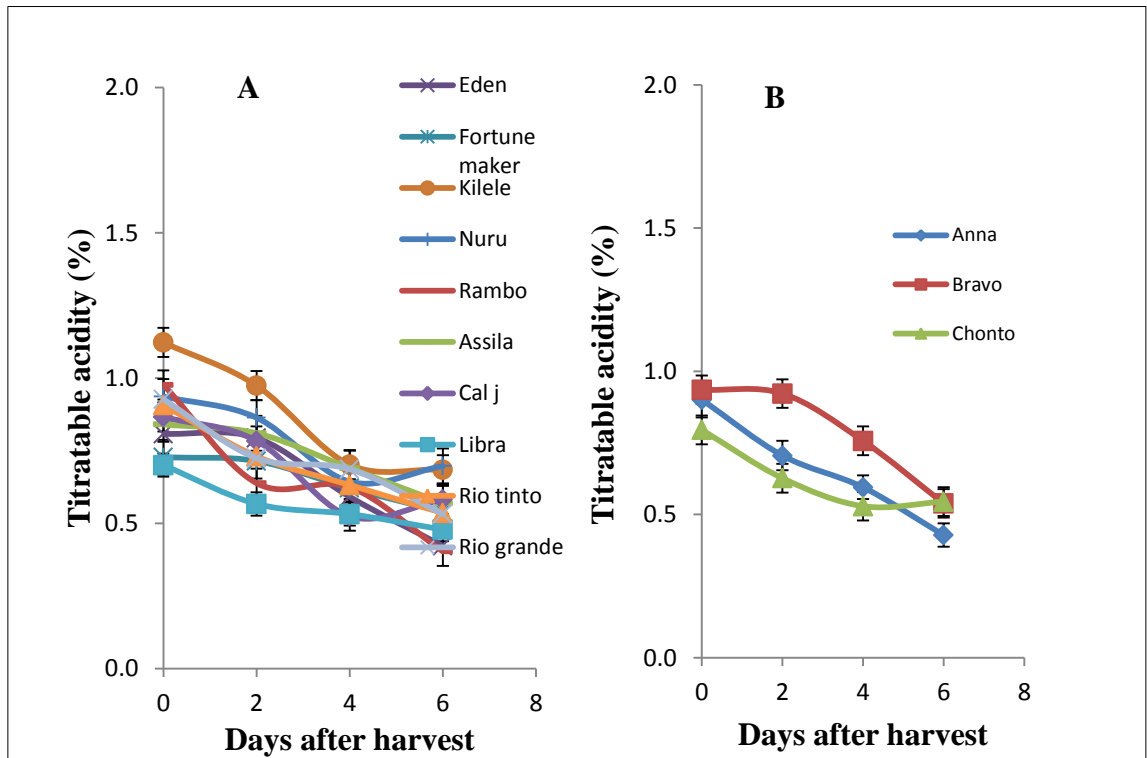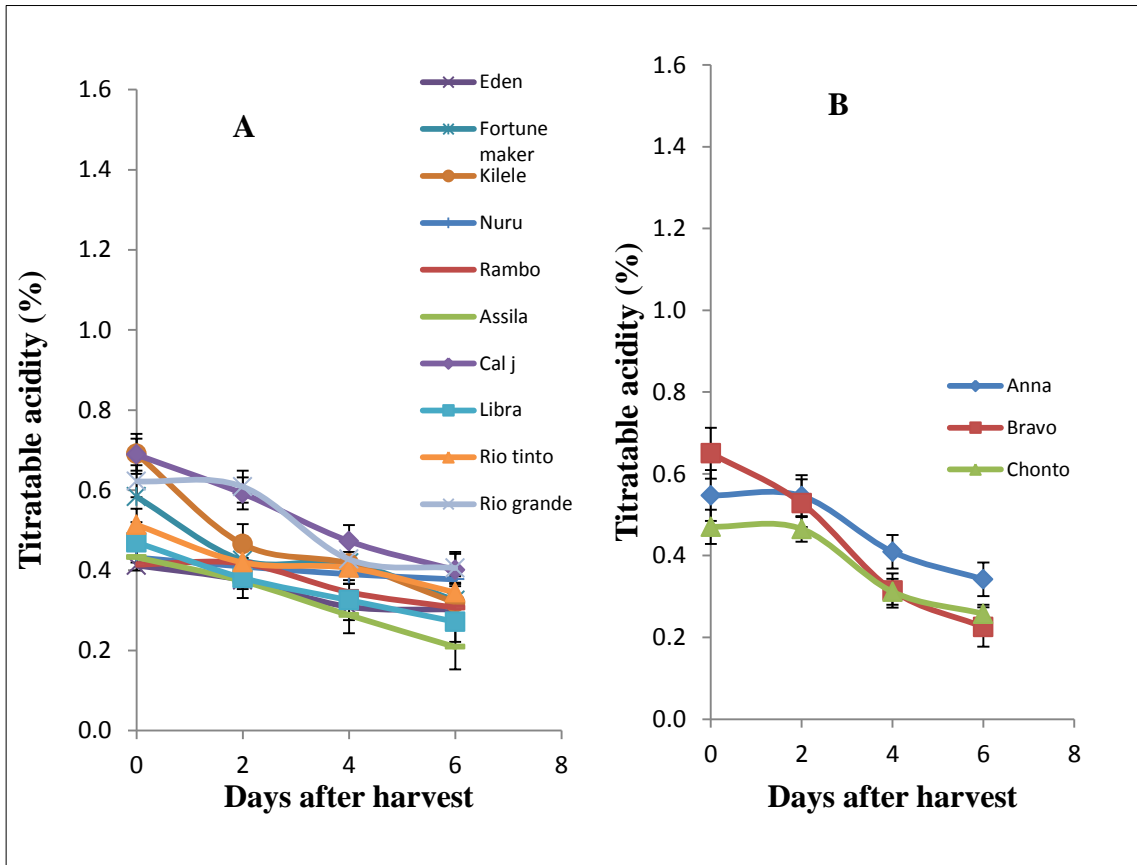**Figure 4.24: % Titratable acidity of the A (Determinate) and B (Indeterminate) tomato varieties respectively after harvest at the red ripe stage. Values are presented as mean of three replicates**

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the study its clear there is a significant difference in tomato varieties in terms of their postharvest and nutritional quality. The indeterminate varieties; Anna F1, Chonto F1and Bravo F1 had more desirable qualities like lower percent weight loss and hence shriveling is minimized and therefore retaining their attractive appearance to appeal to the consumer. The Bravo, Kilele, Rambo, Eden, Nuru and Anna varieties had lower rates respiration and ethylene production rate and therefore they are all suitable for use in markets where delayed or slowed ripening is desired. Both the rates of respiration and ethylene production were lower in the second season in comparison to the first season.

Harvesting tomatoes at the turning stage of maturity was better if uniform color development and extended storage period is required. The season of planting and harvesting affected the rate of respiration and ethylene but didn't significantly affect the days that the rates peaked. Harvesting at the mature green stage may result in development of yellow- orange color as a result of delayed ripening or immaturity while harvesting at the red ripe stage results in quick spoilage of the tomatoes if not delivered in the market on time.

To obtain high lycopene content and a high antioxidant capacity, it is advisable to harvest the tomatoes at the red ripe stage. The Rambo, Bravo F1 and Anna F1 varieties were rich lycopene and can be used in processing of lycopene based products. Varieties such as Cal J, Rio Tinto and Libra had high acid to sugar that gives the tomatoes a good flavor and suitable for processing.

Recommendations

1. Further research can be done on the hybridization (genetic modification) of all suitable traits so that a farmer may grow a single variety that meets the traders, consumers and processors demands.

2. More work is also needed on production of high quality lycopene from tomatoes for the food and by pharmaceutical industry from the varieties with high lycopene content.

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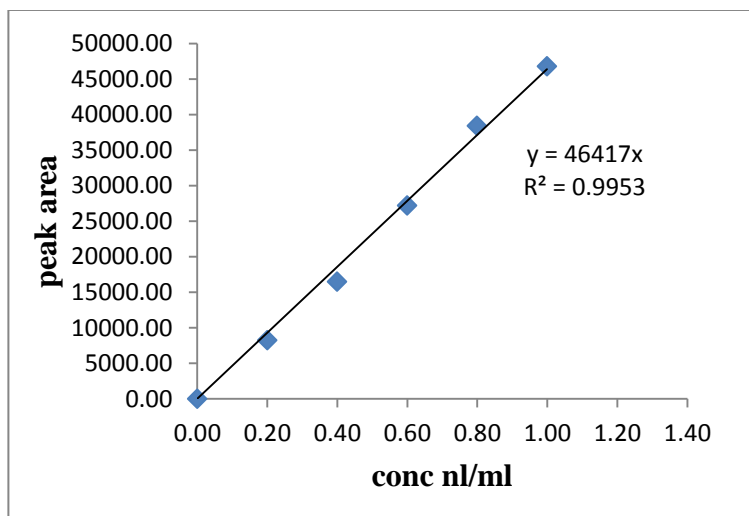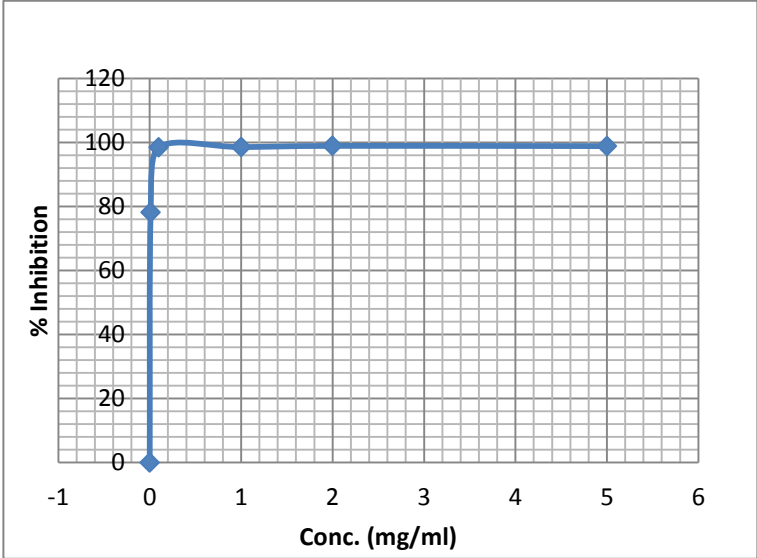# APPENDICES

Appendix 1: Standard curves

Ethylene standard curve

$y = 6598.3x$
$R^2 = 0.9939$
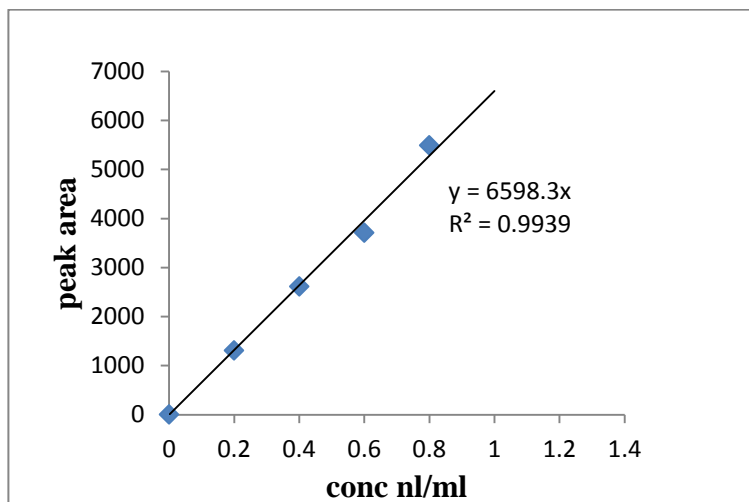
CO_2 standard curve

$y = 46417x$
$R^2 = 0.9953$

Vitamin C standard curve

Appendix 2: Pictorials of the tomatoes

Seedlings the in planting pots

Plants supported using sturdy treads in the greenhouse