PRETREATMENT AND DRYING EFFECT ON THE ANTIOXIDANT, COLOR, REHYDRATION PROPERTIES AND MICROBIAL QUALITY OF FOUR TOMATO VARIETIES

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Pretreatment and drying effect on the antioxidant, color, rehydration properties and microbial quality of four tomato varieties

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DECLARATION

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

Signature……. Date.....

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This thesis has been submitted for examination with our approval as university supervisors

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DEDICATION

To my beloved parents Wambugu and the late Kanini, my dearest grandmother, husband, daughter, brothers and sisters. Thank you for your prayers and support.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
C.C	Calcium chloride
cfu/g	Colony forming unit per gram
dSm^{-1}	Dicisiemens per meter
dw	Dry weight
E.coli	*Escherichia coli*
EC	Electrical conductivity
ERA	Economic Review of Agriculture
FAO	Food and Agriculture Organization
f.w	Fresh weight
GAE	Gallic acid equivallent
GDP	Gross domestic product
Ha	Hectare
HCD	Horticultural Crops Directorate

HPLC	High performance liquid chromatography
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KEBS	Kenya Bureau of Standards
KES	Kenyan shilling
m.c	Moisture content
mg/g	milligram per gram
mmolNL^{-1}	millimole nitrogen per liter
MOA	Ministry of Agriculture
MT	Metric Tonnes
MOALF	Ministry of Agriculture Livestock and Fisheries
N.M	Sodium metabisulphate
PCA	Plate count agar
PDA	Potato dextrose agar
RR	Rehydration ratio
TPC	Total phenolic content
USDA	United States Department of Agriculture
UV	Ultra violet

ABSTRACT

Tomato, whose consumption popularity is on the rise, is one of the most important vegetable grown in Kenya. However, 50% postharvest losses in this commodity are experienced. Drying, as a preservation method is essential in increasing its shelf stability. However, during drying quality of the product is affected as a result of heat induced reactions. Pretreatment before drying offers an effective control of these reactions. This study was therefore carried out with an objective of investigating the effect of pretreatment on the antioxidant properties, drying time, rehydration ratio, color and microbial quality of selected tomato varieties. The tomato fruits were divided into quarters and sprayed with 0.5% sodium metabisulphate, 0.5% calcium chloride and untreated (control). The quarters were oven-air, vacuum–oven, solar and freeze dried to 13% moisture content. Drying time, moisture content, total phenolics, lycopene, β-carotene, vitamin C, rehydration ratio and color were determined using standard methods. Total fungal and total bacterial count as well as *Escherichia coli* and *Salmonella* presence was determined at onset and once monthly for six months in the dried samples. Results showed that drying time was shortest in Riogrande variety (762-2097 minutes) and longest in Anna F1 variety (948-3055 minutes). Lycopene, β-carotene, total phenolic content and redness value in the fresh samples were significantly affected by variety ($P<0.05$). However, initial moisture content, ascorbic acid and lightness value did not differ significantly ($P>0.05$) in the fresh samples. Significantly ($P<0.05$) higher levels in lycopene, β-carotene, total phenolics, rehydration ratio, redness and lightness was observed in pretreated samples compared to the control after drying. However, the effect of pretreatment on the antioxidant properties during freeze drying was not significant ($P>0.05$). Percentage retention of ascorbic acid relative to the fresh samples ranged between 74.8-80.0% and was only present in freeze dried samples. At the end of the storage duration, the total bacterial growth ranged 30.0×10^1—49.0×10^1, 17.0×10^1—21.5×10^1 and 2.5×10^1—6.0×10^1 cfu/g in the control, 0.5% calcium chloride and 0.5% sodium metabisulphate samples, respectively. The maximum total fungal count during the storage period was 17.5×10^1, 12.5×10^1 and 5.0×10^1 in the control, 0.5% calcium chloride and 0.5% sodium metabisulphate respectively. *Escherichia.coli* and *Salmonella* were absent throughout the storage duration. These findings show that pretreatment in tomato drying is effective in maintaining the antioxidant quality and physical attributes of the dried product. In addition, pretreatment reduces microbial growth in dried tomatoes and may offer longer shelf stability.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tomato (*Lycopersicon esculentum* Mill) is among the most highly consumed and popular vegetable in the world (Hanson *et al*., 2004). Botanically it is a fruit but often considered a vegetable by use (Hanson *et al*., 2004).The shape of the fruit differs per cultivar and the color of the fruit ranges from yellow to red when ripe (Maršić *et al*., 2005). The production of this crop serves as a source of income for most rural and sub-urban producers in most developing countries of the world (Wachira *et al*., 2014). Nutritionally, tomatoes are rich sources of antioxidant compounds such as β-carotene, lycopene, ascorbic acid and phenolic compounds (Freeman & Reimers, 2010; Georgé *et al*., 2011; Lumpur, 2008).

Lycopene and β-carotene are carotenoids responsible for the red, yellow and orange colors of most plants which cannot be synthesized by animals *in vivo* and require consumption in the diet (Eldahshan & Singab, 2013). Scientific evidence shows that consumption of these phytonutrients on a regular basis contribute to significant health benefits such as prevention against lifestyle diseases such as prostate cancer, age degenerative diseases and cataracts (Noor *et al*., 2014; Brooks *et al*., 2008). This is attributed to their ability to quench singlet oxygen and trap peroxyl radicals (Bayili *et al*., 2011; Ozlem *et al*., 2015). Tomatoes are mostly consumed fresh in food salads and soups (Ayandiji *et al.*, 2011) while a significant amount is processed into ketchup, concentrate sauces or canned in the food industry (Luengwilai *et al*., 2012; Nisha *et al*., 2011).

In Kenya, tomato is the third major crop after kales and cabbage in terms of production volumes (Geoffrey *et al*., 2014). However, being climacteric crops, tomatoes are

inherently perishable (Ayandiji *et al*., 2011) with a shelf life of 8-12 days in their fresh state after harvest (Ahmed *et al*., 2016). This has led to extensive postharvest losses in the product that have been estimated to be as high as 50% (Addo *et al*., 2015). These losses lead to a subsequent imbalance in supply and demand and consequential losses in income to both small and large scale farmers. In order to sustain surplus harvest, appropriate postharvest preservation technologies are needed to extend the commodity's shelf life. Drying technology can lower the moisture content and consequently the water activity of food to a level that does not support microbial growth (Joshi *et al*., 2009). As a result, the product can be stored for a longer period of time and still be safe for human consumption. Drying also reduces the weight of the product thus decreasing the product volume as well as transportation costs (Gouda & Nidoni, 2014). However, during drying some nutrients are degraded by heat thus affecting the quality and acceptance of the final product (Taylor *et al*., 2010). This degradation has generally been associated with isomerization and oxidation that occurs during the drying process (Owureku-asare *et al*., 2014). The degree and extent of oxidation as well as isomerization is directly related to the duration and intensity of heating (Eldahshan & Singab, 2013). As a result, there is need to enhance the rate of drying to ensure maximum retention of antioxidant molecules in tomatoes as well as reduce oxidative, non-enzymatic and isomerization reactions during drying. Since color, rehydration ratio, lycopene, total phenolic content, β-carotene and ascorbic acid in tomato are regarded as good quality indicators of the dehydration process (Santos-Sánchez *et al*., 2012), minimization of degradation in these indicators is paramount. In this regard, pretreatment with compounds such as calcium chloride and sodium metabisulphate has been shown to increase the drying rate in plant tissues by enhancing water mobility (Phomkong *et al*., 2010). It has also been reported that pretreatment prior to dehydration improves general product quality (Azoubel & Oliveira, 2008) by preserving the nutritional, sensorial and functional properties of the food matrix (Kennedy, 2007). Therefore, the aim of this study was to investigate the effect of pretreatment on lycopene, β carotene, total phenolics, rehydration ratio, color and microbial quality of tomato during drying.

1.2 Problem statement

Tomato production in Kenya has increased (by 11% in area to 20,111 ha, 6% in volume to 341,000T and 6% in value to Kshs 13.7 Billion) from 2014 to 2016 (HCD, 2016). Despite the increase in production, tomatoes are highly perishable and if care is not taken after harvest, they soon decay (Brooks *et al*., 2008). The high perishability in tomato is associated with its high moisture content that allow rapid microbial infection in their fresh state (Arah, 2015). This has led to extensive postharvest losses that are estimated to be 50 percent of what is harvested (Owino *et al*., 2015). Postharvest losses results in considerable loss of income to the small holder farmers and also removes surplus produce from the market and contributes to rising tomato prices during the tomato offseason. In order to sustain surplus harvest appropriate postharvest preservation methods are needed to extend the commodity's shelf life. One such technology is drying. However, during drying nutrients are degraded by heat thus affecting the quality and acceptance of the final product (Athanasia & Konstantinos, 2010). The degree and extent of nutrient and quality degradation, is directly related to the duration and intensity of heating (Eldahshan & Singab, 2013). As a result, there is need to enhance the rate of drying to ensure maximum retention of antioxidant molecules in dried tomatoes as well as reduce undesirable non-enzymatic reactions and microbial infection in the commodity.

1.3 Justification

In order to minimize postharvest losses, there is the need to develop postharvest loss prevention technologies that are appropriate and do not impact negatively on the quality of the produce. One such technology is pretreatment prior to drying. Drying lowers the moisture content of food to a level that does not support bacterial and mold growth. As a result, the product can be stored for a longer period of time and still be safe for human consumption. Reduction in postharvest losses can therefore bridge the gap between demand and supply and increase availability of tomatoes during tomato offseason.

Optimization of tomato quality during drying can be achieved by pretreatment which maximizes the drying rate and minimizing oxidative damage. Use of pretreatments such as calcium chloride and sodium metabisulphate prior to drying would lead to faster drying to achieve safe moisture content and consequentially lead to preservation of the antioxidant and physical properties in the dried product as well as reduce microbial load in the dried product. Use of common drying methods such oven-air, vacuum-oven drying, solar and freeze drying will provide adequate information to all stakeholders in the tomato value chain on the impact of the drying method on quality of the dried tomatoes.

1.4 Objectives

1.4.1 Main objective

To determine the pretreatment and drying effect on the drying time, antioxidant properties, rehydration properties, color, and microbial quality of four selected tomato varieties.

1.4.2 Specific objectives

I. To determine the effect of pretreatments on the drying time, total phenolic content, lycopene, β carotene and ascorbic acid, during oven-air, vacuum-oven, solar and freeze drying in Anna F1, Kilele, Prostar F1 and Riogrande tomato varieties.
II. To determine the effect of pretreatment on the rehydration ratio and color in Anna F1, Kilele, Prostar F1 and Riogrande varieties during oven-air, vacuum-oven, solar and freeze drying.
III. To determine the effect of pretreatment on microbiological quality of dried tomatoes during six month storage duration.

1.5 Null Hypothesis

I. Ho: Pretreatment of tomatoes does not significantly affect the drying time, total phenolic content, lycopene content, β carotene and ascorbic acid during tomato drying.

II. Ho: Pretreatment of tomatoes does not significantly affect rehydration ratio and color during tomato drying.

III. Ho: Pretreatment does not have any significant effect on the microbial quality of dried tomatoes during storage.

CHAPTER TWO

LITERATURE REVIEW

2.1 The tomato plant, origin and distribution

The tomato (*Lycopersicon esculentum* Mill) plant which belongs to the solanaceae family is a perennial warm seasoned plant that typically grows into a shrub but it is often grown as an annual crop for its edible fruit (Hafeznia *et al*., 2014). The plant typically grows to 1-3meters in height and the fruit weighs approximately 100g in its native habitat (Atiqah *et al*., 2014). Tomato fruit is botanically a berry but is cultivated and used as a vegetable (Slimestad & Verheul, 2009). Structurally, the fruit **(**Figure 2.1**)** is juicy and is composed of the pericarp, placental tissue and seeds as well as 2 to 25 locules in transection and the fruit is yellow to red when ripe (Georgé *et al*., 2011). The shape of the fruit vary considerably with variety and can be either round, long, rectangular or ellipsoid shaped (Visa *et al*., 2014).

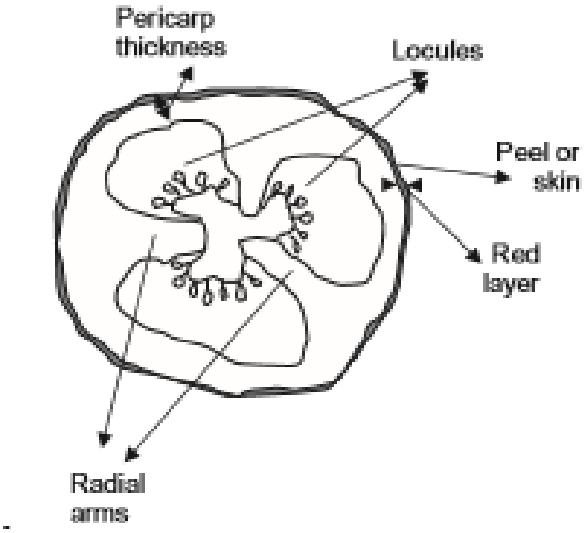


Figure 2.1: Transverse cut of a tomato fruit (Georgé et al., 2011).

The tomato fruit is believed to have originated from the south American Andes in Peru where it grew in the wild (Paran *et al*., 2007). The early explorers later took it to other parts of the world where it was planted as ornamental but not consumed since it was considered to be toxic (Paran *et al*., 2007). In 1840, it was accepted as an edible crop in Europe (Paran *et al*.,, 2007). Toxicity concerns were dispelled in the 1800's and consumption intensified all over the world. Global tomato production increased in the 1920's as a result of intense mechanization in processing (Tan *et al*., 2010). Today, through horticultural genetic modification, there has been improvement in more desirable parameters such as size shape, color and pest and disease resistance enhancing its consumption (Dorais *et al*., 2008). Many varieties of tomatoes suited to different ecological conditions are currently grown all over the world and utilized in diverse foods (Passam *et al*., 2007).

2.2 Soil and climatic requirement for tomato production

Tomato is a warm season crop and grows well in clay or silty soils that are deep and well drained (Hafeznia *et a*l., 2014). However, growth is limited when the soil is waterlogged (Pascale, 2001) since soil aeration in the root zone is decreased and nutrient leaching enhanced (Marouelli *et al*., 2007). This crop is reported to be moderately tolerant to salinity and can tolerate total salt concentration of up to 2.5-2.9 dSm^{-1} in the root zone (Passam *et al*., 2007). However the exact level may vary depending on cultivar sensitivity and environmental conditions (Passam *et al*., 2007). Optimum production is achieved in soil pH in the range of 6.0–7.5. However, growth of the root is restricted in acidic soil (Chaignon *et al*., 2002). Furthermore, tomato plants have within certain limits the ability to integrate temperature (Koning, 2001). However, fluctuations in temperature may affect the pattern of crop yield as the rate of developmental events such as fruit maturation is largely determined by temperature (Koning, 2001). Temperatures below 10°C and above 30°C lead to poor or failure of fruit to set as a result of reduction in pollen release and viability (Satoi *et al*., 2006). Successful cultivation is best achieved in temperatures of 20°C–27°C (Koning, 2001).

2.3 Tomato production

Tomato is one of the most widely consumed vegetable in the industrialized world. It is one of the most important vegetable and has the highest acreage of any vegetable crop in the world (Hanson *et al*., 2004). The production of this crop serves as a source of income for most rural and sub-urban producers in most developing countries of the world (Wachira *et a*l., 2014). In 2010, its global production was approximately 145.6 million tonnes of fresh fruit and tops in the category of canned vegetable (Olaniyi *et al*., 2010). The major tomato growing countries in the open and protected cultivation in the world are China, USA, Italy, Turkey, India and Egypt. China leads world tomato production with about 50 million tonnes followed by India with 17.5 million tonnes (Arah *et al*., 2015). The major tomato producing countries in Africa are Egypt, Nigeria and Morocco (Table 2.1).

Table 2.1: Top ten tomato producing countries in Africa

Rank in Africa	Country	Total production(Tonnes)
1	Egypt	8 625 219
2	Nigeria	1 560 000
3	Morocco	1 219 071
4	Tunisia	1 100 000
5	Cameroon	880 000
6	Algeria	796 963
7	South Africa	564 740
8	Sudan	529 200
9	Kenya	397 000
10	Ghana	321 000

Source:(FAOSTAT, 2014)

The horticultural industry in Kenya contributes 8% of Kenya's gross domestic product (GDP) and 36% of the agriculture GDP and is one of the greatest contributors to the Kenyan economy (Geoffrey *et al*., 2014). Tomato is one of the most promising commodities in agricultural production for the economic growth and development of the country. Kenya ranks 9th in tomato production in Africa with a total production of 397,007 Tonnes (FAOSTAT, 2014). It is a promising commodity especially in horticultural expansion and growth where it accounts for 14% of the total vegetables produced and 6.72% of the total horticultural crops in volume (MOA, 2012). In 2016, tomato was the second most important exotic vegetable accounting for 20 percent by value of the exotic vegetables grown in Kenya (HCD, 2016).

The major producing counties in terms of value in Kenya are Kirinyaga (17.8%), Kajiado (11.8%) and Taita Taveta (8.5%) (HCD, 2016) as shown in Table 2.2. The moderate to hot temperatures as well moderate to high environmental conditions in these counties provide optimum conditions for tomato growth (Ochilo *et al*., 2018). In Kenya, tomato production is mainly carried out in the open fields but the adoption of greenhouses in the past five years has been noted (MOALF, 2015). Cultivation in the open fields accounts for 95% while greenhouse production account for 5% of the total tomato produced in Kenya (Geoffrey *et al*., 2014).

Table 2.2: Tomato production trends in Kenya by counties from 2015-2016

	Year 2015			Year 2016			
County	**Area (ha)**	**Volume(MT)**	**Value(KES)**	**Area(ha)**	**Volume (MT)**	**Value (KES)**	**% of Total value**
Kirinyaga	2,015	42,780	2,099,670,000	3,128	54,185	2,323,140,000	17.8
Kajiado	1,360	27,440	1,388,231,040	1,452	32,789	1,612,592,000	11.8
Taita Taveta	579	13,745	556,580,000	830	18,026	1,157,692,000	8.5
Laikipia	536	12,674	650,058,200	583	14,070	986,420,000	7.2
Bungoma	1,055	25,429	1,211,210,000	811	21,305	951,330,000	7
Trans Nzoia	659	14,690	617,200,030	733	16,660	638,237,500	4.7
Narok	784	14,920	528,959,999	1,561	20,744	596,402,394	4.4
Nakuru	851	14,158	293,884,050	946	15,179	491,697,047	3.6
Kisumu	591	16,512	725,882,539	646	8,545	397,342,500	2.9
Homabay	752	6,771	324,371,006	669	8,249	393,580,000	2.9
Machakos	795	9,500	245,599,000	689	12,765	380,772,000	2.8
Kiambu	986	16,545	692,217,200	965	9,132	327,305,000	2.4
Meru	928	7,903	229,754,016	1,050	9,951	322,565,018	2.4
Bomet	862	10,785	283,500,000	527	9,047	261,152,000	1.9
Lamu	360	7,719	284,855,000	374	7,190	247,700,000	1.8
Others	5,265	89,108	2,790,050,634	5,147	83,189	2,599,234,852	19
Total	**18,378**	**330,679**	**12,922,022,714**	**20,111**	**341,026**	**13,687,162,311**	**100**

Source: The Horticultural Crops Directorate (HCD) of the Agriculture and Food Authority 2016.

2.4 Tomato trade in Kenya

Tomato is a key commercial vegetable especially for the horticulture farmers in Kenya (Geoffrey *et al*., 2014). The tomato market has progressively grown in the recent past. This has been attributed to the adoption of greenhouses that allows availability of tomatoes during offseason (Geoffrey *et al*., 2014). Tomato production in Kenya provides income to smallholder farmers, government revenue and foreign exchange (Ochilo *et al*., 2018). The major stakeholders in the tomato value chain include: producers, traders, transporters, retailers, service providers and exporters. Tomato produce in Kenya are marketed by individual farmers who pack and sell to the retailers and wholesalers (Ongeri, 2014). The retail sector involves supply of the commodity to diverse segments such as kiosks, supermarkets and open markets. Another tomato marketing channel in Kenya is the broker who enters into agreement with the individual farmer and later sells to the retailer, wholesaler or exporter (Ongeri, 2014). About 75% of tomato farmers sell their produce in close proximity to their farms to avoid transportation and storage costs. Therefore, a majority of the total volume produced finds its way to the local market (Karuku *et al*., 2016). Income between the producer, retailer and wholesaler is generally unequally distributed suggesting imperfect market (Ruttoh *et al*., 2018).

2.5 Utilization of tomato

Tomato plays a key economical role globally through local and international trade (Ayandiji *et al*., 2011; Samuel & Orji, 2015). Furthermore, its association with health benefits such as reduction in age degenerative diseases, cancers such as prostate cancer also contributes to its high demand (Athanasia & Konstantinos, 2010; Nisha *et al*., 2011; Sacilik, 2007). It is mainly consumed fresh in salads or cooked sauces, soups and meats (Ayandiji *et al*., 2011). Tomato also finds wide application in the food industries for the processing of products such as puree, paste, ketchup, sauces, preserves and powder (Herna, 2008; Koh *et al*., 2010; Luengwilai *et al*., 2012; Nisha *et al*., 2011). In Kenya, tomato is mainly consumed in the fresh sate (Karuku *et al*., 2016). The interest in the

production of dried tomatoes is due to the possibility of using them in pizza toppings, pesto, snacks and other dishes (Botineștean *et al*., 2012).

2.6 Tomato varieties

Based on the plant growth habit, tomatoes are broadly classified into determinate and indeterminate varieties (Tigist & Workneh, 2013). Determinate varieties tend to appear bushy since their foliage grows first after which flowers set into fruits after successful pollination. Each shoot on the plant clusters to form eventual fruit clusters and the fruits tend to mature and ripen at the same time on the plant (Maršić *et al*., 2005). Once the first fruits have ripened, the plants starts to gradually decline in vigor and few or no fruits set thereafter hence has short harvest periods. Examples of such varieties are Eden, Cal J, Riogrande, Kilele, Monyalla and Tanzanite which are mainly grown in the open field in Kenya (Geoffrey *et al*., 2014; Ochilo *et al*., 2018)

Indeterminate varieties first produce some foliage in the start after which flowering occurs throughout the growing season and are mainly grown for fresh market (Rausch *et al*., 2008). The plant therefore has tomato fruits in different maturity stages at any given period of time and are often trellised on stakes to prevent breakage (Kuehn *et al*., 2005; Perkins-veazie *et al*., 2007; Rausch *et al*., 2008). Examples of indeterminate varieties are Kenom, Marglobe, Anna F1, Prostar F1, Nemonneta and Monset. These varieties are mainly cultivated in greenhouses in Kenya (Geoffrey *et al*., 2014).

2.7 Nutritional composition of tomatoes

The nutritional composition of tomato fruit depends on cultivar, maturity, light, temperature, soil, fertilization, irrigation, handling practices and storage in which they are grown (Isack *et al*., 2016). Tomatoes contain significant amounts of vitamins, minerals and dietary fiber. However, they are poor in protein and fat (Idah *et al*., 2010). According to Dipak (2004), tomatoes contain 0.10mg/100g of thiamine, 0.06mg/100g of riboflavin and 30mg/100g of ascorbic acid, 5g/100g dietary fiber, 14.9g/100g

carbohydrate, 7.1g/100g protein and 0.5g/100g fat. A separate study reported that eight cultivars of tomatoes contained 0.59-0.65% ash, 1.71-1.92% total fiber, 0.78-0.87% protein, 0.85-1.16% glucose and 0.96-1.24% fructose (Herna, 2008). Tomato normally contains high amounts of moisture content in the range of 89.03-93% (Idah *et al*., 2010). Carbohydrate content of glucose and fructose increases through maturation and ripening of tomato and can account for 50% of dry matter (Isack *et al*., 2016). The fruit normally contain 5 to 10% dry matter, of which about 75% is soluble, and about 1 to 3% of which consists of skin and seed. Nearly half of the total dry matter is reducing sugars, and about 10% is organic acid, principally citric and malic acids (Shi *et al*., 2000).

2.8 Bioactive compounds in tomatoes

To a certain degree, all the products obtained from tomatoes present antioxidant activity determined by the bioactive compounds like lycopene, β-carotene, vitamin C, polyphenols and flavonoids (Omodamiro *et al*., 2013). This makes tomatoes a very nutritive vegetable (Brooks *et al*., 2008). Evidence affirms that an increase in fruit and vegetable consumption is a good means of protection against free radicals (Appliqu *et al*., 2014). Free radicals which include singlet oxygen, reactive nitrogen species are known to cause damage to lipids, proteins, enzymes and nucleic acids that lead to cell or tissue damage implicated in the process of ageing as well as in a wide range of degenerative diseases including inflammation (Chauhan *et al*., 2011; Periago *et al*., 2002; Xue, *et al*., 2015). Epidemiological studies describe an inverse relationship between a diet rich in tomatoes and tomato products and the incidence of cardiovascular diseases (Jacob *et al*., 2010). However the antioxidant activity of tomatoes depend on both generic, environmental factors and the ripening stage (Biochimie *et al*., 2014; Chauhan *et al*., 2011).

2.8.1 Lycopene

Lycopene ($C_{40}H_{56}$) is a lipid soluble bioactive carotenoid found in most fruits and vegetables such as tomatoes, watermelon, pink grapefruits, apricots, red pepper and pink

guava (Rao *et al*., 2007). It has eleven conjugated double bonds and two unconjugated double bonds that are arranged in a linear array (Figure 2.2) thus has a high potency as a singlet oxygen scavenger (Chawla *et al*., 2008).

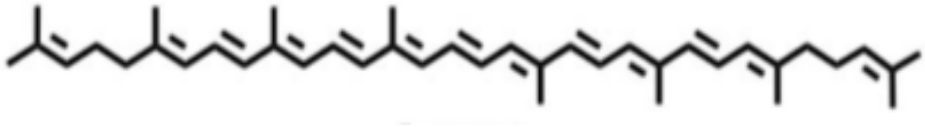


Figure 2.2: Structure of Lycopene (Boon et al., 2010)

Lycopene absorbs light during photosynthesis and offers protection from photosensitization in plants (Shi *et al*., 2000). In tomatoes, it is the predominant carotenoid that is responsible for the red pigment and constitutes 80-90% of the total carotenoids (Appliqu *et al*., 2014; Freeman *et al*., 2010). Research suggests that tomatoes contain lycopene concentration in the range of 0.85-13.6 mg /100 g fresh weight with a two-fold higher concentration being reported in the pericarp than the locular cavity (Chauhan *et al*., 2011). However, lycopene content of tomatoes depends on species and increases as the fruit ripens (Chauhan *et al*., 2011).

Lycopene exists in foods primarily in the trans sterisomeric configuration; however, cooking and processing help convert trans-lycopene to cis-lycopene, which is more readily absorbed (Shi *et al*., 2000). Studies have reported that bioavailability of lycopene increases through matrix disruption during mechanical homogenization and heat treatment (Capanoglu *et al*., 2010). However intensive heat treatment has been reported to cause lycopene degradation (Jude *et al*., 2014). Degradation is mainly as a result of oxidation and isomerization which is manifested through loss of color and reduced biological value of lycopene (Chauhan *et al*., 2011). The major factors that lead to lycopene loss during dehydration include: heat, light and oxygen (Goula *et al*., 2012). Increase in temperature during dehydration translates to increase in lycopene loss. The thermal damage incurred is directly proportional to the heating temperature and exposure time (Abano *et al*., 2011). Isomerization of lycopene causes conversion of all

trans to cis forms (Tola & Ramaswamy, 2015). Cis isomers generally increase with increase in temperature and duration of processing (Olufemi *et al*., 2009). Therefore heat processing should be done at low temperatures to avoid significantly high lycopene losses (Charles *et al*., 2014).

The content of lycopene decreases with increase in illumination (Nisha *et al*., 2011). Exposure of lycopene to light is therefore detrimental to lycopene. Only gold, yellow or red light should be used to minimize lycopene degradation and isomerization (Hong, 2014). In addition, exposure of lycopene to oxygen has negative effects on lycopene stability during drying. Therefore, gases such as carbon dioxide, nitrogen or vacuum conditions are ideal during heat treatment (An *et al*., 2013). Use of pretreatments such as calcium chloride and sodium metabisulphate also reduces lycopene degradation (Hossain & Gottschalk, 2009; Mwende *et al.*, 2018) These solutions remain on the surface layer of the tomato and prevent oxygen from penetrating and oxidizing lycopene (Latapi, 2006).

2.8.2 β-carotene

β-Carotene ($C_{40}H_{56}$) is an organic pigmented terpenoid compound (Figure2.3) that abounds in vegetables and fruits (Jude *et al*., 2014). It can be found in yellow, orange, green and red colored fruits and vegetables and is a precursor for vitamin A (Boon *et al*., 2010; Lemmens *et al*., 2013).

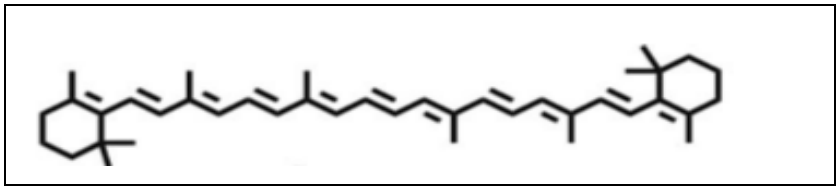


Figure 2.3: Structure of β-carotene (Shi et al., 2000)

Plant based sources of β-carotene include beet root, apricots, cantaloupe, carrots, pumpkin, sweet potato, pink grapefruit, tomatoes, watermelon, mango, papaya, peaches, prunes, squash and oranges (Eldahshan *et al*., 2013). Naturally, β-carotene is mostly found as all-trans isomers and lesser as cis-isomers (Eldahshan *et al*., 2013). However, trans-β-carotene is very unstable and can be easily isomerized into cis-isomers which have been found to possess reduced pro-vitamin A activity, when exposed to heat and light (Lemmens *et al*., 2013). However, in regards to absorption *cis*- isomers are more readily absorbed into micelles as compared to the *trans* isomers (Lemmens *et al*., 2013). In biological systems, β-carotene function as a single oxygen quencher, a free radical trapping agent and have anti-mutagenic, photo protective ,immune enhancing and chemo-protective properties (Sharma *et al*., 2012).

The content of β-carotene in tomatoes varies with variety and decreases with fruit ripening (Wilhelmina, 2005). According to Jacob *et al*. (2010) ripe fresh tomatoes contain total β-carotene content of 0.25mg/100 on fresh weight. A separate study carried out by Hanson *et al*. (2004) reported β-carotene content in the range of 0.20-1.16mg/100g fresh weight of the tomato varieties. This was comparable to findings reported by Georgé *et al*. (2011) that fresh red tomato contain β-carotene content of 1.0mg/100g fresh weight while yellow tomatoes contain 0.3mg/100g fresh weight.

Despite the antioxidative advantages of β-carotene, heat processing causes degradation of this compound (Hathan, 2014). Degradation of β-carotene is characterized by loss in its content after drying. Degradation of β-carotene has been reported to increase with increase in processing temperature (Purkayastha & Nath, 2013). Furthermore, the kinetics of degradation in β-carotene have been reported to follow first order kinetics during hot air drying (Demiray *et al*., 2013). (Demiray *et al*. (2013) reported that increase in drying temperature from 50 to 100°C led to subsequent increase in β-carotene loss. Oxidative damage which is the major cause of β-carotene loss can be minimized by maximization of the drying rate, dehydration at low temperatures, use of pretreatments and drying under vacuum conditions (Arun *et al*., 2014; Brooks *et al*., 2008; Onwude *et al*., 2016).

2.8.3 Ascorbic acid

Vitamin C, also known as ascorbic acid, is a white crystalline and odorless antioxidant compound that is polar hence soluble in water (Santos *et al*., 2008). It exists as four isomers but only L-ascorbic and arabo-ascorbic have similar physiological activity to vitamin C. In its crystalline and pure form, ascorbic acid is stable when exposed to light, heat and air for a considerable period of time (Tola *et al*., 2015). It is more heat labile compared to lycopene and β-carotene (Demiray *et al*., 2013). However, its stability is related to the conditions of storage as well as the food matrix composition when in the aqueous state (Santos *et al*., 2017).

In plants, high ascorbic acid levels improve both biotic and abiotic stress tolerance (Matteo *et al*., 2010). In a biological system, vitamin C is a potent reducing agent and acts synergistic with tocopherol to regenerate the tocopheryl radicals and scavenge peroxyl radicals (Boonkasem *et al*., 2015). Its content in tomatoes has been found to vary depending on the cultivar, growing conditions, maturity and geographic location (Hanson *et al*., 2004). The ascorbic acid of tomato pulp decreases with advancement of ripening (Lumpur, 2008). Ripe tomatoes have been found to contain vitamin C in the range of 37.59-62.90 mg/100g dry matter (Boonkasem *et al*., 2015). However, higher values in the range 310.34± 7.23 to 360.7±1.1mg mg/100g dry matter have been reported in ripe tomatoes (Ozlem *et al*., 2015; Santos-Sánchez *et al*., 2012).

Ascorbic acid is generally unstable in the presence of heat and oxygen (Santos *et al.*, 2008). In addition, its stability during drying varies with the food material (Santos *et al*., 2008). The decrease in vitamin C during drying is mainly a function of temperature and the duration of drying (Charles *et al*., 2014). As a result, enhancing drying rate and drying at low temperatures best preserves vitamin C during dehydration (Sahin et al., 2011). Freezing has been determined to have limited detrimental effect on vitamin C (Tosun, 2008). Therefore freeze drying is one of the best techniques that best preserves vitamin C (Mwende *et al*., 2018).

2.8.4 Phenolic compounds

Phenolic compounds are secondary plant metabolites, which are important determinants of the sensory and nutritional quality of fruits and vegetables (Bayili *et al*., 2011). The main classes of phenolic compounds include flavonoids, tannins, chalcones and coumarins and phenolic acids. Polyphenolic compounds are synthesized from phenylalanine from the shikimic acid pathway and protect plants from abiotic and biotic stress (Ruiz-garcía *et al*., 2013). The amount of phenolic compounds in fruits is strongly dependent on the degree of ripeness, variety, climate, soil composition, geographic location and storage conditions, among other factors (Luthria *et al*., 2006). Phenolic content of tomatoes is significantly affected by the spectral quality of ambient solar or radiation available (Luthria *et al*., 2006). High total phenolic content has been reported in tomatoes grown under UV transmitting materials than in those grown under UV blocking films (Devanand *et al*., 2006).

Phenolic compounds relate with corresponding antioxidant activity which has been linked to slow down the ageing process and lowered risks of many prevalent chronic diseases such as cancer and coronary heart diseases (Boonkasem *et al*., 2015; Brooks *et al*., 2008; Ruiz *et al*., 2013).

Total phenolic compounds are vulnerable to degradation during drying (Kerkhofs *et al*., 2005). Oxidative reactions set in during the drying process resulting in loss of total phenolics in a food material (Orak *et al.*, 2011) The presence of double bonds and OH group in phenolic compounds make them vulnerable to heat damage. It has been reported that activation of oxidative enzymes occurs during thermal dying leading to loss of phenolic compounds (Gümüsay *et al*., 2015). Reducing exposure of phenolics to heat and oxygen by increasing the drying rate, use of low drying temperatures and also use of pretreatments such as sodium metabisulphate and calcium may result in reduced phenolic loss (Jacob *et al*., 2010; Mwende *et al*., 2018).

2.9 Factors affecting tomato quality.

Tomato quality may be judged from the physical and chemical characteristics of the tomato fruit (Santos-Sánchez *et al*., 2012; Tigist & Workneh, 2013). Lycopene, color, β carotene, total solids and phenolic compounds are major parameters that are used to characterize the quality of tomato fruits (Abano *et al*., 2011; Majidi, *et al.*, 2014). Several interacting factors have been reported to influence the quality of tomato fruits from planting to consumption (Arah *et al*., 2015). They include; environmental factors, cultural practices, maturation and cultivar type (Dumas *et al*., 2003; Gruda & Gruda, 2005; Matteo *et al*., 2010; Tigist & Workneh, 2013; Wilhelmina, 2005).

1. Cultural practices

a) Salinity and Irrigation

Saline soil is generally defined as one in which the electrical conductivity (EC) of the saturation extract on the root zone exceeds 4 dSm^{-1} at 25°C. It has an exchangeable sodium percentage of 15 and may be caused by either ion toxicity, water deficit and or nutritional imbalance (Foolad, 2004). High salt levels in soil and water limits agricultural production since salinity inhibits plant growth due to possible effects of ion toxicity or soil/plant osmotic imbalance (Ben-gal *et al*., 2002; Flores *et al*., 2001; Karaki, 2000; Kaya *et al*., 2006). However, in tomato fruits, saline conditions significantly improve their antioxidative quality due to reduction in water accumulation in the pericarp (Ben-oliel *et al*., 2006; Leonardi *et al*., 2000). Increasing the electrical conductivity of soil by application of either a high ionic compound or reducing irrigation rate increases the content of starch in immature tomato fruits (Diane, 2012). This is due to the decreased fruit mass from loss of water thus extending the period of starch accumulation which in turn stimulates starch-sugar conversion and dry matter accumulation per fruit as the fruit advances towards ripening (Passam *et al*., 2007; Santamaria *et al*., 2004). Similar effects of increase in sugar and dry matter content with increase in EC were reported by Fanasca *et al*. (2012) who found that total soluble solids

and dry matter in tomato increased by 19% and 10% respectively when EC was increased from 2.5dSm^{-1} to 8dSm^{-1}.

Approximately 10, 30 and 50% reduction in fruit size has been observed following irrigation with 5-6, 8 and 9dSm^{-1} saline water respectively (Foolad, 2004). Furthermore, decrease in volume, fruit weight and marketable yield were reported by Fanasca *et al*. (2007) when EC was increased from 2.5dSm-^{1} to 8dSm-^{1} by 30cm^{3}, 30 g and 14% respectively. Moreover, fruit firmness, titratable acidity and citric acid was increased at high EC (8dSm-^{1}) as compared to the low EC (2.5dSm-^{1}) (Fanasca *et al*., 2007).

Increase in soil salinity subsequently increases fruit sodium ions content as an adaptation to salinity originating from a decrease in the osmotic potential of the whole plant (Fernández-garcí *et al*., 2004). However, greater sodium ions content of fruits enhances taste and the perception of sweetness thus improving flavor and aroma balance (Santamaria *et al*., 2004). A linear relationship between lycopene, ascorbic acid and β-carotene accumulation and increase in EC of up to 8dSm^{-1} in tomatoes has been reported (Fanasca *et al*., 2007; Fernández-garcí *et al*., 2004). This has been attributed to a positive effect of osmotic stress on genes that regulate and or encode enzymes responsible for lycopene and β-carotene biosynthesis as well as part of the detoxification of free radicals induced by salinity (Fernández-garcí *et al*., 2004).

b) Fertilizer application

Tomatoes are heavy feeders of plant nutrients such as nitrogen, potassium and phosphorus which are necessary for crop yield (Diane, 2012). The availability of inorganic nitrogen has the potential to influence the synthesis of secondary plant metabolites such as carotenoids and proteins (Mtchel *et al*., 2007). For instance, Dumas *et al.* (2003) reported a 30% increase in lycopene content in tomato fruits when nitrogen supplied was increased from 300kg/ha to 600kg/ha. Increasing of Nitrogen fertilization enhances the action of enzymes involved in lycopene synthesis pathway (Cesare et al., 2010). According to Simonne *et al*. (2007), increase in nitrogen rates from 0 to 392

kg/ha resulted in increased β-carotene content, decreased redness level (a*) and increased yellowness value in tomatoes. On the other hand, an increase in nitrogen rates tends to decrease the vitamin C content in tomato fruits (Simonne *et al*., 2007). This has been associated with increased foliage cover with increased nitrogen rate hence reduced exposure of the fruit to direct sunlight (Dumas *et al*., 2003).

The concentration of volatile compounds increases with increasing nitrogen application to a maximum of 2.25mmolNL^{-1}. However, excess nitrogen supply can deteriorate it (Wang *et al*., 2007). In addition, the concentration of titratable acidity, soluble solids and soluble sugars increases with increasing nitrogen application. This is related to the enhancement of photosynthesis due to an increasing leaf area under high nitrogen supply and to some degree, postponing the process of leaf senescence (Wang *et al*., 2007). Therefore, more photosynthates are produce some of which can be stored as reducing sugars, leading to the accumulation of soluble solids and soluble sugars in tomato fruits (Wang *et al*., 2007).

A limited supply of nitrogen supply is associated with higher levels of phenolics due to increased deamination of phenylalanine that is vital in the metabolic pathway of phenolic compounds (Slimestad & Verheul, 2009). On the contrary, increasing phosphorous fertilization may increase the level of flavonoids and ascorbic acid (Cesare *et al*., 2010). An adequate supply of potassium fertilizer in tomato production has been demonstrated to improve fruit color and reduces the incidence of yellow shoulder (Arah, 2015). An increase in phosphorus content from 0- 100mg/L has also been reported to cause an increase in lycopene content in tomatoes under hydroponic growth (Dumas *et al*., 2003).

c) Pruning

Culling the number of fruits, flowers and tomato branches effectively, reduce inter fruit competition for photosynthetic food (Azevedo, 2010). Therefore, more assimilates are diverted to fewer fruit sinks (Adams & Fenlon, 2001).This leads to increased fruit size

and in some cases increased sugars and total soluble solids (Bertin, 2005). It has been reported that under the single stem pruning method, fruit length, weight and width increases as compared to double stem pruning method (Ara, Bashar, Begum, & Kakon, 2007). Moreover, decreasing competition during the cell elongation period decreases the fruit dry matter and increases the acid content (Bertin *et al*., 2001). However, citric acid content in the mature tomato fruit decreases after fruit pruning (Fanasca *et al*., 2012). Additionally, total antioxidant activity in tomato fruits increases after fruit pruning (Fanasca *et al*., 2012). This is due to the positive effect of pruning on the total phenolic content which constitutes part of the water soluble antioxidants in tomato fruits (Ruiz-garcía & Gómez-plaza, 2013). Reducing the competition among sinks during the whole fruit development period induces an increase in the concentration of carotenoids (Bertin *et al*., 2001).

2. Maturation and ripening

The maturity stage of the tomato fruit affects its quality. The acid content in mature tomato is relatively higher than in immature fruits (Beckles, 2012). Furthermore, a decrease in the titratable acidity occurs as the fruit advances from the mature green stage towards the red ripe stage (Garcia *et al*., 2005). The decrease in titratable acidity and subsequent increase in pH with maturity is due to loss of citric acid which is the predominant acid in ripe tomatoes (Anthon & Barrett, 2011). Moreover, the metabolic conversion of acids into sugars through gluconeogenesis results in reduced acidity and increased sugar content as the fruit advances towards ripening (Anthon & Barrett, 2011; Martínez-romero *et al*., 2007). The interactive effect between reducing sugars and pH affect the sweetness, sourness and flavor intensities of tomatoes (Tigist & Workneh, 2013). In addition, fruit weight increases with maturity with the most pronounced increase occurring between the pink and red maturity stages (Garcia & Barrett, 2006). β-carotene which contributes more to the yellowness of the fruit decreases as the lycopene content increases during ripening (Bertin *et al*., 2001).

Research show that reducing sugar content and pH increase with advancement in tomato fruit ripening (Garcia & Barrett, 2005; Lumpur, 2008). As the fruit ripens, hydrolytic changes of starch occur thus higher sugar accumulation (Ringeisen, Barrett, & Stroeve, 2014). Softening of the tomato fruit occurs as it ripens making it vulnerable to spoilage (Herna, 2008).

3. Cultivar type

Diversity in cultivar types translates to differences in color, shape, size, texture, chemical composition and storage life of tomatoes (Tigist & Workneh, 2013). High genetic diversity with regard to antioxidant activity is found in tomato cultivars. Even though the fruit of many tomato cultivar visually look the same, slight changes in size and pigmentation may influence antioxidant levels (Aldrich *et al*., 2010). While some wild tomato accessions contain very high (11-15%) total soluble solids, most common processing tomato cultivars contain moderate (4.5-6.25%) total soluble solids content (Garcia & Barrett, 2006). Salad and elongated tomato types have lower carotene content as compared to the cherry tomatoes (Leonardi *et al*., 2000) while cherry tomatoes have higher hydrophilic antioxidative activity as compared to elongated, cluster and salad tomatoes (Leonardi *et al*., 2000).

Tomato cultivars vary in shape with elongated and blocky shaped tomatoes being common in processing tomato varieties (Paran *et al*., 2007). The variation in color of tomatoes is largely controlled by mutations in the enzymes of the carotenoid biosynthesis pathway whereby the red colored tomatoes accumulate red colored carotenoids as they progress towards ripening while the purple colored tomatoes accumulate higher than usual anthocyanin content (Paran *et al*., 2007). Some tomato mutants (ripening inhibitor and non-ripening mutants) lack major physiological and biochemical changes associated with ripening. Such mutants of tomato fail to produce ethylene and have low levels of carotenoids and remain firm with an extended shelf life (Paran *et al*., 2007). On the other hand, the cherry tomato variety contain significantly higher β-carotene content as compared to the round and plum tomato (Aherne *et al*.,

2009). Tomato cultivars with different skin-volume and different skin color have different flavonoid content (Slimestad & Verheul, 2009). For instance, under the same growth conditions, tomato cultivar Favorite has twice higher flavonoid content compared to tomato cultivar Bond (Slimestad & Verheul, 2009).

4 Environmental conditions

a) Temperature during growth

Tomato plants have within certain limits the ability to integrate temperature. However, 11% loss in marketable yield of tomatoes due to raising temperature from 21°C to 26°C has been reported (Adams, 2002). Tomatoes exposed to high temperatures in the field can develop poor color since fruits exposed to high temperatures have low lycopene content (Dumas *et al*., 2003). At temperatures beyond 30°C, synthesis of carotenes which impart color to tomato fruits is inhibited (Dumas *et al*., 2003). Nonetheless, when the temperature decreases to less than the threshold, pigment synthesis is restored (Garcia & Barrett, 2006). An increasing incidence of fruit uneven ripening and skin softening in tomatoes is linearly related to increase in temperature in the range of 20.4-25.9°C with the incidence of uneven ripening being caused by localized high temperature effect on a fruit (Mulholland *et al*., 2003).

b) Light

Light is a vital resource for plant growth since it drives carbon capture and photosynthesis (Groot *et al*., 2001). The incidence of defective coloring of the shoulders of tomatoes fruits has been reported to be higher in fruits exposed to the sun than in those shaded by foliage (Dumas *et al*., 2003). The amount and intensity of light during the growing season have a definite influence on the amount of ascorbic acid formed (Aldrich *et al*., 2010; Santamaria *et al*., 2004). Outermost fruits exposed to maximum sunlight contain higher amounts of vitamin C than shaded fruits on the same plant (Santamaria *et al*., 2004). Thus, poor light quality contributes to inferior taste of out of

season tomatoes produced in greenhouses. Accumulation of flavonoids is generally promoted by light. This is because plants have an effective protection mechanism in the synthesis of flavonoids and other absorbing phenolics which act as sunscreen for protection against harmful UV radiation (Slimestad & Verheul, 2009).

2.10 Causes of postharvest losses in tomatoes

Postharvest losses generally refer to the loses that usually occur along the supply chain of food from the production to the consumer (Emana *et al*., 2017). The major causes of postharvest losses in tomatoes include: mechanical damage, biological activity and socio-economic factors (Emana *et al*., 2017).

I. Mechanical damage

Mechanical injury may take the form of cuts, punctures, bruises or scarring and drastically reduce the overall quality of the produce (Beckles, 2012). During postharvest handling of tomatoes, mechanical injuries are common (Owureku-asare *et al*., 2014). These injuries are mainly caused by careless handling of the product especially during harvesting and transportation (Yahaya & Mardiyya, 2019). In addition, use of the wrong harvesting equipment during harvesting such as wooden crates and woven baskets cause fruit cracking and also bruising (Aidoo *et al*., 2014). These injuries make the fruit vulnerable to further attack by insects and pests. Insects, pests and rodents also causes injury to tomato fruits (Emana *et al*., 2017) leading to bruising and cracking of the fruit by feeding on the fruits at the farm level or during storage. This leads to a total breakdown of the structure of the affected cells which is accompanied by unwanted metabolic activities such as increased ethylene production, accelerated respiration rates, pathogen infection, ripening, altered aroma profiles and altered aroma perceptions (Arah *et al*., 2015). Mechanical injuries can also occur due to poor staking leading to product damage. Puncturing of the tomato containers have also been reported to causes mechanical injury to the produce (Yahaya & Mardiyya, 2019). Injured tomato fruits

generally become vulnerable to further natural deterioration through pathogenic attack of the fruit thus leading to significant losses (Yahaya & Mardiyya, 2019).

II. Biological factors

Biological causes of tomato deterioration include respiration rate, ethylene production pests and disease. The rate of biological deterioration depends on several environmental factors including temperature, relative humidity and air velocity (FAO, 2018). Since tomato fruits are naturally living tissues, biological activities continue even after harvesting (Arah, 2015). As a result, several changes such as ripening, water loss and senescence cannot be stopped to a certain degree (FAO, 2018; Ochida & Itodo, 2019). In conditions of high temperature and low humidity during storage, tomato fruits loose moisture resulting to undesirable fruit shriveling and subsequent loss of the produce (Arah, 2015). Also it has been reported that mechanical damage to tomato fruits accelerates respiration and ripening (FAO, 2018). These processes lead to eventual postharvest losses. On the other hand, the high water content in tomato make them susceptible to attack by insects and decay causing microorganisms such as fungi (Arah, 2015; Samuel & Orji, 2015). Diseases such as gray mold, *rhizopus* rot, bacterial wilt and fusarium rot affect tomatoes before harvest and lead to decay of the commodity before harvest resulting to further tomato losses (Lemma *et al*., 2014).

III. Socio-economic factors

Some of the socio-economic factors that lead to postharvest losses in tomatoes include: poor infrastructure and lack of ready markets. Due to the highly perishable nature of tomatoes, they require intensive utilization over a short duration (Addo *et al*., 2015). However, in most developing countries transportation is characterized by poor infrastructure, lack of appropriate transport systems and lack of refrigerated system (Arah *et al*., 2016). These factors result in significant delay between harvest and consumption (Arah, 2015). In addition, road network from the farms to the markets are not adequate for transportation of perishables (Aidoo *et al*., 2014). Poor road network is

characterized by vibration to the produce during transit and a likely cause for mechanical damage (Arah, 2015). Transport vehicles that are suitable for the transportation of perishables, are also not available (Arah *et al*., 2016). The majority of most farmers being small scale cannot afford to purchase these vehicles. It has also been reported that lack of accessible markets lead to spoilage and increasing postharvest losses in this commodity (Aidoo *et al*., 2014). Time consuming market distributions also contribute to significant losses of tomatoes due to their high perishability (Owino *et al*., 2015).

2.11 Tomato preservation methods

The high perishability of tomatoes has for a long time necessitated the need for shelf life extension. Some of the methods that are used to extend this commodity's shelf life include canning, low temperature storage and freezing (Ukponmwan, 2015). Other methods that have been employed include; use of permitted chemicals such as calcium chloride, and controlled or modified atmosphere storage (Ahmed *et al*., 2016).

I. Calcium chloride treatment

Postharvest calcium chloride application is a key preservation practice in tomatoes since it reduces respiration, decreases ethylene production, and delay softening and ripening of fresh tomato fruits (Xue *et al*., 2015). As a result, soluble solids, reducing and non-reducing sugars in tomatoes treated with calcium chloride is reduced due to slowed respiration and metabolic processes responsible for the ripening process (Pila *et al*., 2010). Vacuum infiltration at -30kps with 6% calcium chloride has been found effective in extending the shelf life of tomatoes by delaying color development and increasing firmness (Gharezi *et al*., 2012). Calcium chloride has been reported to slow down metabolism rate and as a result reduce respiration (Shirzadeh *et al*., 2011) and eventually increase tomato shelf life (Akhtar *et al*, 2010; Xue *et al*., 2015). This is achieved through the firming effect of calcium chloride on the fruit walls thus hindering rapid cell wall softening (Lozel *et al*., 2010). In addition, calcium chloride also reduces fungal attack on

tomato fruits therefore reducing incidences of fruit decay (Arah *et al*., 2016). However, the shelf life of calcium chloride treated samples is limited (Pila *et al*., 2010).

II. Modified atmosphere packaging & controlled atmosphere storage

Modified atmospheric packaging is a preservation technique in tomatoes that is used to control product deterioration and provide protective atmosphere around the package (Majidi *et al*., 2014). In modified atmosphere packaging, the level of oxygen decreases during storage while carbon dioxide levels increase inside the packaged due to fruit respiration (Aguayo *et al*., 2004). The packaging material used in modified atmosphere packaging allows diffusion of gases between the external environment and inside the package until an equilibrium is reached (Ochida & Itodo, 2018). The increased levels of CO_2 alleviate the metabolism of the fruit thus weight loss, softening and fungal infection of the fruit (Agar & Sabir, 2011). The rate of respiration and ethylene production is also slowed down in modified atmosphere packaging (Majidi *et al*., 2014). However, as respiration progresses, oxygen gets depleted and anaerobic conditions set in leading to unfavorable anaerobic metabolism, alcohol accumulation and off flavor development (Bico *et al*., 2009). Polyethylene, low density polyethylene, high density polypropylene, polyvinyl chloride, polyethylene terephthalate and polystyrene material may be used to create modified atmosphere during storage (Yadav & Singh, 2014).

In controlled atmosphere packaging, the composition of gases is strictly controlled (Majidi *et al.*, 2014). Therefore, storage requires regulation of oxygen and or carbon dioxide to prevent ethyl alcohol accumulation and anaerobic metabolism (Bico *et al*., 2009). Controlled atmosphere packaging may be done in storage rooms, transportation vehicles or can be individually wrapped (Beckles, 2012). This method has been successfully used to control color and weight loss in mature tomatoes as well as increase the shelf life of fresh tomatoes for up to 42 days (Ahmed *et al*., 2016) and provides an effective control against insects (Perera, 2005). However, this method is relatively expensive.

III. Canning

Canning has been used in preservation of tomatoes to produce safe and shelf stable products (Parnell *et al*., 2004). However due to heat intensive processes, this technique has significant effect on heat sensitive food components especially vitamin C (Tola *et al*., 2015). In addition, overripe tomatoes are not suitable for canning since tomatoes decrease in acidity as they ripen (Parnell *et al*., 2004).

IV. Cold storage

Cold storage involves storage of produce under low temperature such as refrigeration temperature so as to slow down metabolic reaction and as a result increase shelf life (Idah *et al*., 2010). The low temperatures used slow down tomato ethylene production and ripening. However, postharvest losses associated with cold storage result in color changes and off-flavor development (Luengwilai *et al*., 2012). However, at 4°C during storage there is no change in lycopene content of conventionally grown tomatoes (Wilhelmina, 2005). Furthermore, chilling injury characterized with water soaking, failure to ripen and flavor loss occurs when tomatoes are stored at 2-12°C (Luengwilai *et al*., 2013). Tomato flavor and carotenoid derived volatiles have also been reported to negatively affected when tomatoes are stored at below 12.5°C and 10°C respectively (Herna, 2008).

2.12 Drying

Drying is a simultaneous heat and mass transfer process in which moisture is transformed into vapor state and removed (Chawla *et al*., 2008). It is an energy intensive process that offers a means of preserving foods in a stable and safe condition as it reduces water activity and extends shelf-life much longer than that of fresh fruits and vegetables by slowing down the activity of enzymes and microorganisms (Bala, 2012; Faisal *et al*., 2013; Zhang *et al*., 2006). The drying rate

during the drying process is significantly influenced by the drying temperature which consequently influences the duration of drying (Elkhodiry *et al*., 2015).

2.12.1 Drying techniques in fruits

Some of the methods of fruit dehydration include direct sun drying, solar drying, oven-air drying, vacuum-oven drying, osmotic dehydration, drying by microwave and freeze drying (Serna-cock *et al*., 2015).

a) Direct sun drying and solar drying

Direct sun drying is a traditional drying method that simply involves exposure of fruits to direct sunlight whereby the warm air takes up moisture from the produce until the produce is moisture appropriate for storage (Ringeisen *et al*., 2014). It offers significant advantage in sunny and arid areas since it is simple, relatively inexpensive, and renewable and is environmental friendly (Bala, 2012; Hii *et al*., 2008). Furthermore, sun drying allows flavors to concentrate thus preventing loss of volatiles and undesirable caramelization (Latapi, 2006). However, in tropical regions it is impeded by high humidity, and intermittent cloudy weather which may lead to product contamination and loss due to possible mold infection that is mainly associated with reduced ability of humid air to remove water from produce (Bala, 2012). To mitigate this, solar driers fitted with solar concentrators are usually commonly used since they are effective in improving the rate of drying by significantly increasing the internal dryer temperature (Hossain *et al*., 2008). In the recent years, different versions of solar driers such as solar tunnel driers, roof integrated solar driers and greenhouse type solar driers have been developed in an effort to make solar drying versatile and more effective in drying of most fruits (Bala, 2012). Solar drying has been employed in drying of tomato in many studies (Gümüsay *et al.*, 2015; Latapi, 2006; Sahin *et al.*, 2011; Rajkumar *et al*., 2007).

The effects of solar and sun drying on quality of tomato are diverse and vary greatly depending on the drying conditions. Gümüsay *et al.* (2015) reported lower levels of total phenolic content (314mg/100g dw) and ascorbic acid (24.39mg/100g dw) as compared to their fresh counterparts. Lightness index in solar dried samples has been reported to be lower than the fresh samples due to direct exposure to the sun as well as long drying time (Mwende *et al.*, 2018; Sahin *et al*., 2011; Rajkumar *et al*., 2007). In addition, water activity has been report to decrease to 0.5 from 0.9 after solar drying thus reducing the water content in the dried samples (Rajkumar *et al*., 2007). Lycopene content has been reported to decrease after sun drying in tomatoes (Sahin *et al*., 2011). 36.32 percent retention of lycopene relative to the fresh has been reported in sun dried tomatoes (Sahin *et al*., 2011). On the other hand the rehydration ratio in solar dried samples have been reported to range between 2.95-3.24 (Rajkumar *et al*., 2007).

b) Microwave drying

Microwave drying is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material (Workneh *et al*., 2011). Consequently, water vapor pressure differences between the interior and surface regions provide a driving force for moisture transfer resulting in drying (Alibas, 2009). As a result, microwave drying causes heat generation throughout the food material thus greatly reduces the drying time of the products with unknown quality degradation and also confers many advantages in producing a wide variety of the dried product (Workneh *et al*., 2011; Zhang *et al*., 2006). However, it is limited to small fruit and vegetable categories due to high cost of installation and complicated technology as compared to the convectional drying methods (Zhang *et al*., 2006). Microwave power during microwave drying has been reported to cause un-uniform heat distribution. Excessive temperatures along the edges and corners of produce during drying have been reported to cause irreversible drying out accompanied with off flavor development (Andrés *et al*., 2007)

Microwave drying in tomato is limited. However, it is mainly accompanied with other forms of drying such as hot air drying (Catalano *et al*., 2013; Workneh *et al*., 2011). Microwave drying has commonly been applied in the drying of other vegetables such as collard leaves and spinach which have a short drying time (Alibas, 2009; Dadalı *et al*., 2007). Quality changes in food materials during microwave drying have been reported (Demırhan & Özbek, 2011). Dadalı *et al*. (2007) reported that color change during microwave follow first order.

c) Hot air drying

In hot air drying, convective drying which creates a vapor pressure gradient between the moisture present in the food and the moisture in the air causes drying of the produce (Faisal *et al*., 2013). Due to its cost effectiveness, air drying is currently the dominating technology of preserving perishable agricultural products (Zhang *et al*., 2006). However, product quality is significantly compromised with respect to appearance, nutritional value and flavor (Vergeldt *et al*., 2014). The two most common forms of hot air drying are oven-air drying and vacuum-oven drying.

Vacuum drying is a method of drying used for drying of food materials to ensure better retention of quality attributes such as color and vitamins (Alibas, 2009). It is mainly used to dry heat-sensitive products since the vacuum in the system allows the use of low drying temperatures to reach similar final moisture content of the product when compared to other drying methods (Rajkumar *et al*., 2007). In a vacuum drier, the drying chamber operates at a reduced pressure. In addition, there is absence of drying medium in the vacuum drier and as a result enhances mass transfer at lower temperatures (Mujumdar & Law, 2010). Vacuum conditions facilitate mass transfer as a result of pressure difference between the inside and outside of the sample(Mujumdar & Law, 2010). Food materials that are dried using a vacuum drier have better attributes such as taste, flavor and rehydration properties. In this method, heat is supplied by conduction and temperature of the product can easily be controlled (Lewicki, 2006).

Oven air drying is a form of hot air drying that is used in tomato drying. Hot air is subjected to the food material and moisture difference caused by heated air allows drying to occur (Purkayastha & Nath, 2013). Therefore vapor pressure difference causes water movement from the food material to the drying medium. During oven air drying, the moisture ratio decreases with drying time. Lightness index has been reported to decrease with increase in drying temperature (Purkayastha & Nath, 2013). Purkayastha & Nath (2013) reported that color change at 50°C and 60°C was lower than at 70°C. In addition, 64-13 percent retention of ascorbic acid has been reported in oven air dried samples. Overall hot air drying has been reported to decrease the quality of the dried product with respect to total phenolic content, lycopene, ascorbic acid and β carotene (Gaware *et al*., 2010; Gümüsay *et al*., 2015; Purkayastha & Nath, 2013; Rajkumar *et al*., 2007). However, oven air drying is common due to its high drying rate and also a wide temperature range in which it operates (Hossain & Gottschalk, 2009). Oven air and vacuum oven drying has been used in drying of tomato and ginger (Gümüsay *et al*., 2015), potato (Faisal *et al*., 2013) and strawberry (Orak *et al*., 2011).

d) Freeze drying

Freeze-drying is a dehydration method which involves crystallization of water into ice crystals, which subsequently sublimate, thus leaving a porous dried product (Voda *et al*., 2012). The freeze drying process mainly occurs through three main steps which are; freezing, primary drying (sublimation phase) and secondary drying whereby about 90% of water is removed in the first drying phase (Serna-cock *et al*., 2015). The freezing step generally involves conversion of water into ice crystals (Shishehgarha *et al*., 2002). The freezing process is best achieved by slow freezing or annealing. When the crystals are too large, they may break the cell walls and that leads to undesirable freeze drying results (Voda *et al*., 2012). During the primary phase, pressure is lowered and heat added to the food material so as to allow water to sublimate (Valerie *et al.*, 2015). Presence of vacuum hastens the process of sublimation. In addition, the cold condenser provides a surface for the water to

adhere to and solidify. The secondary phase is also regarded as the adsorption phase. During this step, the ionically bound water molecules are removed (Sablani *et al*., 2011). Temperatures are raised to a higher level than in the primary drying step resulting into breaking of bonds between the material and the water molecules. This results in a material with a porous structure (Marques *et al*., 2006). After the freeze drying process is over, the vacuum can be broken using an inert gas.

Due to the absence of liquid water and the low temperature (approximately 0°C) used in the operation process, most of deterioration and microbiological reaction are stopped (Antal, 2015). In this method shrinkage is eliminated, minimum loss of flavor, aroma, vitamins, and near-perfect preservation results are obtained thus yields high quality products which also rehydrate more rapidly, albeit at larger operational costs (Vergeldt *et al*., 2014). It is therefore generally recommended in drying food materials which contain heat sensitive antioxidants such as tocopherols, vitamin C and phenolics (Shofian *et al*., 2011). Freeze drying has been employed in drying of carrots (Vergeldt et al., 2014), strawberries (Shishehgarha *et al*., 2002).

e) Osmotic drying

Osmotic drying is a process based on the immersion of a food, either whole or in pieces, in hypertonic solutions, promoting a simultaneous water loss and solutes penetration into the food (Dalben *et al*., 2012). Its driving force is the difference in the osmotic pressure of solutions on both sides of the semi-permeable cell membranes (Akbarian *et al*., 2014). The effectiveness of osmotic dehydration is affected by factors such as the solute concentration, osmotic agent, solute concentration, temperature, time, solution/sample ratio and the tissue type of the material (Dalben *et al*., 2012; Pandharipande *et al*., 2012). This method causes less damage to the cell wall and to the heat labile nutritive components, pigments and aromas, since it demands lower temperature (Yadav & Singh, 2014). Osmotic assisted dehydration preserves the sensorial, functional and the nutritional properties of the food matrix (Yadav & Singh, 2014) during heat processing (Kennedy, 2007).

However, the amount of water remaining after osmotic dehydration does not guarantee stability of the product. Therefore, when shelf stability is ultimately of key value, convective or freeze drying should be applied to ensure water activity significantly below 0.9 (Kennedy, 2007). Osmotic dehydration has been used in many fruits and vegetables such as: star fruit (Dalben *et al*., 2012), sweet potatoes (Ahmed *et al*., 2010), chilli (Phomkong *et al*., 2010), carrots (Barrett *et al*., 2012) apricots (Djamel *et al*., 2009), cucumbers (Valerie *et al*., 2015). Some of the salt compounds that are considered osmotic include: calcium chloride and sodium metabisulphate.

i. Calcium chloride

Suitable calcium salts generally used in food include: calcium sulphate, calcium chloride and calcium citrate (Andrew *et al*., 2004). These salts are used in aqueous solutions at a concentration of 0.1 to 10% calcium (Andrew *et al*., 2004). Calcium chloride has been extensively used in the vegetable and fruit industries as a preservative as well as a firming agent (Rico & Henehan, 2007)**.** In addition, calcium chloride is therefore widely used as a strengthening agent of cell walls (Pila *et al*., 2010). These make the cell wall of food material to become more stable to different treatments (Ioannou, 2013). This is vital especially during heat processing since undesirable oxidative and isomerization as well as color change is minimized. Furthermore, contact of polyphenol oxidases with the phenolic compounds is inhibited in presence of calcium chloride (Ioannou, 2013). As a result phenolic degradation is reduced during drying. It has also been reported that calcium chloride when used during drying may enhance the drying rate. As a result exhibit increased water mobility (Owureku-asare *et al*., 2014). This may therefore reduce exposure time of the food material to oxygen and heat leading to reduced heat damage to the food material (Owureku-asare *et al*., 2014).

The use of calcium salts in food has been permitted by the U.S Food and Drug Administration (Quintero-ramos *et al*., 2001). Calcium chloride pretreatment in fruits and vegetables has been used in pepper to improve texture and rehydration properties

(Quintero-ramos *et al*., 2001), improve texture in banana (Bico *et al*., 2009), reduce color changes in apples (Ioannou, 2013), reduces microbial load in fruits and vegetables (Rico & Henehan, 2007), improve lycopene, brightness and β carotene in sweet potatoes (Ahmed *et al*., 2010). Elsewhere, Phomkong *et al*. (2010) reported that use of calcium as pretreatment in chilli during drying increased drying rate and improved color stability.

ii. Sodium metabisulphate

The primary function of sulfites during drying include; inhibition of non-enzymatic browning, prevention of oxidative spoilage (acts as an antioxidant), antimicrobial effect and facilitates cell plasmolysis thus facilitates faster drying (Latapi, 2006). Use of sodium metabisulphate during drying of fruits and vegetables is therefore common. This is attributed by its ability to alter the cellular structure of tissues therefore increased drying rate, increased color stability (Latapi, 2006) and acts as an anti-browning agent during drying (Phomkong *et al*., 2010). Owureku-asare *et al*. (2014) reported that oxidation of lycopene is reduced when sodium metabisulphate is used prior to drying. This is as a result of the sulfite group binding with the carbonyl group of reducing sugars as well as other compounds to retard the browning process (Phomkong *et al.*, 2010). In addition sulfites retard the activity of polyphenol oxidase during drying through the action of sulfites and quinines and depletion of oxygen (Ahmed *et al*., 2010). Latapi, (2006) reported sulfites also increase shelf life of dried samples by inhibit on of fungal growth during storage.

The limit of sodium metabisulphate in dried foods varies with diversity in company regulations (Latapi, 2006). However, 3000mg/kg at onset ensures the product sulfites level is acceptable (Latapi, 2006). Sodium metabisulphate has been used during drying of perishables such as chili (Phomkong *et al*., 2010), sweet potato (Ahmed *et al*., 2010).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The four tomato varieties under study were grown in a greenhouse in Juja, Kenya (latitude: 1˚ 10'S, longitude: 37˚ 7'E, altitude: 1416M) in the Jomo Kenyatta University of Agriculture and Technology (JKUAT) experimental farm from March 2015 to July 2015. Environmental temperatures in Juja ranges between 11.3-28.9°C while rainfall averages 14-175mm annually.

3.2 Selection of tomato varieties, cultivation and harvesting

The varieties planted were Anna F1, Prostar F1 (indeterminate varieties) and Kilele, Riogrande (determinate varieties). These varieties were selected due to their resistance to diseases such as bacterial wilt and also due to their popularity in Kenya (Geoffrey *et al*., 2014; Ochilo *et al*., 2018). Seeds were sown in sterilized loamy soil on germination trays at a depth of 3cm and covered with soil. Twenty days after germination, the weak and malformed seedlings were thinned out to avoid overcrowding. Watering was done in the morning and in the afternoon until the seedlings were ready for transplanting.

Twenty five seedlings of each variety were transplanted into polythene bags (one seedling per plastic pot) after the first true leaves appeared. Transplanting was done in the morning when temperatures were low to prevent withering of the seedlings after transplanting. The polythene bags used for transplanting the seedlings were 30cm deep and 15cm wide. Placement of the pots in greenhouse was done using completely randomized design. Soil replenishment of nutrients and the control of undesirable pest and diseases followed practices of tomato production described by Pascale, (2001). Pruning was carried out to remove undesirable side branches after every 2 weeks. Irrigation was done twice a day and three times a day during the bloom and early fruiting stages respectively. This was done using a hand held watering can.

Tomato varieties of uniform maturity (red ripe maturity stage), color, size (7cm major diameter) and shape were randomly selected for the study. Harvesting of the four varieties was done 35 days after flowering so as to ensure sample uniformity. Harvesting was done by hand in all the twenty five seedlings of the four varieties planted and placed in plastic crates. Random sampling was employed during harvesting. Color selection of the tomato fruits was based on the USDA color scale (USDA, 1997) where at least 90% of the surface of the tomato was red**.**

3.3 Sample preparation

One hundred and twenty kilograms of each tomato variety was harvested after reaching red ripe maturity stage. The harvested tomatoes were washed in chlorinated (5ppm) tap water at room temperature to remove debris and dried using a dry cloth. The tomato samples were cut into uniform quarters from the stem scar to the blossom end using a stainless steel knife. The 120kg batch was divided into four groups; 2 groups (solar and freeze drying) of 15kg each and two other groups (oven –air and vacuum –oven drying at 50°C, 60°C and 70°C) of 45 kg each (Table3.1).

Table 3.1: Summarized description of the drying process

Drying method	Temperature	Treatments
Oven-air drying (45kgs)	50°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
	60°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
	70°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
Vacuum-oven drying(45kgs)	50°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
	60°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
	70°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg)
		0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
Solar drying	50-60°C	Control (4kgs)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg) 0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)
Freeze drying	-41°C,-47°C	Control (4kgs), moisture loss with time (1kg)
		0.5%calcium chloride (4kgs), moisture loss with time (1kg) 0.5%sodium metabisulphate (4kgs), moisture loss with time (1kg)

3.4 Drying conditions

The drying conditions below, as summarized on Table 3.1 were applied on the fresh tomato quarters.

3.4.1 Oven-air drying

Oven drying was performed in an oven drier (Memmert UF 110 model, Germany) at pre-selected temperatures of 50°C, 60°C and 70°C. The temperatures selected in this study were determined to be optimum with regards to drying time and tomato quality during the preliminary studies. Each tomato variety was dried separately during oven drying.

The oven drier was operated for 1.5 hours before loading to achieve steady state conditions. Forty five kilograms of tomato quarters of each variety were divided into three equal groups of 15 kg. The first group was further divided into four batches and placed separately in a single layer on 2 mm aperture 60cm×30cm removable meshed drying trays. The first batch (4kg) was the control (untreated) dried at 50°C (control, 50°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 50°C (0.5% C.C, 50°C), the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 50°C (0.5% N.M, 50°C) and the fourth batch (3kg) was divided into three sub-batches of 1kg each. Each sub-batch was used to monitor moisture loss with time at the respective treatments (control, 50°C; 0.5% C.C, 50°C and 0.5% N.M, 50°C). The second group was also divided into four batches and placed separately on drying trays. The first batch (4kg) was untreated (control) dried at 60°C (control, 60°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 60°C (0.5% C.C, 60°C) ,the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 60°C (0.5% N.M, 60°C) and the fourth batch (3kg) was divided into three sub-batches of 1kg each. Each sub-batch was used to monitor moisture loss with time at the respective treatments (control, 60°C; 0.5% C.C, 60°C and 0.5% N.M, 60°C). The third group was also divided into four batches and placed

separately on drying trays. The first batch (4kg) was untreated (control) and dried at 70°C (control, 70°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 70°C (0.5% C.C, 70°C) ,the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 70°C (0.5% N.M, 70°C) and the fourth batch (3kg) was divided into three sub batches of 1kg each. Each sub batch was used to monitor moisture loss with time at the respective treatments (control, 70°C; 0.5% C.C, 70°C and 0.5% N.M, 70°C). Drying was done to final moisture content of 13%.

3.4.2 Vacuum-oven drying

Vacuum-oven drying was performed in a vacuum drier (VDO-S0, Tokyo, Japan) at pre-selected temperatures of 50°C, 60°C and 70°C. The temperatures were determined to be optimum with regards to drying time and tomato quality during the preliminary studies. Each tomato variety was dried separately during vacuum-oven drying. The vacuum drier was fitted with a high performance vacuum pump (C55JXHJE-4071, ST. Louis, MO U.S.A) so as to operate at a vacuum of 62cmHg. The vacuum drier was operated for 1.5 hours before loading to achieve steady state conditions. Forty five kilograms tomato quarters of each variety were divided into three equal groups of 15 kg. The first group was further divided into four batches and placed separately in a single layer on 2 mm aperture 10 cm×10 cm removable meshed drying trays. The first batch (4kg) was untreated (control) and dried at 50°C (control, 50°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 50°C (0.5%C.C, 50°C) ,the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 50°C (0.5%N.M, 50°C) and the fourth batch (3kg) was divided into three sub-batches of 1kg each. Each sub-batch was used to monitor moisture loss with time at the respective treatments (control, 50°C; 0.5%C.C, 50°C and 0.5%N.M, 50°C). The second group also divided into four batches and placed separately on drying trays. The first batch (4kg) was untreated (control) and dried at 60°C (control, 60°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 60°C (0.5% C.C, 60°C) ,the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 60°C (0.5% N.M, 60°C) and the fourth batch (3kg) was divided into three sub-batches of 1kg

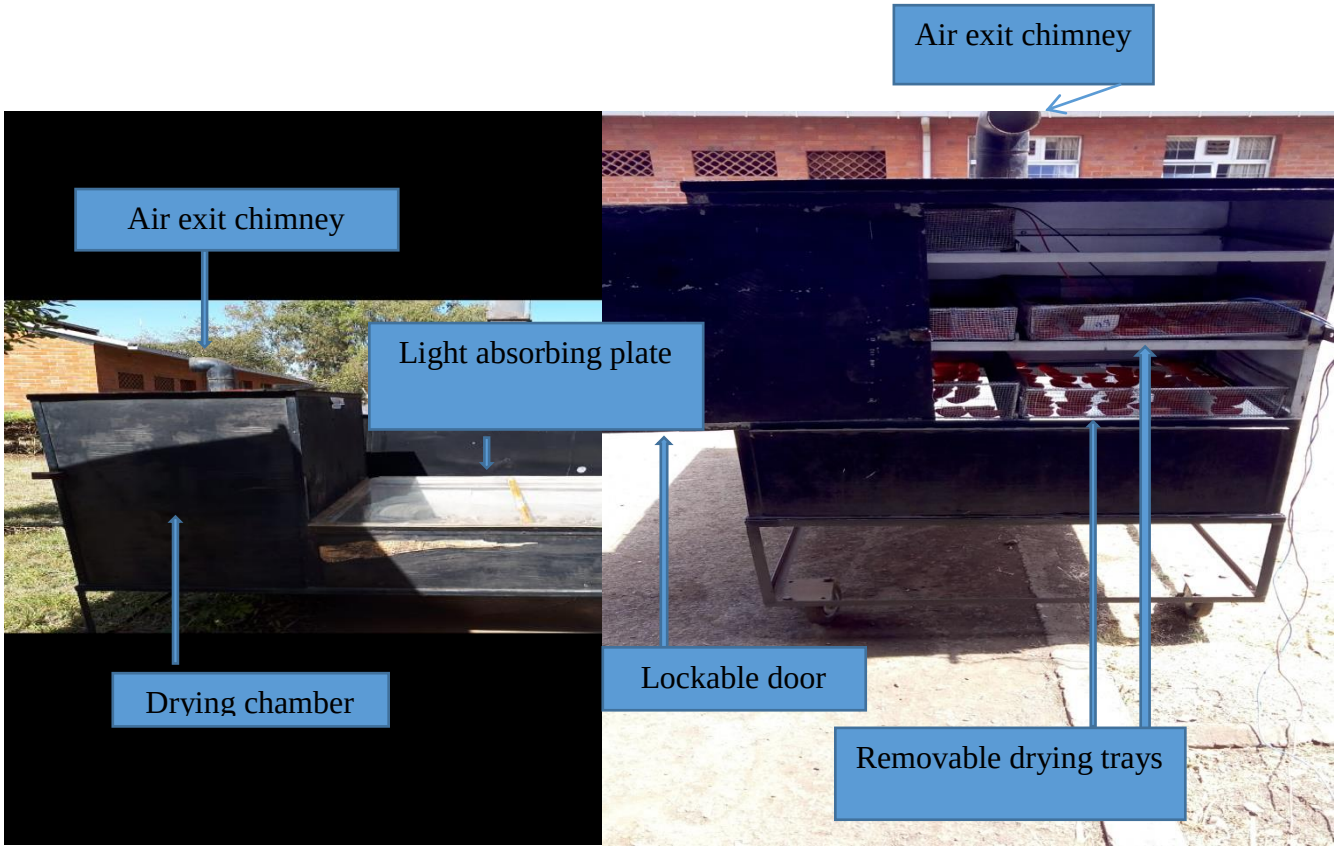
each. Each sub-batch was used to monitor moisture loss with time at the respective treatments (control, 60°C; 0.5% C.C, 60°C and 0.5% N.M, 60°C). The third group was also divided into four batches and placed separately on drying trays. The first batch (4kg) was untreated (control) and dried at 70°C (control, 70°C), the second (4kg) was treated by spraying with 0.5% calcium chloride and dried at 70°C (0.5% C.C,70°C), the third (4kg) was treated by spraying with 0.5% sodium metabisulphate and dried at 70°C (0.5% N.M, 70°C) and the fourth batch (3kg) was divided into three sub-batches of 1kg each. Each sub-batch was used to monitor moisture loss with time at the respective treatments (control, 70°C; 0.5% C.C, 70°C and 0.5% N.M, 70°C). Drying was done to final moisture content of 13%.

3.4.3 Solar drying

Fifteen kilograms of tomato quarters of each variety were divided into 4 batches and each batch placed separately in a single layer (5cm deep) on 2mm aperture 60cm×40cm meshed drying trays. Each tomato variety was dried separately during solar drying. The first batch (4kg) was untreated (control), the second (4kgs) with 0.5% calcium chloride (0.5% C.C) and the third (4kg) with 0.5% sodium metabisulphate (0.5% N.M). The fourth batch (3kg) was further divided into three equal batches and used to monitor water content with time at the respective treatments. The treated batches were allowed to stand for 30 minutes to drain away the excess sprayed solution. At night, the samples remained in the drier. The samples were dried for 5 days in a solar drier to a final moisture content of 13%. Temperature in the drying chamber was determined using an EL-USB-2 data logger (Lascar electronics Inc., Pennsylvania, USA), programmed to record temperature every one hour. Temperature in the drying chamber was determined to vary from 50°C-60°C during the day.

The solar drier used in this study was fabricated in the department of biomechanical and environmental engineering in JKUAT. Its basic sections were; a light absorbing plate, drying chamber, a fan and an air exit chimney (Figure 3.1). The light absorbing plate was made from a clear plastic material (polyvinyl chloride) with dimensions of 2m

length, 1.5m width and 5 mm thick. The drying chamber was fitted with six 2mm aperture 60cm×40cm removable aluminium meshed drying trays. A 10 cm in diameter exit chimney was fitted above the drying chamber to remove moist air from the drying chamber. A fan fixed on the rear end maintained relatively continuous flow of hot air to the drying unit. A lockable black painted metallic door was fitted to allow access to the drying chamber. The walls of the drying chamber were made from black painted metallic sheets to increase heat absorption. The drying chamber was insulated with 6mm thick wood to prevent heat loss.



(a) (b)

Figure 3.1: (a) Solar drier, (b) drying chamber of the solar drier used in drying of tomato in this study.

3.4.4 Freeze drying

Freeze drying was performed in a freeze drier (Alpha 1-4 LD plus –Martin Christ model-101541, Germany). Fifteen kilograms tomato quarters of each variety were divided into four batches. The first batch (4kg) was untreated (control), the second (4kg) treated with 0.5% calcium chloride (0.5% C.C) and the third (4kg) treated with 0.5% sodium metabisulphate (0.5% N.M). The fourth batch (3kg) was further divided into three equal batches and used to monitor water content with time at the respective treatments. The treated batches were allowed to stand for 30 minutes to drain away excess spray. Each batch was put separately in perforated labeled ziplock bags and evenly distributed on 6 detachable non perforated drying trays (20cm in diameter) of the

freeze drier. Initial drying (stage 3) and drying stages (stage 4) were performed at -41°C and 0.11 mbars while final drying stage (stage 5) was performed at -47°C and 0.055 mbars .Samples were dried for 120 hours to 13% moisture content.

3.5 Sample stabilization

At the end of each drying procedure (oven-air, vacuum-oven and solar drying), the samples were allowed to cool for 30 minutes. The moisture content of the samples was determined and the dried samples were put into zip lock bags and stored at -20°C in a chest freezer (GE FCM 11PHWW model, Qingdao, China) until further analysis.

3.6 Storage for microbial analysis

Seventy grams of sample was randomly selected from each combination of the pretreatments (control, 0.5% C.C and 0.5% N.M) applied in each of the four drying method. The dried sample was divided into seven equal groups of 10g each and put in 7×12 inches paper bags and stored at room temperature in a cabinet oven at 30°C to simulate controlled temperature storage. The samples were used for microbial tests that were carried out once monthly for six months to determine their quality during storage. Only dried samples of Riogrande variety dried at 70°C (oven-air and vacuum-oven drying) was selected for microbial tests because it exhibited the shortest drying time to attain stable moisture content (13%) required in this study.

3.7 Sample analysis

Quantification of moisture, total phenolic content, lycopene content, β-carotene, ascorbic acid content and color was carried out in all the dried and fresh samples. However, rehydration test was only carried out on the dry samples. The results were expressed on dry weight basis (dw) except moisture content which was expressed on fresh weight basis.

3.7.1 Moisture content determination

Five grams of sample (fresh/ dry) was weighed into a moisture dish and heated in the oven at 150°C for 2 hours. It was cooled to room temperature in a desiccator and the final weight of the sample taken. Percentage moisture content in each sample was determined using the following formula (AOAC, 2000)

$$\% \text{ moisture content} = 100 \times \frac{a - b}{a}$$

Where:

a = sample weight before drying

b = sample weight after drying

3.7.2 Determination of total phenolic compounds

The folin ciocalteu method was used to determine the amount of total phenolic compounds as described by Ainsworth & Gillespie, (2007) with slight modifications. Gallic acid was used as the standard. Two grams of crushed tomato sample was put in a vial after which 50 ml of cold methanol was added. The sample was vortexed for 3 hours and incubated for 72 hours at 25°C away from light. The extract was filtered through a whatman no. 4 filter paper to remove the debris and centrifuged at 13,000 g for 10 minutes at 25°C after which the supernatant was collected. Seven concentrations of the standard (0, 50, 100, 200, 300, 400, 500 mg/l) were prepared using gallic acid. A 1ml of the extract was passed through a 0.45 µl membrane filter. A 2 ml of 10% (V/V) Folin ciocalteu reagent was added and vortexed after which 4 ml of 0.7 M Na_2CO_3 solutions was added. Folin ciocalteu reagent was added before Na_2CO_3 to prevent air oxidation of the phenols in the extract. The mixture was allowed to stand for 2 hours at 25°C and the absorbance measured at 765 nm using uv-VIS spectrometer (Shimadzu uv-VIS 1800, Tokyo, Japan model). A standard curve was plotted from the blank corrected absorbance of the gallic acid standard. The amount of total phenolic content was expressed as gallic acid equivalents (GAE) per 100 g of the sample on dry basis.

3.7.3 Lycopene and β-Carotene content determination

The method by Chen, (2005) was used with some modification for the determination of lycopene and β-carotene. Five grams of crushed tomato sample was weighed using a digital balance and put into amber bottles after which 50 ml of hexane-acetone-ethanol solution (2:1:1 v/v/v) containing 1% BHT (w/v) was added to solubilize lycopene and β-carotene. The content was then agitated for 20 minutes after which 15 ml of distilled water was added to the mixture and mixed for 10 minutes. The solution was separated into a polar and a non-polar phase using a separating funnel. A 50 ml of the upper hexane layer was collected and 1.5 ml of it was micro-filtered using 0.45 µl membrane filters into amber glass vials. The extracts were stored at -20°C in a chest freezer for 24hours (GE FCM 11PHWW model, Qingdao, China) until high performance liquid chromatography (HPLC) analysis. β-carotene and lycopene were analyzed using a Shimadzu brand HPLC (10A model ,Tokyo, Japan) fitted with a LC-10AS pump, CTO-10A Column oven, SPD-10AV uv-VIS detector and a C18 ODS non polar column. The mobile phase contained acetonitrile: methanol: dichloromethane: hexane (40:20:20:20, v/v/v/v) at a flow rate of 1.5 ml/min. Injection volume used was 20 µl while the detection wavelength for lycopene was 470 nm and that of β-carotene was 445 nm. The temperature of the oven was maintained at 30°C. Lycopene and β-carotene standard concentrations (0, 2, 5, 10, 15 mg/ml) were prepared in hexane. Lycopene and β-carotene in the sample was identified by comparing the retention time of pure lycopene and β-carotene which was 3.5 and 7 minutes respectively Quantification was done by using chromatographic peak areas generated to determine the lycopene content and β-carotene content.

3.7.4 Determination of vitamin C

The method detailed by Vikram *et al*. (2005) was employed with slight modifications. Five grams of homogenized sample was placed on centrifuge tubes and 30 ml of 0.8% metaphosphoric acid added. The mixture was centrifuged at 10,000rpm for 10 minutes at 4°C in a centrifuge (model H-2000C). A 1ml of the supernatant was filtered through a

0.45 µl micro filter into 2 ml amber glass vials. Six concentrations of the standard (100 ppm, 80 ppm, 60 ppm, 40 ppm, 20 ppm, 10ppm) were prepared using pure ascorbic acid dissolved in 0.8% metaphosphoric acid. The samples was analyzed using a Shimadzu HPLC machine (20A Model, Tokyo, Japan), fitted with a ODS-C18 (250cm×4.6mm ×5µl) column, CTO-10AS VP oven, SPD-M20A Diode array detector, DGU-20ASR prominence degassing unit, CBM-20A prominence communications bus module, SIL-20A HT prominence auto sampler and an LC-20AD prominence liquid chromatograph. The mobile phase contained 0.8% metaphosphoric acid at a flow rate of 0.8ml/min. The injection volume used was 20µl at a wavelength of 266nm and oven temperatures of 30°C. The retention time (4.1 minutes) of pure ascorbic acid was used to identify ascorbic peaks in sample chromatographs. Quantification was done using chromatographic peak areas generated.

3.7.5 Rehydration ratio determination

The Elkhodiry *et al*. (2015) method was used with some modifications. Two grams of each dried tomato variety sample were weighed into 250 ml beakers and submerged in 50 ml distilled water at 25°C for 24 hours. The samples were then drained for 5 minutes and the adhering water absorbed onto cotton wool and re-weighed. The rehydration ratio was calculated as shown below;

$$\text{Rehydration ratio} = \text{Final weight}(w1) \div \text{initial weight}(w0)$$

3.7.6 Color determination

The color of both the fresh and dried samples was determined following the method detailed by Dadalı *et al*. (2007) using a hunter lab color difference meter (Minolta, Tokyo, Japan). The instrument was standardized with a black and white ceramic plate before use. The color of the sample was measured at three regions along the blossom end, the stem end and around the equatorial region. Reflected colors L*, a* and b* were determined directly as displayed on the color meter screen. L* represented lightness, a*

represented chromaticity from red (+) to green (-) axis while b* represented chromaticity from yellow (+) to blue axis (-).w_1

3.8 Microbiological analyses

3.8.1 Total plate count

Enumeration of total mesophilic aerobic bacteria was done using the spread plating method on plate count agar (PCA) (Sigma-Aldrich) plates according to the method described by Gassem, (2002). Ten grams of dried tomato sample was added in 90ml of sterilized peptone water in 250ml conical flasks and mixed thoroughly by shaking. The mixture was pre-enriched by incubation for 30 minutes at 37°C and shaking done for 1 minute. A 1ml of the sample was drawn using sterilized micropipette tips and added in 9ml sterile peptone water and serially diluted to a dilution of 10^{-3}. Aliquots of 0.1ml of 10^{0} to 10^{-3} were spread plated in duplicate plates on PCA. The plates were incubated at 37°C for 48 hours. The number of colonies on the plates were counted and reported as colony forming units per gram (CFU/g) using the formula below;

$$\text{CFU/g} = (\text{Number of colonies observed} \times \text{dilution factor}) \div \text{Volume of aliquot plated}$$

3.8.2 *Escherichia coli* (E. coli) enumeration

Detection of *E.coli* was done according to the method detailed by Gagliardi & Karns, (2002). Ten grams of dried sample was thoroughly mixed with 90 ml of sterile peptone water (0.1% w/v) in 250 ml conical flasks. The mixture was pre-enriched by incubation for 30 minutes at 37°C and shaking done for 1 minute. Serial dilutions (10^{0}-10^{-3}) in 0.1% peptone water were prepared and the samples inoculated in duplicate on MacConkey agar (Sigma-Aldrich) using the spread plate method. The colonies were counted after the plates were incubated at 37°C for 48 hours. The numbers of colony

counts on the plates were reported as colony forming units per gram (CFU/g) using the formula below;

$$\frac{\text{CFU}}{\text{g}} = (\text{Number of colonies observed} \times \text{dilution factor}) \div \text{volume of aliquot plated}$$

3.8.3 *Salmonella spp* detection

Ten grams of dried tomato sample was mixed in 90 ml of sterile peptone water in 250ml conical flasks. The mixture was incubated at 37°C for 30 minutes and shaking done for 1 minute. A 0.1 ml of serial dilutions(10^{0}-10^{-3}) were plated in duplicate on violet red bile glucose agar (Sigma-Adrich) for the detection of *Salmonella* spp (Lues *et al*., 2007). The plates were incubated at 37°C and the presence or absence of colonies detected after 48 hours.

3.8.4 Total yeast and mold count

Total yeast and mold counts(total fungal count) were determined using the spread plating method on potato dextrose agar plates (PDA) (Sigma-Aldrich) (Obire *et al*., 2009). Ten grams of dried tomato sample was added in 90ml of sterilized peptone water in 250ml conical flasks and mixed thoroughly by shaking. The mixture was pre-enriched by incubation for 30 minutes at 25°C and shaking done for 1 minute. A 1ml sample was drawn using sterilized micropipette tips and added in 9ml sterile peptone water and serially diluted to a dilution of 10^{-5}. Aliquots of 0.1ml from of 10^{0} to 10^{-5} dilutions were spread plated in duplicate on PDA. The plates were incubated at 25°C for 72 hours. The number of colonies on the plates were counted and reported as colony forming units per gram (CFU/g) using the formula below;

$$\text{CFU/g} = (\text{Number of colonies observed} \times \text{dilution factor}) \div \text{volumeof aliquot plated}$$

3.9 Statistical analysis

The data obtained in the study was subjected to analysis of variance (ANOVA) using Stata SE version 12 (Stata Corp LP, Texas USA). ANCOVA which combines features of both ANOVA and regression was applied to test effects of pretreatments, variety and temperatures of drying. When the coefficient of the interaction term was significant ($P<0.05$), it was concluded that there was a significant difference between treatments. One-way ANOVA was performed where treatment outcomes needed to be compared. Means were separated using Bonferroni adjustment at 95% level of significance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The effect of pretreatments on the drying time, total phenolic content, lycopene, β-carotene and ascorbic acid content, during oven-air, vacuum-oven, solar and freeze drying in Anna F1, Kilele, Prostar F1 and Riogrande tomato varieties

4.1.1 Effect of pretreatment on the drying time during tomato drying

The initial moisture content (m. c) in the four varieties was not significantly different (P>0.05) and ranged between 94.2 %– 94.6 % fresh weight basis (f. w). Similar values were reported by Maqsood *et al*. (2015) who determined tomato to contain 94.8% moisture content in their fresh state. The time required to attain 13% m. c fresh weight during oven-air and vacuum-oven drying is shown in Table 4.1 and 4.2 respectively. During oven-air drying, it was observed that the interaction effect between drying temperature, variety and pretreatment applied was highly significant (P>0.05). In Anna F1, Kilele, Prostar F1 and Riogrande tomato varieties the interaction effect between drying temperature and pretreatment applied was significant (P>0.05). The drying time required in 0.5% Calcium chloride (C.C) and 0.5% Sodium metabisulphate (N.M) pretreated samples was not significantly different when oven-air drying at 50°C in Anna F1, Kilele, Prostar F1 and Riogrande (P>0.05) tomato varieties under study. This indicates that the rate of water removal from the tomato quarters in the pretreated samples at 50°C was similar in all the varieties. Contrastingly, drying time in 0.5% N.M and 0.5% C.C pretreated samples during oven-air drying at 60°C in Anna F1 and Prostar F1 was significantly different (P<0.05). At the same temperature (60°C), the drying time in pretreated (0.5% C.C and 0.5%N.M) Kilele and Riogrande varieties was not significantly different (P>0.05). On the other hand, the drying time in the pretreated Kilele and Riogrande varieties dried at 70°C was significantly different (P<0.05) while the pretreated Anna F1 and Prostar F1 varieties drying time was not significantly different (P>0.05) at the same drying temperature during oven-air drying.

Table 4.1: Time (minutes) required to attain moisture content (13% fresh weight) during oven-air drying of four tomato varieties at specific drying temperatures

Tomato Variety	Treatment	Oven-air dried samples		
		50°C	60°C	70°C
Anna F1	Control	$2886\pm1_a^a$	$1446\pm3_a^b$	$1032\pm7_a^c$
	0.5% C.C	$2826\pm2_b^a$	$1368\pm3_b^b$	$972\pm8_b^c$
	0.5%NM	$2838\pm5_b^a$	$1344\pm4_c^b$	$948\pm5_b^c$
Kilele	Control	$2826\pm4_a^a$	$1326\pm4_a^b$	$954\pm1_a^c$
	0.5%C.C	$2724\pm3_b^a$	$1236\pm1_b^b$	$912\pm7_b^c$
	0.5%NM	$2718\pm2_b^a$	$1224\pm1_b^b$	$882\pm3_c^c$
Prostar F1	Control	$2844\pm5_a^a$	$1404\pm4_a^b$	$996\pm3_a^c$
	0.5%C.C	$2784\pm4_b^a$	$1338\pm8_b^b$	$930\pm3_b^c$
	0.5%NM	$2784\pm11_b^a$	$1290\pm9_c^b$	$924\pm2_b^c$
Riogrande	Control	$2772\pm8_a^a$	$1230\pm4_a^b$	$858\pm8_a^c$
	0.5%C.C	$2670\pm3_b^a$	$1176\pm2_b^b$	$798\pm5_b^c$
	0.5%NM	$2664\pm3_b^a$	$1158\pm6_b^b$	$762\pm7_c^c$

Data are mean values of three replicates ± standard errors. Entries in the same column at a given variety followed by the same subscript are not significantly different ($p>0.05$). Entries in the same row at a given treatment followed by the same superscript are not significantly different ($p>0.05$). Mean values were separated using Bonferroni adjustment.

Overall, the shortest drying time at 50°C, 60°C and 70°C during oven-air drying was 2664, 1158 and 762 minutes respectively observed in Riogrande variety in 0.5% N.M pretreatment. The longest time was 2886, 1446 and 1032 minutes observed in the control samples in Anna F1 at 50°C, 60°C and 70°C respectively. In a different study, it was reported that tomatoes took 1800 minutes, 1560 minutes and 1200 when dried at 50, 60 and 70°C respectively to dry during oven-air drying (Sacilik, 2007). In another study, drying time at 55°C was reported to be in the range of 2634-2970 minutes (Owusu *et al.*, 2012). The shorter drying time in Riogrande than the other varieties may be associated

with its thinner skin and less fleshy attributes as compared to Anna F1, Kilele and Prostar F1.

The drying time required to achieve 13% moisture content during vacuum-oven drying is as shown on Table 4.2. Generally, analysis of covariance and variance (ANCOVA) tests showed that the interaction effect between variety, drying temperature and pretreatment applied was significant ($P<0.05$). With regards to variety, the interaction effect between drying temperature and pretreatment was significant in Kilele, Prostar F1 and Riogrande ($P<0.05$). However, in Anna F1 the interaction effect was not significant ($P>0.05$). This may be attributed to its thick skinned properties as compared to the other varieties hence reduced the drying rate during vacuum-oven drying. However, the main effect including drying time and pretreatment were significant ($P<0.05$). Drying time between 0.5% C.C and 0.5% N.M pretreated samples in Anna F1, Kilele, Prostar F1 and Riogrande varieties at 50°C, 60°C and 70°C was not significantly different ($P>0.05$). This show that pretreatment of either 0.5%C.C or 0.5% N.M in tomatoes quarters during vacuum drying at each specific drying temperature would achieve a similar rate of water removal. However, drying time in the pretreated samples relative to the control at each specific drying temperature was significantly different ($P<0.05$). The pretreated samples took shorter time to achieve 13% m.c than in the control samples. An increase in drying temperature from 50°C to 70°C resulted in a significant reduction in drying time. At 50°C, the shortest drying time of 2658 minutes was observed in Riogrande variety pretreated with 0.5% N.M while the longest drying time of 3055minutes was observed in Anna F1 (control). At 60°C, Riogrande variety pretreated with 0.5% N.M exhibited the shortest drying time of 1195 minutes while the control samples in Anna F1 took the longest time of 1573 minutes to attain a moisture content of 13%. At 70°C, the shortest drying time of 804 minutes was also observed in the Riogrande samples (0.5% N.M) while the longest time of 1147 minutes was observed in Anna F1 (control). This phenomenon was attributed to the thicker cuticle in Anna F1 than in Riogrande and also the higher fleshy nature of Anna F1 as compared to Riogrande. Therefore, longer drying time in Anna F1 than the other varieties was observed.

Overall, these results show that drying time in tomatoes during oven-air and vacuum-oven drying may significantly differ between different varieties. Generally, shorter drying time was observed during oven-air drying where maximum drying time was 2886 minutes. On the other hand, longer drying time of 3055minutes was observed after vacuum oven drying. It is possible that the presence of air in the oven-air drier facilitated faster drying by creating faster moisture removal from the sample as compared to a vacuum oven where moisture removal is via a vacuum suction (Lewicki, 2006). It was also noted that the pretreated samples in both oven-air and vacuum-oven drying generally exhibited shorter drying time compared to the control. This can be attributed to the ability of osmotic solutions to cause a higher dehydration force compared to the control hence the shorter drying time (Dalben *et al*., 2012). This phenomenon was important in saving of energy to achieve the dried product. Therefore pretreatment was vital in reducing the drying time. It was also observed that raising drying temperature from 50°C to 70°C reduced drying time at every specific treatment in both oven-air and vacuum-oven dried samples. As a result, 13% moisture content was attained after a shorter period of time. This was attributed to a greater vapor pressure deficit that resulted after increase in temperature from 50°C to 70°C. It is also possible that more energy was available to evaporate water. Similar findings were observed by Faisal *et al*. (2013) during hot air drying of potato cubes whereby an increase in moisture migration from the food matrix to the drying medium was observed when drying temperature was raised from 60°C to 80°C. In another study, reduced drying time was observed during drying of collard leaves when drying temperatures were raised from 50°C to 75°C (Alibas, 2009). This was attributed to increased mass transfer associated with increase in temperature.

Table 4.2: Time (minutes) required to attain moisture content (13% fresh weight) during vacuum-oven drying of four pretreated tomato varieties at specific drying temperatures.

Tomato Variety	Treatment	Vacuum-oven dried samples		
		50°C	**60**°C	**70**°C
Anna F1	Control	$3055\pm18_a^a$	$1573\pm9_a^b$	$1147\pm12_a^c$
	0.5%C.C	$2961\pm17_b^a$	$1472\pm20_b^b$	$1061\pm23_b^c$
	0.5%N.M	$2948\pm7_b^a$	$1494\pm4_b^b$	$1039\pm9_b^c$
Kilele F1	Control	$2945\pm8_a^a$	$1482\pm5_a^b$	$1092\pm19_a^c$
	0.5%C.C	$2869\pm2_b^a$	$1367\pm6_b^b$	$960\pm20_b^c$
	0.5%N.M	$2864\pm10_b^a$	$1371\pm5_b^b$	$957\pm12_b^c$
Prostar F1	Control	$2965\pm15_a^a$	$1538\pm8_a^b$	$1107\pm6_a^c$
	0.5%C.C	$2801\pm20_b^a$	$1455\pm7_b^b$	$1007\pm13_b^c$
	0.5%N.M	$2802\pm15_b^a$	$1407\pm17_b^b$	$1026\pm23_b^c$
Riogrande	Control	$2907\pm3_a^a$	$1344\pm12_a^b$	$998\pm9_a^c$
	0.5%C.C	$2702\pm11_b^a$	$1214\pm16_b^b$	$800\pm13_b^c$
	0.5%N.M	$2658\pm29_b^a$	$1195\pm19_b^b$	$804\pm18_b^c$

Data are mean values ± standard errors of three replicates. Entries in the same column at a given variety followed by the same subscript are not significantly different ($p>0.05$). Entries in the same row at a given treatment followed by the same superscript are not significantly different ($p>0.05$). Mean values were separated using Bonferroni adjustment.

4.1.2 Effect of pretreatment on the total phenolic content during drying

Phenolic compounds are important antioxidant compounds in food. As a result retention of these health important compounds during drying is fundamental for consumers' health during consumption. Figure 4.1, 4.2, 4.3, and 4.4 shows the effect of drying on

the total phenolic content in four tomato varieties after oven-air drying, vacuum-oven, solar and freeze drying, respectively.

Total phenolic content in fresh tomato samples

Results showed that the total phenolic content (TPC) in the four fresh tomato under study was significantly different ($P<0.05$) and occurred in the range of 672-764mg GAE/100g dry weight (dw). It was observed that Anna F1 contained the highest TPC content of 764mg GAE/100g dw while Riogrande tomato variety contained the least of 672mg GAE /100g dw amongst the four tomato varieties studied. The high phenolic content in Anna F1 variety as compared to that of other varieties may be attributed to its thick skin representing a higher skin to flesh ratio as compared to other varieties which have a thinner skin. Previous studies have shown that most phenolic compounds are located on the skin of the fruit (Dumas *et al*., 2003). Thus, thick skinned tomato varieties have a higher TPC content than their thin skinned counterparts. Since all the varieties in this study were grown under the same environmental and cultural conditions and were of uniform ripeness, the differences in TPC may be attributed to genetic differences. Large genetic variations have been reported between different tomato varieties (Hanson *et al*., 2004). The TPC values observed in this study was in agreement with findings of Santos-Sánchez *et al*. (2012) who reported that saladette tomatoes contained 699.8±14.9 mg GAE/100g. Other researchers have reported TPC content of 735.26±5.2 mg GAE/100g in Roma beef tomato variety (Maqsood *et al*., 2015). A separate study carried out by Gümüsay *et al*. (2015) reported that tomatoes contain 792.22±43.34 mg GAE/100g. The differences in the phenolic content may be attributed to varietal differences that have been identified as influencing factors in the synthesis of phenolic compounds in plants (Boonkasem *et al*., 2015).

a) Effect of pretreatment on the total phenolic content during oven-air drying

The effect of pretreatment on the total phenolic content (TPC) content in oven-air dried tomato samples is as shown in Figure 4.1. Generally, the TPC in the fresh samples

(672.45-764.28 mg/100g dw) was higher than the oven-air dried samples (212.00-539.07mg/100g dw). The presence of vicinal OH groups and conjugated double bonds in phenolic compounds (Wilhelmina, 2005) make them vulnerable to degradation in presence of oxygen and heat. It has been reported that activation of oxidative enzymes occurs during thermal dying leading to loss of phenolic compounds (Gümüsay *et al*., 2015). ANCOVA tests showed that the interaction effect between variety, temperature and pretreatment on the TPC content of oven-air dried samples was found to be highly significant ($P<0.05$). The TPC retained across all the varieties and temperatures under study occurred in the range of 212.00-405.21, 237.17-478.18, 263.87-539.07 mg GAE/100g dw in the control, 0.5% C.C and 0.5% N.M, respectively. This corresponded to percentage retention of 27.73-60.25%, 31.03-71.11% and 34.52-80.16% in the control, 0.5%C.C and 0.5%N.M respectively. The higher retention of TPC in the pretreated samples as compared to the control may be attributed to the protective role of sodium metabisulphate against phenolic degradation and the increased drying rate of calcium chloride (Owureku-asare *et al*., 2014). Since most phenolic compounds are located on the skin surface of fruits, (Wilhelmina, 2005) possible breakdown of cell constituents by the pretreatments may also be responsible for this effect.

The maximum percentage retention was 59.72%, 69.06%, 61.08% and 80.16% for Anna F1, Kilele, Prostar F1 and Riogrande varieties respectively depending on the drying temperatures and chemical pretreatment applied. This accounted for maximum TPC of 456.47, 520.19, 443.55, 539.07 mg GAE/100mg dw in Anna F1, Kilele, Prostar F1 and Riogrande respectively. This showed that phenolic compounds were best preserved in Riogrande variety and least in Anna F1 after oven-air drying. This may be as a result of the shorter drying time in Riogrande as compared to the other varieties (Table 4.1) hence reduced exposure to heat. Reduced exposure to heat has been associated with increased retention of phenolic quality during thermal processing (Jacob *et al*., 2010). Elsewhere, 57-72% retention of phenolic compounds has been reported after thermal processing (Georgé *et al*., 2011). Noteworthy, the effect of temperature on the final TPC content was significant ($P<0.05$). Drying at higher temperatures corresponded to overall higher

retention of TPC as compared to drying at lower temperatures. In this aspect, retention occurred in the order of 70°C>60°C>50°C in all the varieties under this study. This represented percentage TPC retention of 27.73-55.53%, 38.95-59.66% and 40.88-80.16% when drying at 50°C, 60°C and 70°C respectively. This accounted for 212-373.35, 297.75-433.25 and 312.54-539.07 mg GAE/100 dw after drying at 50°C, 60°C and 70°C respectively. It is possible that at higher temperatures phenolic compounds bound to cell wall were released and phenolic oxidizing enzymes were denatured (Kerkhofs *et al*., 2005). It has also been argued that some simple phenols including chlorogenic acid concentrate during tomato thermal processing leading to a consequential increase while complex phenolics such as ferulic acid may reduce (Maqsood *et al*., 2015). In a separate study, 89.5 % retention in TPC was reported during oven drying of Saladette tomato variety (Santos-Sánchez *et al*., 2012).

Overall, the least degradation of phenolic compounds occurred at 70°C accompanied with 0.5% N.M pretreatment for all varieties under study. The final TPC content in those samples was 456.47±17.89, 520.91±13.80 and 443.55±15.30 and 539.07±7.76 mg/100g GAE dw for Anna F1, Kilele, Prostar F1 and Riogrande respectively. The lowest final TPC content after oven-air drying was 212.00±5.80, 332±13.34, 230.60±16.57 and 238.75±9.93 mg/100GAE dw for Anna F1, Kilele, Prostar F1 and Riogrande which occurred in the control samples dried at 50°C. This emphasizes the importance of higher temperature (70°C) and 0.5% sodium metabisulphate pretreatment on maximum retention of TPC as compared to the other pre drying conditions applied in this study. It is reported that sulphates act as competitive inhibitors by binding at active sites of polyphenol oxidase causing irreversible inhibition therefore causes reduced phenolic degradation (Owureku-asare *et al*., 2014).

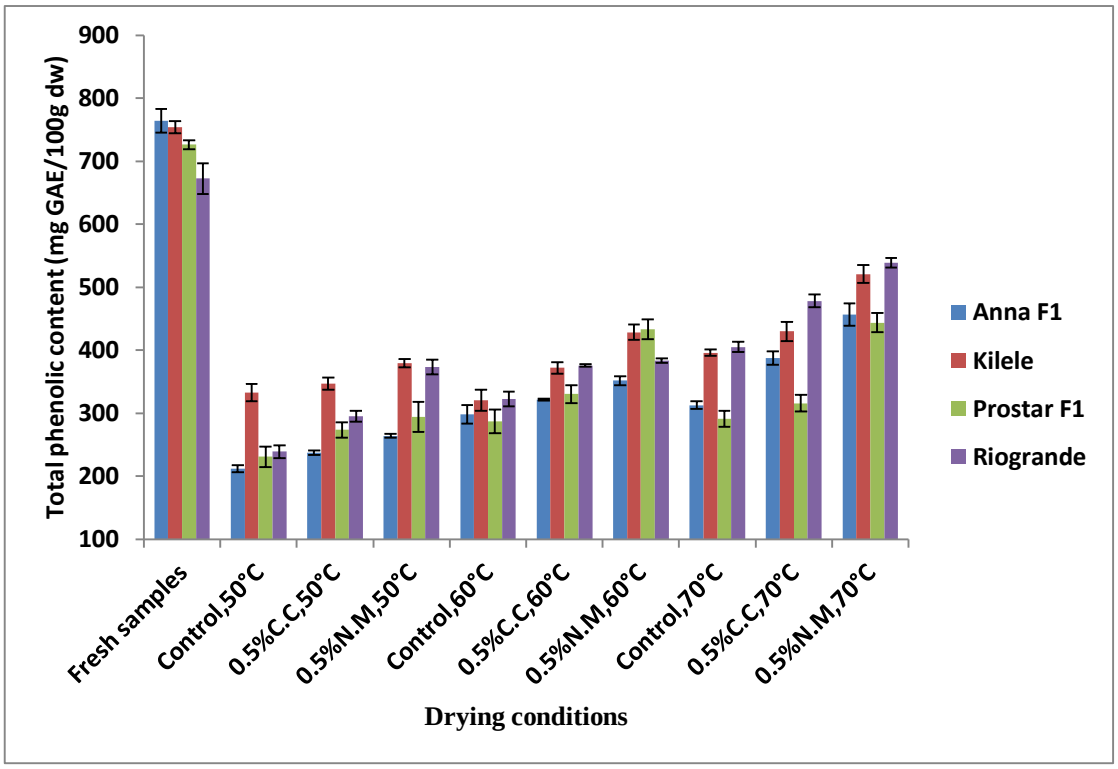


Figure 4.1: Effect of pretreatment on the total phenolic content during oven-air drying in four selected tomato varieties. Plotted data are mean values ± standard error of three replicates.

b) Effect of pretreatment on the total phenolic content during vacuum-oven drying

Generally the TPC in the vacuum-oven dried samples was lower (273.33-732.66mg/100g dw) than the fresh samples (672.45-764.28 mg/100g dw). This shows that despite absence of oxygen during vacuum-oven drying, heat had a detrimental effect on the stability of TPC. It has been reported that degradation of phenolic compounds during thermal treatment is a direct effect of heat (Santos-Sánchez *et al*., 2012). Also, since phenols are polar (Wilhelmina, 2005), it is also possible that leaching may have resulted in TPC loss during sample spraying before drying. Similar to oven-air drying, it was observed that increase in drying temperature significantly retained higher TPC in all the varieties under study in the order 70°C>60°C>50°C (Figure 4.2). The percentage

retention of TPC was 35.76-79.77, 42.04-84.19 and 68.83-98.14% when vacuum-oven drying was done at 50°C, 60°C and 70°C respectively among the four varieties studied. This accounted for 273.3-535.66, 321.7-639.0 and 526-732.66 mg GAE/100g dw in the respective drying temperatures. This might be due to shorter drying time at higher temperature (Table 4.2), thus reduced exposure to oxygen and heat. Also it is possible that at higher temperatures, cellular integrity of the sample was compromised thus facilitating higher extractability of TPC as compared to lower drying temperatures. This result compares closely with that of Jacob *et al*. 2010 who reported an increase from 63% to 89% in TPC during thermal concentration of tomato paste.

ANCOVA analysis showed that there was no interaction effect between treatment, variety and temperature on the TPC ($P>0.05$) after vacuum-oven drying. However, the main effects that is; treatment, temperature and variety had a significant effect ($P<0.05$) on the final TPC in the dried samples. With respect to variety, final total phenolic content in the dried samples ranged 273.3-721, 348-732.6, 303-712.7, 347.6-628.66mg GAE/100g dw in Anna F1, Kilele, Prostar F1 and Riogrande respectively. This represented 35.76-94.37, 46.14-97.14, 41.72-98.14 and 51.70-93.48 % retention in the respective varieties. Moreover, it was noted that there was significantly higher retention of TPC in the samples pretreated with 0.5% C.C and 0.5% N.M as compared to the control. In this case, percentage retention of TPC followed the order 0.5% N.M>05% C.C>control at each specific drying temperature and occurred in the percentages of 35.76-77.97% (273.3-524.3mg/100g), 42.04-84.19 % (321.4-611.4mg/100g) and 56.47-98.14% (431.6-712mg/100g) for the control, 0.5%C.C and 0.5%N.M respectively across all the four varieties studied. Overall, TPC was best retained in samples dried at 70°C and pretreated with 0.5% N.M in all the four varieties studied. Minimisation of phenolic degradation through pretreatment may be attributed to the ability of sodium metabisulpahte and calcium chloride to retard oxidative reactions and tissue damage (Sgroppo *et al*., 2010; Tan *et al*., 2010) that may cause irreversible changes in the phenolic quality of dried produce. Also being osmotic compounds, its likely that sodium metabisulpahte and calcium chloride treatment of samples before drying may have

increased transfer of water from the inner tissues to the surface thus increasing the drying rate and consequently reducing the time required to reach stable moisture content thus reducing extent of degradation. Osmotic compounds have been associated with increased water removal from plant tissues during drying (Owusu *et al*., 2012).

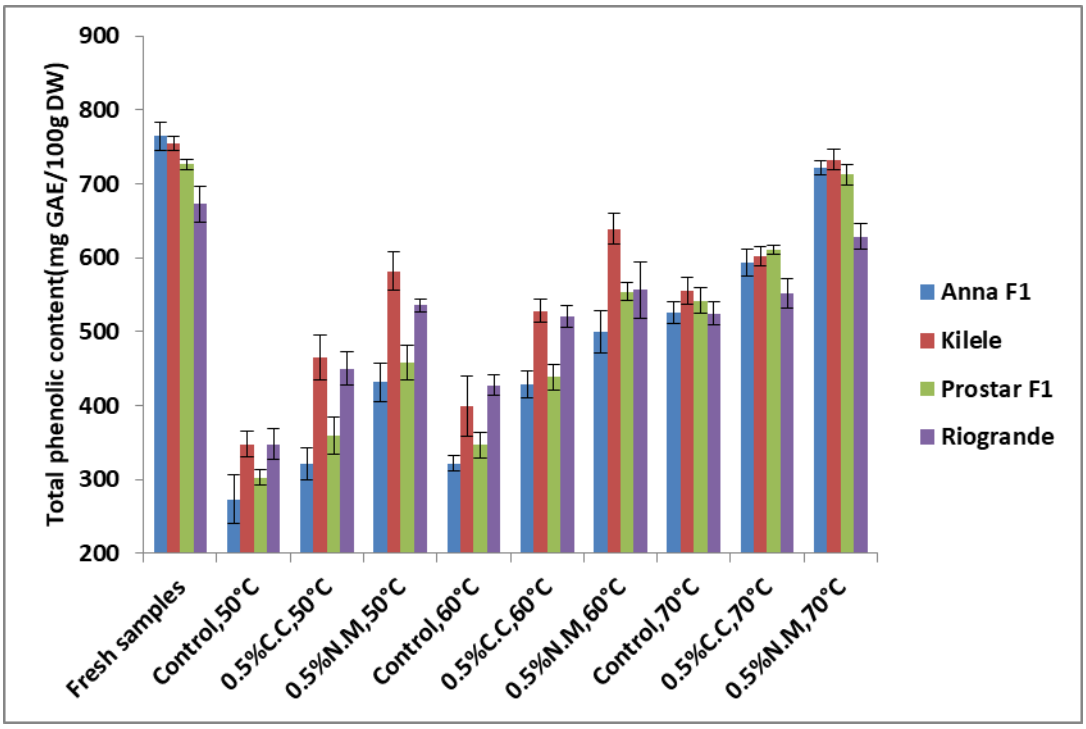


Figure 4.2: Effect of pretreatment on the total phenolic content during vacuum-oven drying in four tomato varieties. Plotted data are mean values ± standard error of three replicates.

c) Effect of pretreatment on the total phenolic content during solar drying

The effect of pretreatment on the TPC content during solar drying is as shown in Figure 4.3. Generally, a lower TPC was observed in the dried tomato samples (302.42-551.72mg GAE/100g dw) as compared to the fresh counterparts (672.45-764.28mg/100g DW). This decrease may be due to heat buildup during the solar drying process. Exposure of phenolic compounds to heat and oxygen during solar drying has been reported to cause phenolic degradation through the process of oxidation (Maqsood *et al*., 2015).

An interaction effect between variety and treatment on the TPC content in solar dried samples in this study was observed to be significant ($P<0.05$). The retained TPC content in the pretreated samples occurred in the range of 302.42-383.27, 348.15-405.78 and 381.71-451.72mg GAE/100g in the control, 0.5% C.C and 0.5% N.M respectively. In percentage, this accounted for 40.09-56.99, 45.55-60.34 and 49.94-67.17% retention in the control, 0.5% C.C and 0.5% N.M respectively. This represented highest retention in 0.5% N.M pretreated and the lowest retention in the control samples. With regard to variety, percentage retention was in the range of 41.57-49.94, 40.09-65.21, 44.67-53.93 and 56.99-67-17 in Anna F1, Kilele, Prostar F1 and Riogrande respectively. This represented 317.72-381.72, 302.42-491.87, 324.53-391.64 and 383.27-451.72 mg GAE/100g in the corresponding varieties. Our results concur with Hossain *et al*. (2008) who reported higher phenolic content (135.92 mg GAE/100g dw) in solar dried samples pretreated with 8grams per liter sodium metabisulphate as compared to the control (124.18 mg GAE/100g DW). Elsewhere, Maqsood *et al*. (2015) reported retention values of 79.12% in Roma beef tomato variety after solar drying.

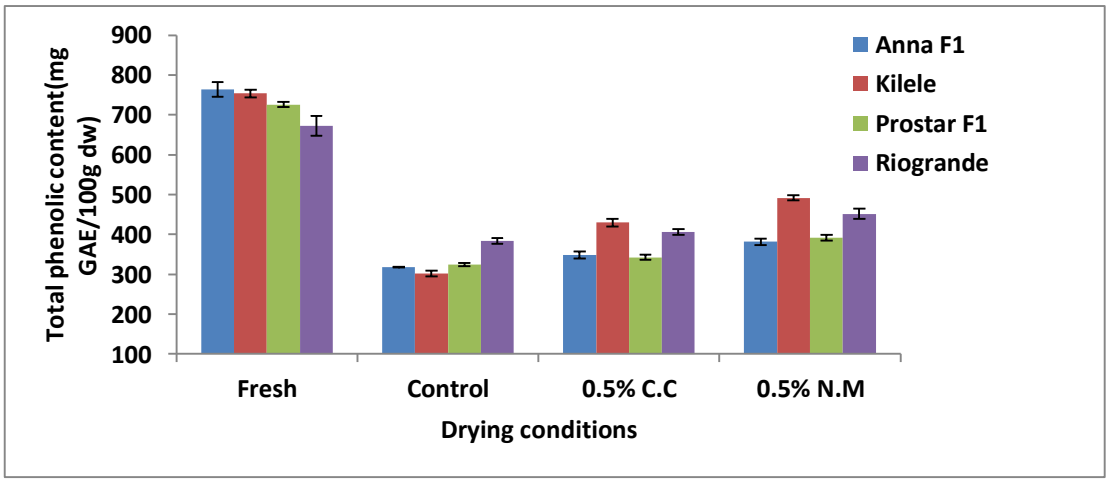


Figure 4.3: Effect of pretreatment on total phenolic content during solar drying in four tomato varieties. Plotted data are mean value ± standard eror of three replicates.

d) Effect of pretreatment on the total phenolic content during freeze drying

The influence of pretreatment on the TPC content during freeze drying is as shown in Figure 4.4. ANCOVA tests showed that the interaction effect between treatment and variety on the final TPC in freeze dried tomatoes was not significant ($P>0.05$). Similarly, the effect of pretreatment as a main effect on the TPC content in the dried samples was also not significant ($P>0.05$). This shows that during freeze drying, pretreatment of samples with calcium chloride and sodium metabisulphate in an attempt to reduce phenolic loss may not be a necessary step. It is possible that freeze drying hindered the osmotic potential of the pretreatments applied. In this regard, the percentage retention of TPC in the dried samples occurred in the range of 90.05-92.46%, 90.89-92.69% and 91.8-93.19% in the control, 0.5% C.C and 0.5%N.M pretreated samples respectively. However, the effect of variety was found to be highly significant ($P<0.05$). The maximum final TPC in freeze dried tomato samples was found to be 712.26, 693.73, 673.09 and 620.85 mg/100g dw in Anna F1, Kilele, Prostar F1 and Riogrande respectively. The amount of TPC retained after freeze drying largely

depended on the initial TPC in the sample since TPC degradation was minimal. This may largely be associated with the low temperatures and vacuum conditions applied during the freeze drying process (Serna-cock *et al*., 2015). Also, freeze drying, occurs through sublimation of ice crystals from the sample hence degradation of total phenolic compounds was minimized. However, though limited the losses in phenolic content during freeze drying (7.31-9.45%) were reported in this study. It is possible that through the freezing process, the fruit cells were disrupted leading to de compartmentalization of some substrates, enzymes and activators. As a result, possible increased degradation of phenolic compounds (Shofian *et al*., 2011). In a different study, the TPC in freeze dried tomatoes was found to be similar to the fresh samples (Gümüsay *et al*., 2015).

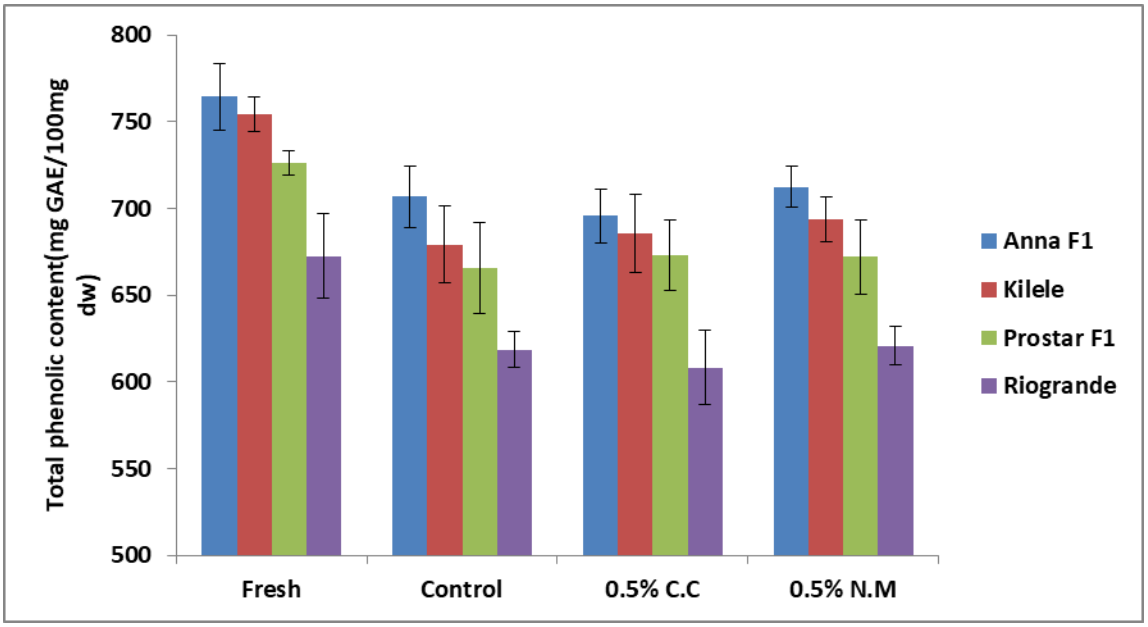


Figure 4.4: Effect of pretreatment on the total phenolic content during freeze drying in four selected tomato varieties. Plotted data are mean values ± standard error of three replicates.

4.1.3 Effect of pretreatment on the lycopene content during tomato drying

The effect of pretreatment on the lycopene content in tomatoes during drying is shown in Figure 4.5, 4.6, 4.7 and 4.8. The lycopene content amongst the fresh tomato varieties studied differed significantly ($P<0.05$). The lycopene content was 174.86, 108.46, 135.80 and 198.25mg/100g dw for Anna F1, Kilele, Prostar F1 and Riogrande respectively. This was comparable to findings of Olufemi *et al*. (2009) who analyzed eight cultivars of tomato and found lycopene to occur in the range of 70.25-147.29 ug/g fresh weight (f.w) which corresponds to about 117-245.33 mg/100g dw. However, lower lycopene values were reported by Chen (2005) who quantified the compound in Tau-tai-lan T93 tomato variety to be 51.2 ug/g fresh weight corresponding to about 85.33mg/100 dw. Similarly, lower values (57.78±1.48ug/g f. w) were reported by Ordoñez-santos & Ledezma-realpe (2013) in LL Milano tomato cultivar. These differences in lycopene content may be due to possible genetic variations that have been reported to influence the level of lycopene in tomatoes (Dumas *et al*., 2003).

a) Effect of pretreatment on the lycopene content during oven-air drying

Effect of pretreatment on the lycopene content in selected tomato varieties after oven-air drying is shown on Figure 4.5. Overall, lower lycopene levels were observed in the oven-air dried samples (43.92-175.11mg/100g dw) compared to the fresh samples (212-539.07mg/100g dw) after oven-air drying in this study. This is because oven-air drying was carried out in presence of heat and oxygen thus leading to significant lycopene loss. Lycopene being the most predominant carotenoid in tomatoes has been reported to be highly susceptible to heat and oxygen (Shi & Qu, 2004). Also, when drying is conducted carotenoids inside the tissues become vulnerable to effects of processing conditions (Kamiloglu *et al*., 2016). This corresponds with report of Olufemi *et al*. (2009) on the detrimental effect of heat and oxygen on lycopene stability.

ANCOVA analysis showed no interaction effect between pretreatment, variety and drying temperature on the lycopene content in the oven-air dried samples ($P>0.05$).

However, the main effects including temperature, pretreatment and variety were found to be significant ($P<0.05$). Moreover, it was observed that pretreatment with 0.5% N.M and 0.5% C.C significantly enhanced retention of lycopene in all the oven-air dried samples as compared to the control. The percentage retention of lycopene ranged between 33.05-58.11%, 52.44-74.13% and 59.38-88.33% in the control, 0.5% C.C and 0.5%N.M pretreated samples, respectively. This may be due to greater oxidation in the control samples as compared to samples pretreated with 0.5% C.C and 0.5% N.M. Also pretreatment with calcium chloride and sodium metabisulphate may have offered protective effect against lycopene oxidation. In a separate study, ethyl oleate, ascorbic acid and citric acid have been used as pretreatments to reduce extent of lycopene degradation during oven-air drying (Sahin *et al*., 2011).

With regard to temperature, lycopene content was found to be best retained after drying at 60°C whereby the percentage retention varied between 52.01-88.33%. The lowest percentage retention occurred after drying at 70°C whereby the retention was 33.05-67.83% while intermediate retention (51.16-74.13%) occurred in samples dried at 50°C across all the four varieties studied. This shows that lycopene degradation is temperature dependent and therefore percentage retention decreased with increase in temperature from 60°C to 70°C. Noteworthy, the increase in temperature from 50°C to 60°C resulted in higher lycopene retention in all the samples. This may be due to probable higher extractability as a result of increased porosity at 60°C as compared to 50°C as well as reduced drying time (Table 4.1) due to higher drying temperature. It has been reported that as drying proceeds so does the increase in sample porosity (Kamiloglu *et al*., 2016). Similarly, Purkayastha and Nath (2013) reported maximum lycopene retention in Punjab Kesri tomato slices that were hot air dried at 60°C as compared to those dried at 50°C and 70°C. The researcher reported 32.23 % loss in lycopene when temperature was increased from 60°C-70°C. With regard to variety, percent lycopene content retained after oven drying in the four varieties in this study followed the order: Riogrande >Kilele >Prostar F1 >Anna F1. This corresponded with 33.05-82.17%, 40.94-85.98%, 33.17-82.26% and 49.31-88.33% retention relative to the fresh in Anna F1, Kilele,

Prostar F1 and Riogrande, respectively. This corresponded to maximum lycopene content of 175.11, 93.25, 111.71 and 143.69 mg/100g dw in Riogrande, Kilele, Prostar F1 and Anna F1, respectively. From this result, Riogrande variety retained the highest lycopene content as compared to the other varieties. This phenomenon was largely influenced by the shorter drying time required in Riogrande to achieve stable moisture content (Table 4.1) and highest initial lycopene content (198.25mg/100g dw) as compared to the other varieties (108.46-174.86 mg/100g dw) under study. Longer drying time may have resulted in increased exposure of the sample to oxygen and heat. This may have catalyzed the rate of oxidation which result in higher lycopene loss (Shi & Qu, 2004). Contrary to the findings in this study, Kerkhofs *et al*. (2005) reported an increase in lycopene in air dried tomatoes. This was attributed to higher extractability of lycopene in the dried samples than in the fresh tomatoes. In a separate study, 8.1-20.9% loss in lycopene has been reported during tomato pulp drying whereby, the extent of loss was reported to be influenced by air temperature, feed rate and compressed air flow rates (Sablani & Sablani, 2006). Elsewhere, thermal cooking of tomato slurry for one to three hours resulted in 14.70-86.42% retention of lycopene (Olufemi *et al*., 2009). The extent of retention was reported to be a direct effect of tomato variety and period of thermal processing.

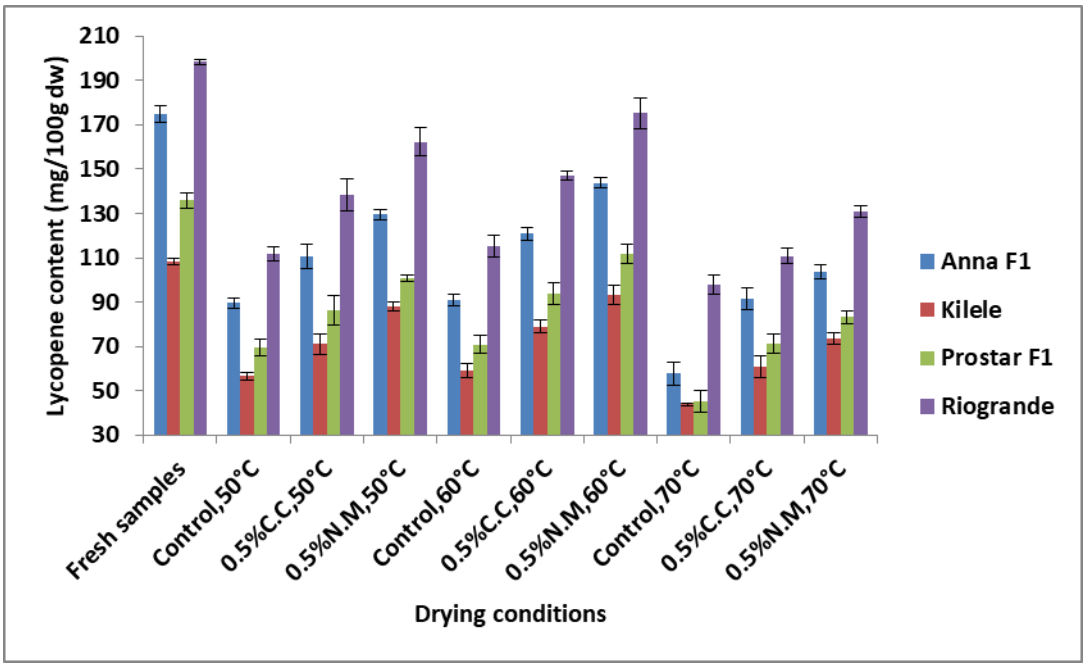


Figure 4.5: Effect of pretreatment on the lycopene content in four selected tomato varieties during oven-air drying. Plotted data are mean value ± standard error of three replicates.

b) Effect of pretreatment on the lycopene content during vacuum-oven drying

Figure 4.6 shows the effect of pretreatment on the lycopene content in vacuum-oven dried tomatoes. Statistically, there was no interaction effect between variety, pretreatment and temperature on the lycopene content retained after vacuum-oven drying ($P>0.05$). However, the main effects including variety, pretreatment and temperature were significant ($P<0.05$). The percentage retention in the varieties after vacuum drying ranged 34.78-84.81%, 49.25-90%, 37.69-83.02%, and 49.30-89.33% in Anna F1, Kilele, Prostar F1 and Riogrande, respectively. This represented maximum lycopene content of 148.31, 110.74, 112.74 and 177.11mg/100g dw in Anna F1, Kilele, Prostar F1 and Riogrande, respectively. In the pretreated samples 34.78-59.74%, 53.33-79.27%, 64.69-90.0% was retained in the control, 0.5% C.C and 0.5% N.M,

respectively. This shows that calcium chloride and sodium metabisulphate was better effective in controlling the extent of lycopene degradation as compared to the control. Sodium metabisulphate acts primarily as an oxygen scavenger and reducing agent therefore preventing oxidative spoilage (Latapi, 2006). A similar effect was reported in tomato slices pretreated with citric acid, ascorbic acid, ethyl oleate and potassium carbonate (Sahin *et al*., 2011). The researcher attributed the higher retention in lycopene to the protective role of the pretreatments against lycopene degradation as compared to the untreated samples. Thus pretreatment during vacuum-oven drying of tomato reduces oxidation. Lycopene loss is due to oxidation reaction which results in fragmented products such as acetone, glyoxal and methylheptenone (Chawla *et al*., 2008).

The effect of temperature on the percent retained lycopene content after vacuum-oven drying was 53.45-87.76%, 56.21-90.10%, 34.78-73.77% in 50°C, 60°C and 70°C, respectively. This shows that increase in temperature from 50°C to 60°C had a positive effect on lycopene retention while an increase from 60°C to 70°C had a detrimental effect on lycopene retention. From this result, it can be concluded that the drying processes performed at temperatures above 60°C may cause higher loss in lycopene as was observed after drying at 70°C. However, if exposure duration to the drying process is longer (Table4.2) as in the case of drying at 50°C, the loss is higher than at 60°C. Therefore, lycopene degradation was least when drying was done at 60°C. This indicates that oxidative reactions were better slowed at 60°C than at 50°C and 70°C.

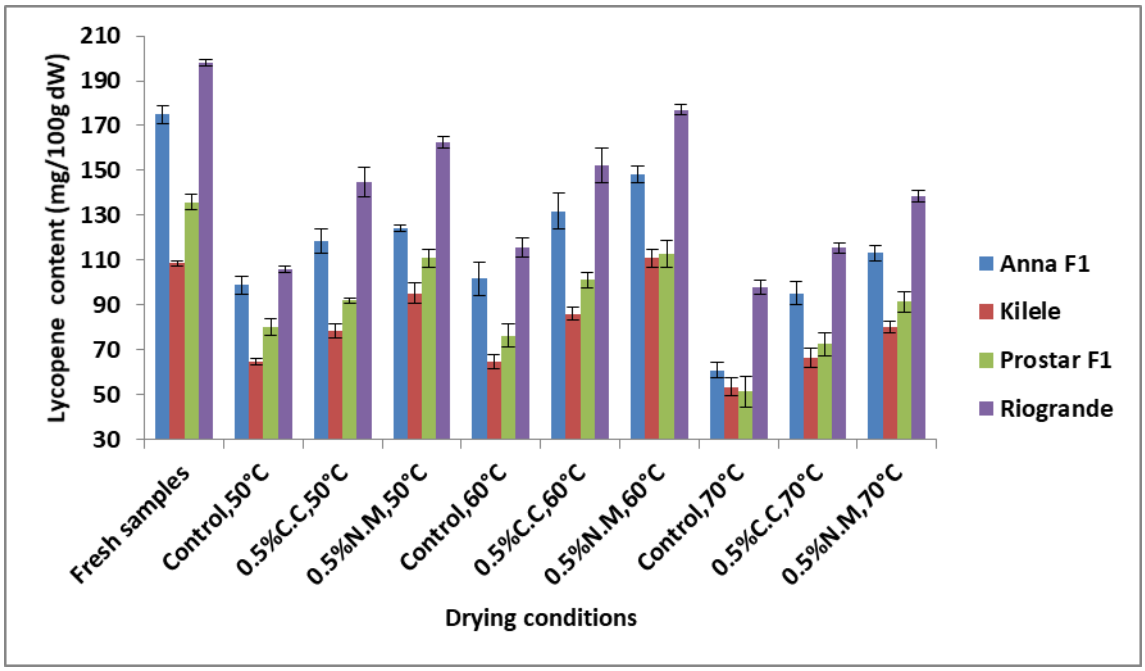


Figure 4.6: Effect of pretreatment on the lycopene content during vacuum-oven drying in four selected tomato varieties. Data are mean values ±standard error of three replicates.

c) Effect of pretreatment on the lycopene content during solar drying

The effect of pretreatment during solar drying of selected tomato varieties is shown in Figure 4.7. Solar dried samples were observed to contain reduced lycopene content (35.68-120.00mg/100g dw) as compared to their fresh counterparts (108.46-198.25mg/100g dw). This suggests a possible detrimental effect of light and heat on the stability of lycopene in tomatoes during solar drying. Researchers have reported that exposure of lycopene to light and heat result in reduced lycopene quality and quantity due to production of oxidation products (Chawla *et al*., 2008; Chen, 2005; Periago *et al*., 2002). In addition, the long drying time experienced during solar drying (5days) as a result of intermittent sunshine may have led to reduced retention in lycopene in the solar dried samples relative to the fresh. The effect of lycopene degradation has been reported to be time depended (Hong, 2014).

Statistically there was no interaction effect between variety, chemical pretreatment and variety on the amount of lycopene retained after solar drying ($P>0.05$). However, the main effects including variety and treatment were significant ($P<0.05$). In this regard, maximum lycopene content of 89.89, 67.26, 81.94 and 120.00 mg/100g dw in Anna F1, Kilele, Prostar F1 and Riogrande, respectively was retained after solar drying. Pretreated samples retained higher lycopene levels as compared to the control. In the pretreated samples, 32.90-40.90%, 45.44-54.85% and 51.45-62.01% of the initial lycopene content was retained in the control, 0.5% C.C and 0.5% N.M pretreated samples, respectively. Therefore, it can be stated that pretreatment was effective in controlling lycopene loss during solar drying of tomato quarters. It is possible that the pretreatments remained on the surface of the sample during drying thus preventing oxygen from penetrating and oxidizing lycopene. In a separate study, Sahin *et al*. (2011) reported 29.85-36.32 % retention of lycopene in solar dried 8354 tomato variety samples.

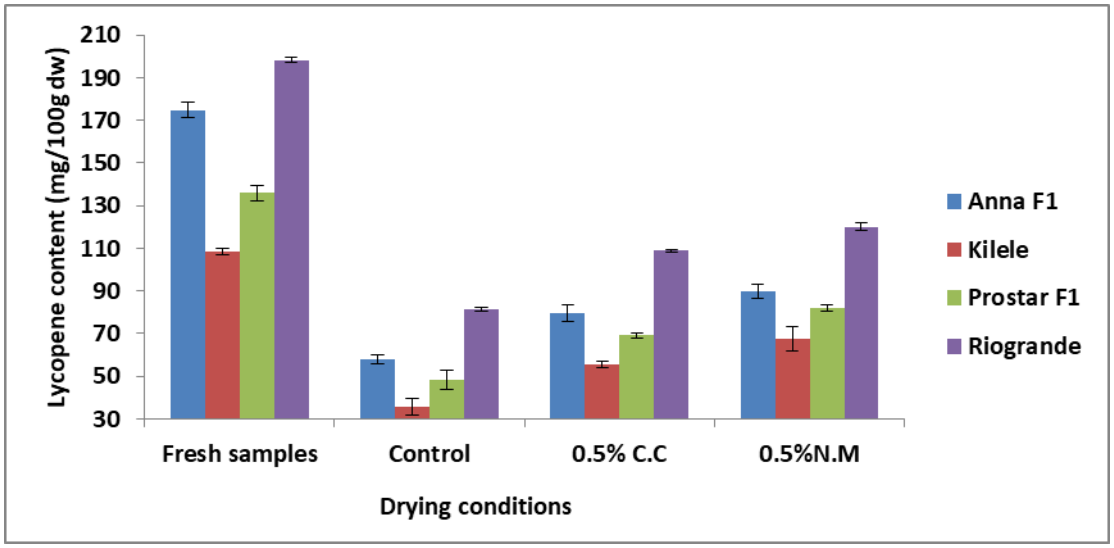


Figure 4.7: Effect of pretreatment on the lycopene content in four selected tomato varieties during solar drying. Data are mean values ± standard error of three replicates.

d) Effect of pretreatment on the lycopene content during freeze drying

Figure 4.8 shows the effect of pretreatment on the lycopene content in freeze dried tomatoes. ANCOVA tests showed that there was no interaction effect between treatment and variety ($P>0.05$) on the lycopene content in freeze dried tomatoes. In addition, pretreatment as a main effect was not significant on the lycopene content in freeze dried tomatoes ($P>0.05$). It was observed that only variety as a main effect was significant ($P<0.05$). This indicated that chemical pretreatment during freeze drying does not significantly affect lycopene content retained after freeze drying. In the pretreated samples, 82.04-88.62%, 83.89-96.08%, 80.40-92.02% lycopene was retained in the control, 0.5% C.C and 0.5% N.M, respectively. This implies that pretreatment during freeze drying may not significantly enhance lycopene retention. The low temperatures employed in freeze drying are therefore adequate in ensuring maximum possible retention. It has been argued that the low temperatures during freeze drying of fruits and vegetables creates a protective atmosphere preventing oxidation of lycopene (Sablani & Sablani, 2006). It is also possible that during freeze drying enzymes responsible for degradation are slowed down. On the basis of variety, 85.23-92.02%, 80.40-83.89%, 88.62-96.08%, 86.03-86.88% was retained in Anna F1, Kilele, Prostar F1 and Riogrande, respectively. This corresponded to maximum lycopene content of 160.92, 90.99, 130.48 and 172.24 mg/100g dw in Anna F1, Kilele F1, Prostar F1 and Riogrande varieties respectively. In a separate study, retention of lycopene in dry matter was reported as 35.12-45.51% after freeze drying (Sahin *et al*., 2011).

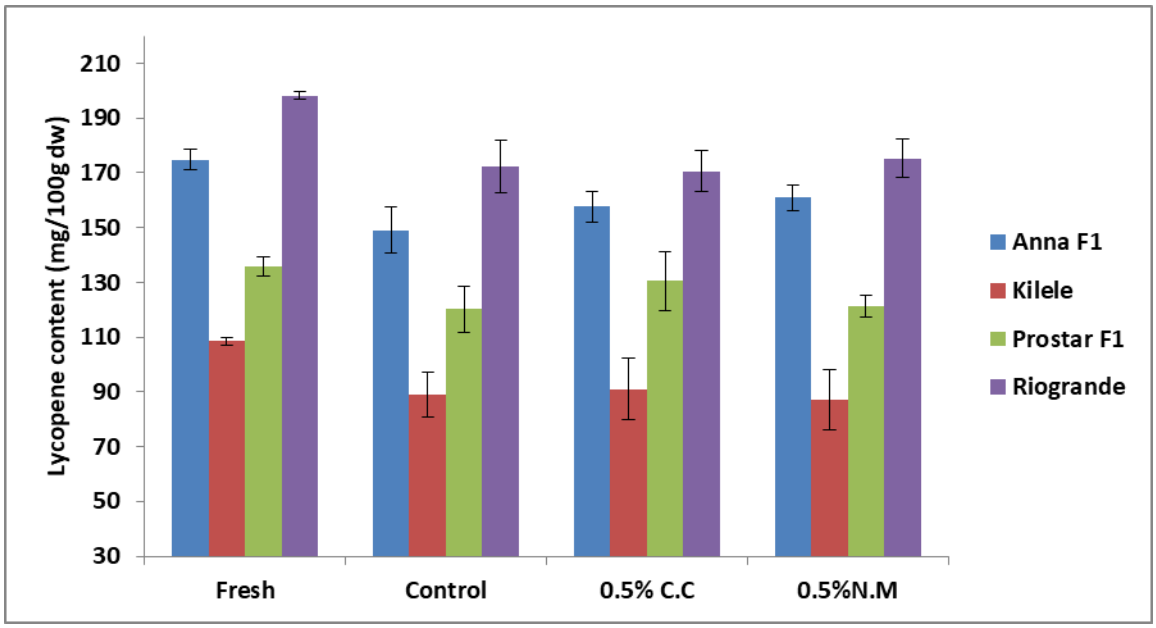


Figure 4.8: Effect of pretreatment on the lycopene content in four selected tomato varieties during freeze drying. Plotted data are mean values ± standard error of three replicates.

4.1.4 Effect of pretreatment during drying on the β-carotene content

Figure 4.9, 4.10, 4.11 and 4.12 shows the effect of pretreatment on the β-carotene content in four tomato varieties during oven-air, vacuum-oven, solar and freeze drying, respectively. The β-carotene content in the fresh tomato varieties was found to be significantly different between the four varieties ($P<0.05$). The β-carotene content was identified as 18.90 ±0.11, 26.07± 0.39, 20.74 ±0.43 and 16.22±0.34 mg/100g dw in Anna F1, Kilele, Prostar F1 and Riogrande, respectively. These results suggest that there are genetic variations in the varieties under this study thus differences in β-carotene content. Similar findings were reported by Barba and Ferna, (2006); Georgé *et al*. (2011) who found β-carotene content to occur in the range of 0.6±0.1–1.0±0.1mg/100g fresh weight in tomatoes which corresponds to about 12-20 mg/100g dw. Differences in the content of β-carotene may be attributed to varietal differences (Aldrich *et al*., 2010).

a) Effect of pretreatment during oven-air drying on the β-carotene content

Figure 4.9 shows the effect of pretreatment on the content of β-carotene during oven-air drying. Statistically, there was an interaction effect between drying temperatures, pretreatment and the variety on the content of β-carotene in the oven-air dried samples ($P<0.05$). Higher β-carotene retention values were observed in the pretreated dried samples as compared to the control. The retention values in the tomato varieties studied ranged 4.30-22.56%, 24.41-46.85% and 33.81-65.58% in the control, 0.5% C.C and 0.5%N.M, respectively. This may indicate possible reduced oxidation in the pretreated samples as compared to the control. Sodium metabisulphate acts primarily as an inhibitor of enzymatic and non-enzymatic browning that cause β-carotene loss during drying (Latapi, 2006). It is also possible that calcium entered the tomato matrix during calcium chloride spraying of the samples. As a result, it strengthened the binding forces on β-carotene into the tomato matrix thus limiting the extent of degradation (Mwende *et al*., 2018). Calcium chloride has been reported to have a firming effect in the structure of fruits and vegetables (Rico & Henehan, 2007). Furthermore, the stabilizing effect of calcium chloride on β-carotene may be attributed to inhibition of oxidases and peroxidases. These enzymes act during the drying process until substrate mobility becomes a limiting factor for catalytic activity (Perera, 2005). Based on temperature, 16.26-65.58%, 11.05-55.21% and 4.30-41.52% of the initial β-carotene was retained after drying at 50°C, 60°C and 70°C, respectively in all the varieties studied. This shows that β-carotene retention was highest in samples dried at 50°C as compared to those dried at 60°C and 70°C despite increased drying time (Table 4.1). This therefore suggests that β-carotene was more sensitive to the drying temperature than the duration of drying. This may be attributed to possible higher isomerization and oxidation rate at 70°C as compared to drying at 50°C (Eldahshan & Singab, 2013). A similar observation was reported by Athanasia & Konstantinos (2010) who studied effect of temperature on β-carotene degradation in carrots and reported final retention of β-carotene as 79%, 76% and 74% when drying at 50°C, 60°C and 70°C, respectively. With regard to variety, 7.28-47.16%, 8.97-54.20%, 8.33-44.21% and 4.30-65.58% of β-carotene relative to the

fresh was retained in Anna F1, Kilele, Prostar F1 and Riogrande varieties, respectively. This shows that the highest retention was observed in Riogrande as compared to the other varieties. This was attributed to its shorter drying time as shown in Table 4.1 required to attain safe storage moisture content as compared to the other varieties. Reduced exposure to heat and oxygen reduces the extent of β-carotene degradation (Demiray *et al*., 2013).

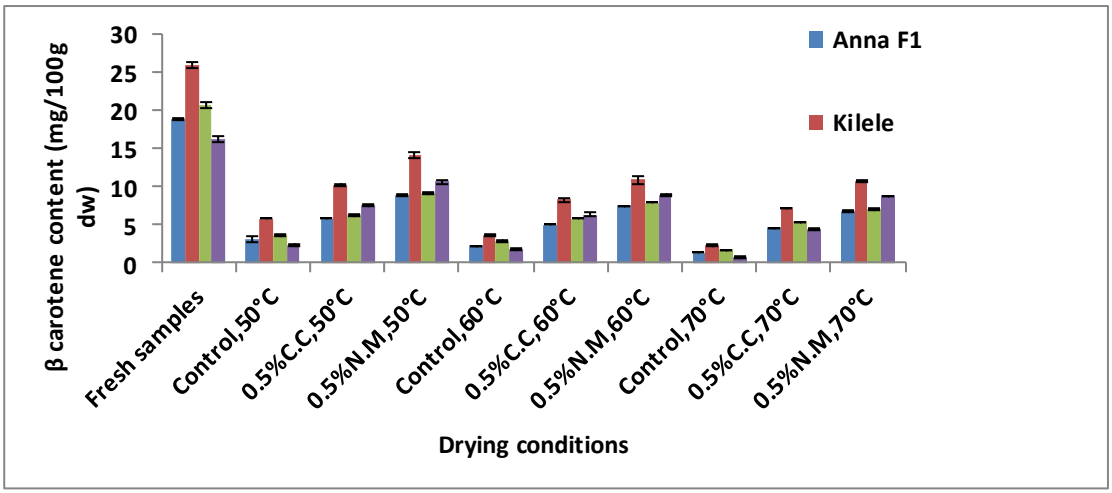


Figure 4.9: Effect of pretreatment on the β-carotene content during oven-air drying in four selected tomato varieties. Plotted data are mean ±standard error of three replicates.

b) Effect of pretreatment during vacuum-oven drying on the β-carotene content

Figure 4.10 shows the mean β-carotene retained after vacuum-oven drying at 50°C, 60°C and 70°C coupled with selected pretreatments. ANCOVA results showed that there was no interaction effect between variety, pretreatment and drying temperature on the amount of β-carotene retained ($P>0.05$). However, the interaction effect between variety and treatment, variety and temperature, treatment and temperature were found to be significant ($P<0.05$). Vacuum-oven drying carried out at 50°C retained the highest

amount of β-carotene in the range of 26.57 -81.21% while at 70°C retained the lowest amount ranging from 13.20-64.29% of the initial β carotene content in the varieties studied. Intermediate retention percentages (19.14-65.85%) occurred after drying at 60 °C. This shows that the higher the drying temperature applied, the lower the percentage retention of β-carotene observed. It has been reported that oxidative damage of β-carotene increases when thermal treatment intensifies (Jacob *et al*., 2010). The maximum amount of β carotene in the four varieties after vacuum-oven drying corresponded to 13.17, 17.23, 12.29 and 9.72 mg/100mg dw in Riogrande, Kilele, Prostar F1 and Anna F1, respectively. The pretreated samples that were vacuum-oven dried contained significantly higher levels of β-carotene as compared to the control. In this respect, 13.20-28.76, 30.07-54.88 and 41.77-81.21 % retention values occurred in the control, 0.5% C.C and 0.5% N.M, respectively. Pretreatment with 0.5% C.C and 0.5% N.M may have provided a better protection mechanism against β-carotene loss than the control.

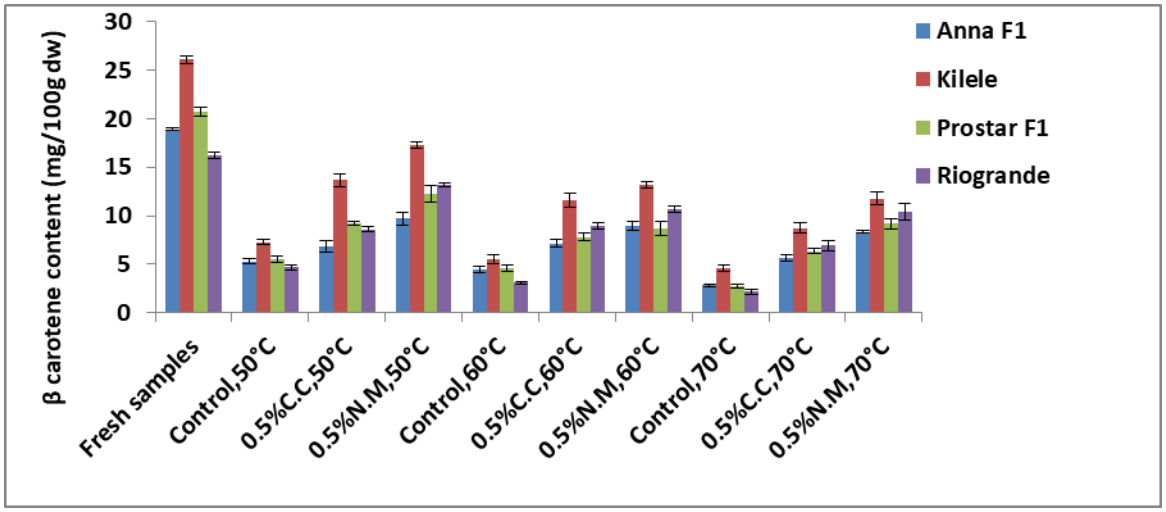


Figure 4.10: Effect of pretreatment on the β carotene content during vacuum oven drying on four selected tomato varieties. Plotted data are mean values ±standard error of three replicates

c) Effect of pretreatment during solar drying on the β-carotene content

Figure 4.11 shows the effect of pretreatment on the β-carotene content in solar dried samples. In this study, the initial β carotene content in the varieties studied declined after solar drying. The reduced β-carotene in solar dried samples as compared to the fresh samples may be due to increased drying time due to intermittent solar exposure as is common during solar drying (Li *et al.,* 2016). Also heat buildup during solar drying may have contributed to this effect. Despite its low operational cost, solar drying has been associated with increased enzymatic and chemical degradation in drying of most fruits and vegetables (Marques *et al*., 2006). ANCOVA results showed that there was an interaction effect between variety and pretreatment on the amount of β-carotene after solar drying ($P<0.05$). Also, the main effects including variety ($P<0.05$) and pretreatment ($P<0.05$) were found to be highly significant. The percentage retention values in dried samples were 5.24-24.07%, 11.53-31.06%, 5.92-29.29% and 7.26-45.21% in Anna F1, Kilele, Prostar F1 and Riogrande relative to the fresh values in the respective varieties. The highest percentage retention value representing 1.17-7.33mg/100g dw was observed in Riogrande tomato variety while the lowest representing 0.99-4.55mg/100g dw were observed in Anna F1 tomato variety. Isomerization and oxidation reactions common during heat processing have been linked to losses in β-carotene (Khoo *et al*., 2011). However, the differences in the retention levels may be attributed to differences in the initial β-carotene content as well as differences in the time taken to achieve stable moisture content. Reduced exposure to heat translates to reduced β-carotene loss (Lemmens *et al*., 2013). Pretreated samples were found to contain higher β carotene content as compared to the control. In the pretreatments applied, the percentage retention was 24.07-45.21%, 12.27-25.58% and 5.24-11.53% in 0.5% N.M, 0.5% C.C and control, respectively. This indicates that 0.5% sodium metabisulphate was best in preservation of β carotene as compared to 0.5% calcium chloride and the control. It has been reported that metabisulphate prevents oxidative reaction that cause carotene degradation (Perera, 2005).

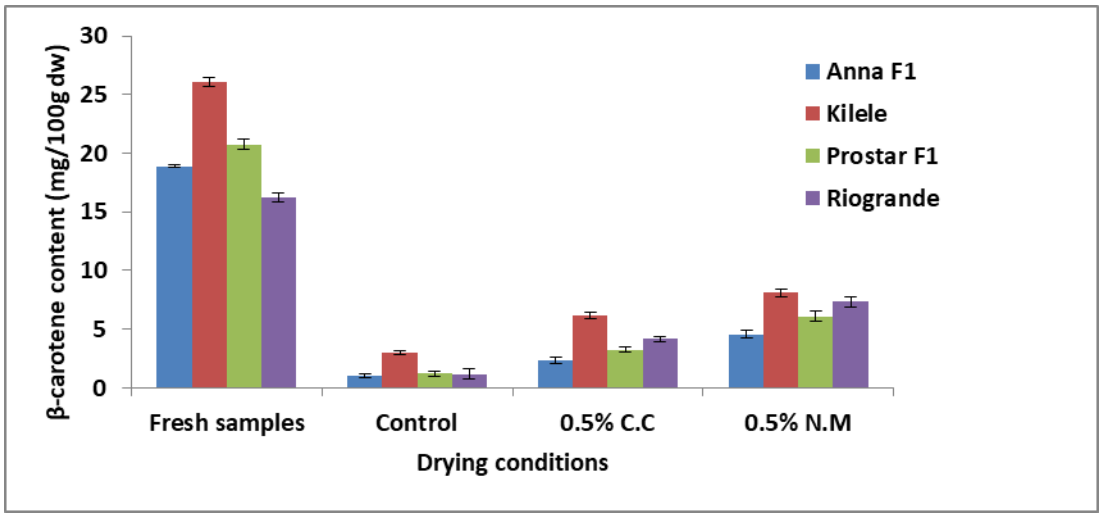


Figure 4.11: Effect of pretreatment on the β-carotene content during solar drying in four tomato varieties. Plotted data are mean ± standard error of three replicates.

d) Effect of pretreatment during freeze drying on the β-carotene

The effect of pretreatment on the β-carotene content after freeze drying is shown in Figure 4.12. ANCOVA tests showed that there was no interaction effect between variety and pretreatment on the β-carotene content in the dried samples ($P>0.05$). Pretreatment as a main effect, was not significant on the amount of β-carotene retained after freeze drying ($P>0.05$). This shows that pretreatment is not significantly important in maximizing β-carotene content during freeze drying. Percentage retention values in the freeze dried samples relative to the fresh samples occurred in the range of 71.79-85.14%, 74.88-86.65% and 78.04-89.12 % in the control, 0.5% C.C and 0.5% N.M samples respectively. On the other hand, effect of variety on the retention of β-carotene was also found to be significant ($P<0.05$). In the four varieties studied the maximum β-carotene retained after drying was 22.48, 18.48, 14.75 and 13.78 mg/100g dw in Kilele, Prostar F1, Anna F1 and Riogrande respectively. The amount retained after freeze drying was mainly dependent on the initial β-carotene present in the fresh sample. This confirms reports that freeze dried fruits contain antioxidant quality close to their fresh counterparts (Chawla *et al*., 2008 ;Gümüsay *et al*., 2015; Sahin *et al*., 2011; Serna-cock

et al., 2015). This is attributed to the fact that freeze drying is done under vacuum and low temperatures of -50°C (Gümüsay *et al*., 2015). However, its prolonged processing time and high energy costs involved make it less popular in food preservation (Kamiloglu *et al*., 2016).

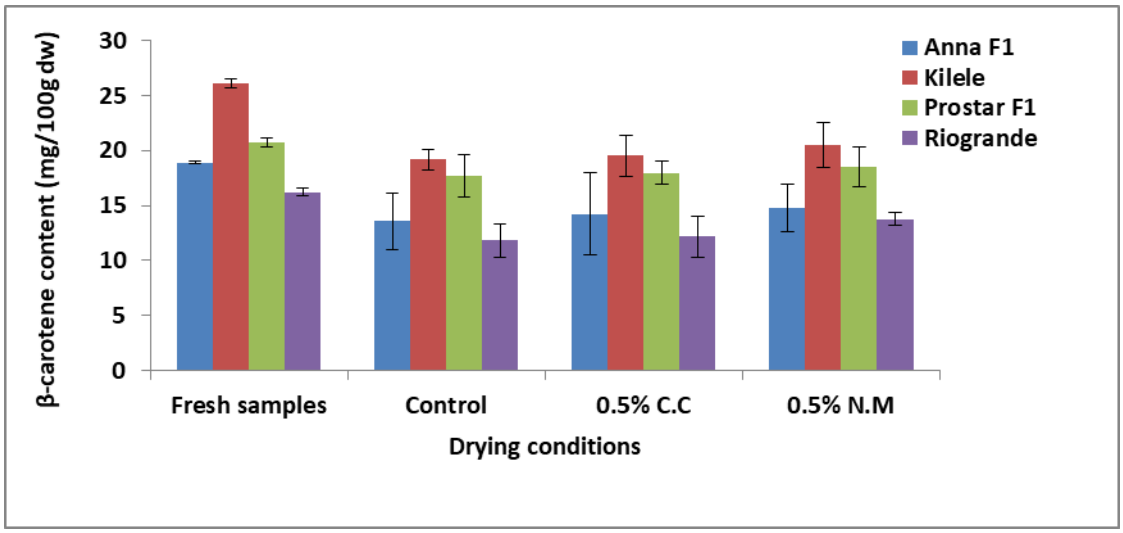


Figure 4.12: Effect of pretreatment on the β-carotene content during freeze drying on the β-carotene content in four tomato varieties. Plotted data are mean values± standard error of three replicates

4.1.5 Effect of pretreatment on the ascorbic acid (vitamin C) content during drying

Ascorbic acid content in the four varieties under study was determined to be 239.44, 237.77, 235, 244.44mg/100g dw in the fresh samples. However, the difference in the ascorbic acid content in the four fresh tomato varieties studied was not significant (P>0.05). Georgé *et al*. (2011) reported higher vitamin C levels (262.4 mg/100g dw) in fresh red tomatoes while lower values (86.96mg/100g dw) were reported by Gari (2010) in fresh Olympian Gold (#4799) tomato. Differences in variety and cultural practices may have influenced the difference in content of vitamin C.

In this study, it was noted that in the dried samples, vitamin C was only found to be present in the freeze dried samples and not detected in the oven-air, vacuum-oven and

solar dried samples (Table 4.3). This may be attributed to the heat labile nature of vitamin C (Tola & Ramaswamy, 2015). A decline in vitamin C content was found to be statistically significant between the fresh samples and the freeze dried samples. The percentage retention levels in the freeze dried samples relative to the fresh was found to occur in the range of 74.77-79.98% amongst the four varieties in this study. ANCOVA results showed that the interaction effect between variety and pretreatment on the vitamin C content after freeze drying was not significant ($P>0.05$). The main effects, variety ($P>0.05$) and pretreatment ($P>0.05$) were not significant. The maximum percentage retention levels of vitamin C were 79.98%, 79.94% and 78.19 % in the control, 0.5% C.C and 0.5% N.M samples respectively. This indicates that during freeze drying of tomatoes; pretreatment may not be a necessary procedure in enhancing better retention of vitamin C. With respect to variety, the vitamin C content did not vary significantly amongst the four varieties after freeze drying. The maximum retention levels were 79.98%, 80.80%, 78.79% and 79.70% in Anna F1, Kilele, Prostar F1 and Riogrande, respectively. Since freeze drying operates under vacuum and low temperatures (Voda *et al*., 2012), the loss in vitamin C may have mainly occurred due to the wash out effect during the pretreatment process since vitamin C is polar in nature. The pretreatment process was done by spraying which may have led to the flow of vitamin C from the fruit. Vitamin C has been reported to be highly soluble and losses occur in processes that use water (Wilhelmina, 2005). In a separate study, vitamin C retained was found to be 7.84%, 1.34% and 5.60% in solar, oven (60°C) and vacuum-oven (60°C) dried tomatoes respectively (Gümüsay *et al*., 2015). Contrary to this study, samples in that study did not undergo any wash out effect before drying. This may have contributed to the presence of vitamin C after solar, oven and vacuum drying in that study. In another study, 24.88% of vitamin C was retained after oven drying at 60°C for 20 hours (Demiray *et al*., 2013). Higher vitamin C retention (54.8%) was reported in seedless Saladette tomato slices after oven drying at 45°C (Santos-Sánchez *et al*., 2012).

This shows that the extent to which vitamin C is retained during tomato drying is closely related to the drying conditions applied to attain the dried product. Loss of vitamin C

during heat processing of foods has been associated with oxidation reactions as well as it utilization for protection of polyphenols from oxidation (Kamiloglu *et al*., 2016).

Table 4.3: Effect of pretreatment on vitamin C content (mg/100g dw) in oven-air, solar, vacuum-oven and freeze dried tomato varieties

Tomato Variety	Treatment	Oven			Solar	Vacuum –oven			Freeze
		50°C	**60**°C	**70**°C		**50**°C	**60**°C	**70**°C	
Anna F1	Control	*	*	*	*	*	*	*	191.51±11.9[a]
	0.5% C.C	*	*	*	*	*	*	*	182.59±7.51[a]
	0.5%N.M	*	*	*	*	*	*	*	187.23±7.90[a]
Kilele	Control	*	*	*	*	*	*	*	192.14±8.78[a]
	0.5%C.C	*	*	*	*	*	*	*	190.10±3.48[a]
	0.5%N.M	*	*	*	*	*	*	*	180.75±10.5[a]
Prostar F1	Control	*	*	*	*	*	*	*	185.16±6.73[a]
	0.5%C.C	*	*	*	*	*	*	*	178.03±5.26[a]
	0.5%N.M	*	*	*	*	*	*	*	181.35±9.92[a]
Riogrande	Control	*	*	*	*	*	*	*	194.83±7.45[a]
	0.5%C.C	*	*	*	*	*	*	*	184.18±8.44[a]
	0.5%N.M	*	*	*	*	*	*	*	182.78±11.0[a]

Pretreatments before drying: Control=untreated; 0.5% C.C=0.5% calcium chloride spraying; 0.5%N.M=0.5% sodium metabisulphate spraying. Data is expressed as means ±standard error of three replicates. Means within a column with same superscript are not significantly different (P>0.05). Means were separated based on benferoni adjustment. *=Not detected

4.2 The effect of pretreatment on the rehydration ratio and color in Anna F1, Kilele, Prostar F1 and Riogrande varieties during oven-air, vacuum-oven, solar and freeze drying

4.2.1 Effect of pretreatment on the rehydration ratio after drying.

Rehydration ratio (RR) refers to the ability of a dried product to absorb water (Faisal *et al*., 2013). It is used as a quality indicator after drying (Doymaz, 2014; Hossain *et al*., 2008). RR is therefore indicative of physical and chemical changes that occur during drying (Doymaz, 2014). Table 4.4 shows the rehydration ratio of dried tomato samples under the study after oven-air, vacuum-oven, solar and freeze drying. Generally the RR value ranged 2.85-7.78 in all the dried samples under this study.

a) Effect of pretreatment on the rehydration ratio after oven-air drying

In oven-air dried tomato samples, the rehydration ratio under the study generally varied from 2.85-4.58 (Table 4.4). ANCOVA results showed that there was an interaction effect between drying temperature, pretreatment and variety on the RR during oven–air drying ($P<0.05$). The lowest RR was reported in control samples of Anna F1 variety while the maximum value was reported in Prostar F1 samples pretreated with 0.5%N.M. Varying drying conditions during oven drying resulted in different rehydration values in the dried samples. The effect of pretreatment on the RR after oven-air drying was found to be significant ($P<0.05$). Our results indicated that better RR (3.15-4.58) was reported in pretreated samples compared to the control (2.85-4.11) after oven-air drying. This may be due to possible higher tissue collapse and changes in tissue porosity during drying in the control as compared to the pretreated samples. Less textural changes during drying lead to higher rehydration ratio of the final product (Ghavidel & Davoodi, 2010). On the other hand, the effect of drying temperature on the RR was found to be significant ($P<0.05$). In this regard, maximum RR (4.58) was reported at 50°C while minimum (3.81) at 70°C. This may indicate that the low drying time that was associated with high drying temperatures (Table 4.4) resulted in possible higher cellular rupture

therefore lower rehydration potential. These results concur with that of Hathan (2014) who reported a decrease in RR during oven-air drying of beetroot from 3.57 to 3.09 when temperature was increased from 50°C to 70°C. The decrease in RR with increase in temperature was associated with cellular dislocation which may have led to loss of tissue integrity and subsequent reduction in tissue hydrophilicity. With respect to variety, maximum RR was observed to be 4.46, 4.08, 4.58 and 4.28 in Anna F1, Kilele, Prostar F1 and Riogrande respectively. In another study, similar rehydration values varying from 3.9±0.4 to 4.8±0.6 were reported in seedless saladette tomato slices dried in rotating tray driers (Santos-Sánchez *et al*., 2012). Lower values in the range of 2.77-3.40 were reported in dried Milen tomato samples by Sacilik, (2007). This indicates that variabilities in RR may depend on the tomato variety and pre drying treatments applied.

b) Effect of pretreatment on the rehydration ratio after vacuum-oven drying

The RR in the vacuum dried samples is as shown in Table 4.4. ANCOVA results showed that the interaction effect between drying temperature, variety and pretreatment was significant ($P<0.05$) This study demonstrated that samples that were sprayed with 0.5% N.M had the best RR value (4.61-6.85) while those pretreated with 0.5% C.C had the least (3.60-5.03). However, 0.5% C.C pretreatment was not significantly different from the control samples ($P>0.05$). This showed that the degree of cellular and structural disruption was least in the 0.5% N.M samples and thus better quality in the dried product in comparison to the control and 0.5% C.C. According to Ghavidel & Davoodi (2010), metabisulphate is effective in enhancing textural quality during drying of fruits. Therefore, it promotes an open structure that results in enhanced water absorption during rehydration. With regards to temperature, RR followed the order 50°C> 60°C >70°C. Generally, increase in temperature from 50°C to 70°C sub sequentially led to decrease in maximum RR from 6.85 to 5.21. It is possible that at higher temperatures more injuries to the tissue might have occurred leading to reduced water absorption after drying.

c) Effect of pretreatment on the rehydration ratio of selected tomato varieties after solar drying

ANCOVA results showed the interaction effect between pretreatment and variety on the RR after solar drying was significant ($P<0.05$). The rehydration ratio in solar dried samples in this study was observed to vary from 4.06-5.18 (Table 4.4). Maximum (5.18) was observed in Riogrande samples pretreated with 0.5% N.M while minimum RR (4.06) was observed in Anna F1 samples pretreated with 0.5% C.C. It is possible that Riogrande exhibited a better cell structure as compared to the other varieties hence better ability to rehydrate. However the difference in RR between the control and 0.5% C.C pretreated samples was found to be insignificant ($P>0.05$) in all the varieties after solar drying. Since rehydration is generally considered as a measure of injuries to the material as a result of drying (Gaware *et al*., 2010), it can be assumed that the damage to cell walls after solar drying was lower in 0.5% N.M pretreated samples as compared to the control and 0.5% C.C. Therefore, the higher the RR the lower the damage caused to the material during drying and the greater the ability of the material to rehydrate. The results of this study are consistent with that of Latapi (2006) who reported significantly higher RR in samples pretreated with sodium metabisulphate than the control. Lower RR values (3.26) were reported by Doymaz (2014) in solar dried tomato eighths. Rajkumar *et al*. (2007) reported similar lower RR values of 2.95 after sun drying of 4mm thin tomato slices. Higher values RR values (5.91) were reported by Gaware et al. (2010) in 6mm thin slices after solar drying of tomato. These differences in RR may be attributed to variations in tomato cuts used between the two studies.

d) Effect of pretreatment on the rehydration ratio of selected tomato varieties after freeze drying

In the freeze dried samples, the rehydration ratio varied from 4.95 (Anna F1, control) to 7.78 (Riogrande, 0.5%N.M) as shown in Table 4.4. The interaction effect between variety and pretreatment on RR was found to be significant ($P<0.05$). Analysis of variance showed that there was a significant difference ($p<0.05$) in the RR between the

pretreated samples (0.5% N.M and 0.5% C.C) and the control after freeze drying of tomatoes. Furthermore, samples pretreated with 0.5% N.M had higher RR (6.49-7.78) than 0.5% C.C (5.63-6.89) and the control samples (4.95-6.67). This indicates that 0.5% N.M and 0.5% C.C pretreated samples rehydrated better than the control. It is possible that the pretreated samples had better porosity thus retained better texture and absorbed more water as compared to the control. Ghaly *et al*. (2015) &Serna-cock *et al.* (2015) suggests that a more porous structure after dehydration facilitates faster and better rehydration. Since rehydration capacity can be used as a quality index after drying (Doymaz, 2014), it can also be concluded that the pretreated samples were of better quality as compared to the control samples. However, the differences in the rehydration ratio between the control and the 0.5% C.C samples was not significantly different in all the varieties except in Anna F1 after freeze drying ($P<0.05$). In a separate study higher rehydration values (11.25) were reported in freeze dried tomato slices (Gaware *et al*., 2010). The differences in RR between their study and this study may be linked to possible better rehydration ability in slices than quarters as used in the current study.

Table 4.4: Effect of pretreatment on the rehydration ratio in selected tomato varieties after oven-air, solar, vacuum-oven and freeze drying.

Tomato Variety	Treatment	Oven dried samples			Solar dried samples	Vacuum dried samples			Freeze dried samples
		50°C	**60**°C	**70**°C		**50**°C	**60**°C	**70**°C	
Anna F1	**Control**	3.76±0.16a	2.99±0.03a	2.85±0.31a	4.46±0.07a	4.75±0.04a	4.46±0.11a	4.26±0.08a	4.95±0.70a
	0.5% C.C	3.64±0.07a	3.42±0.04b	3.81±0.20ab	4.06±0.1a	4.41±0.19a	4.52±0.04a	4.15±0.06a	5.63±0.92b
	0.5%NM	4.14±0.12a	4.46±0.07c	3.67±0.08a	4.72±0.06b	6.56±0.18b	5.85±0.11b	5.21±0.08b	6.49±0.09c
Kilele	**Control**	4.05±0.08a	3.4±0.16a	3.58±0.08a	4.57±0.10a	4.64±0.08a	4.32±0.15a	4.10±0.10a	6.54±0.12a
	0.5%C.C	3.41±0.09b	3.51±0.09a	3.61±0.03a	4.32±0.03a	4.04±0.06b	3.93±0.154a	3.60±0.06b	6.70±0.08a
	0.5%NM	4.08±0.11a	3.95±0.07a	3.63±0.17a	4.98±0.01b	6.85±0.08c	5.26±0.05b	4.72±0.11c	7.21±0.07b
Prostar F1	**control**	4.11±0.12a	3.84±0.20a	3.62±0.08a	4.70±0.02a	4.64±0.08a	5.04±0.06a	4.35±0.28a	6.67±0.04a
	0.5%C.C	3.4±0.04b	3.39±0.06ab	3.15±0.11b	4.58±0.03a	5.03±0.048a	4.13±0.07b	3.94±0.03ab	6.89±0.03a
	0.5%NM	4.58±0.12a	4.28±0.04a	3.84±0.09a	5.04±0.05b	6.43±0.139b	5.65±0.18c	5.06±0.11a	7.31±0.10b
Riogrande	**Control**	3.88±0.08a	3.66±0.062a	3.13±0.01a	4.87±0.01a	4.28±0.10a	4.42±0.05a	4.08±0.08a	5.73±0.33a
	0.5%C.C	3.36±0.15b	3.39±0.04a	3.44±0.03a	4.79±0.04a	4.16±0.06a	4.30±0.10a	3.79±0.09ab	6.11±0.12a
	0.5%NM	3.94±0.05a	4.28± 0.14b	3.76±0.11ba	5.18±0.02b	4.72±0.07b	4.70±0.171a	4.61±0.25a	7.78±0.09b

Data is expressed as mean values ± standard error of three replicates. Means with similar letters in the same column in a given variety and temperature are not significantly different (P>0.05). Means separated using benferroni adjustment

4.2.2 Effect of pretreatment on color during drying

Color is an important quality indicator in most food products and plays a key role in consumer preference during purchase (Ringeisen *et al*., 2014). Thus, undesirable change in the color of tomato during processing is generally associated with a decrease in the quality and marketability of that product. L* (lightness index) and a* (redness) indices were used to characterize the coloration of both fresh and dried tomato samples in this study.

1) Effect of lightness value (L*) during drying

Lightness L* was used as an indicator of the degree of darkening upon heat treatment. It was observed that lightness index in the fresh samples under this study did not vary significantly ($P>0.05$) and occurred in the range of 41.12-42.33.

a) Effect of pretreatment on lightness value during oven-air drying

Significant decrease in lightness relative to the fresh samples occurred in all the oven dried samples as follows: 0.5%N.M<0.5%C.C< control as shown in Figure 4.13. The interaction effect between drying temperature, pretreatment and variety on the lightness value was significant ($P<0.05$). Generally, it was observed that the highest lightness was found in samples pretreated with 0.5% N.M and the lowest lightness was in the control samples. *L** value ranged between 26.13-31.4 (control), 27.2-32.24 (0.5%C.C) and 30.92-37.74 (0.5%N.M). This indicated that sodium metabisulphate pretreatment was best preventive against oxidation that is characterized by formation of darkened products as compared to the control and 0.5% C.C. It has been reported that sulphites and their derivatives are oxidizing agents that are effective in color stabilization (Sgroppo *et al*., 2010). Elsewhere, calcium chloride dip was used to retard *L** reduction in pealed banana during storage (Lozel *et al*., 2010). The low luminosity in the control samples was indicative of possible higher darkening that is characteristic of non-enzymatic reactions that occur during heat processing (Luterotti *et al*., 2014).

It was observed that the influence of drying temperatures during oven-air drying on the degree of darkening varied among the four varieties under study The highest degree of darkening in Anna F1 representing 61.90% retention of *L** relative to the fresh was found to occur upon drying at control, 50°C while the highest retention of *L** (88.98%) occurred at 0.5% N.M, 70°C. Kilele variety demonstrated the highest *L** retention (91.78%) upon drying at 70°C accompanied with 0.5% N.M whereas the lowest retention of L* value (64.39%) was found in control, 70°C pretreated samples. Prostar F1 highest *L** value retention (83.74%) occurred after drying at 70°C accompanied with, 0.5%N.M pretreatment while the lowest *L** value (62.94%) was retained in the control samples dried at 50°C. Decrease in lightness in Riogrande variety was least upon drying at 60°C with 0.5%N.M. pretreatment this represented 88.53% *L** preservation while the highest loss in lightness was found in the control samples dried at 60°C. It has been reported that decrease in *L** value during drying may be associated with carotenoid degradation, maillard and non-enzymatic reactions (Nisha *et al*., 2011). On the other hand *L** values have been used to indicate the degree of browning in fresh cut vegetables and in minimally processed products (Sgroppo *et al*., 2010). Similar findings were observed during tomato puree processing where *L** value significantly decreased during heat processing (Nisha *et al*., 2011). In a separate study, low drying temperatures has been reported to cause a decrease in the *L** value during hot air drying of strawberries due to extended drying period (Ghaly *et al*., 2015). On the contrary, other studies show that an increase in drying temperature has a positive relation with *L** value during drying of plant based foods (Joshi *et al*., 2009).

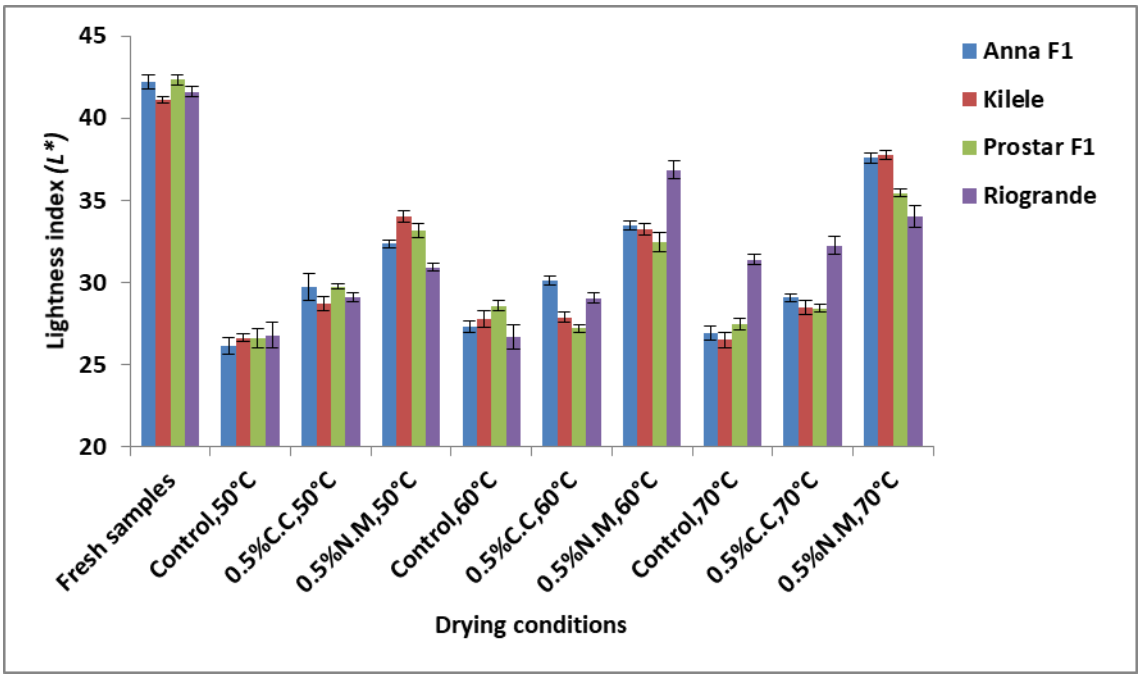


Figure 4.13: Effect of pretreatment on the L* during oven-air drying on four selected tomato varieties. Plotted data are mean value ± standard error of three replicates.

b) Effect of pretreatment on lightness value during vacuum-oven drying

The *L** values after vacuum-oven drying are illustrated in Figure 4.14. The interaction effect between variety, drying temperature and pretreatment was significant ($P<0.05$). A general decrease in the lightness value was observed in the vacuum-oven dried samples (23.63-42.06) relative to the fresh (41.12-42.33). This indicates that the dried samples were darker than the fresh samples. However, the degree to which the decrease in luminosity occurred was found to vary with temperature, variety and pretreatment applied during the drying process. With regard to pretreatment applied, the brightness value (*L**) was found to be significantly higher in the pretreated samples as compared to the control. In this regard, across all the varieties and temperatures, *L** values ranged from 23.63-35.17, 24.36-39.72 and 37.78-42.06 in the control, 0.5% C.C and 0.5 % N.M respectively. With regard to variety, maximum *L** value (42.06) in Anna F1 was

observed after drying at 60°C with 0.5 % N.M pretreatment while the minimum (28.94) was observed in the control dried at 70°C. A similar phenomenon was observed in Prostar F1 where maximum *L** value (42.06) was observed after drying at 60°C accompanied with 0.5% N.M pretreatment. Minimum *L* * value (23.63) in the same variety was observed in the control samples dried at 70°C. In Kilele variety the best drying conditions that led to the best brightness value (39.87) was 0.5% N.M, 50°C while the least value (23.63) was observed in the control samples dried at 70°C. Similarly, in Riogrande variety, the best drying conditions that attained maximum *L** values (41.47) were 0.5%N.M, 50°C, while the lowest value (24.27) was achieved in the control samples dried at 70°C. From these results, it can be reported that at higher drying temperatures (70°C) the degree of darkening was considerably higher than at lower drying temperatures (50°C and 60°C). This findings concur with those reported by Purkayastha & Nath, (2013) who reported darker Punjab Kesri tomato slices after drying was done at 70°C as compared to 50°C and 60°C due to possible higher browning reactions at higher temperature than at lower dehydration temperatures. Contrary findings were reported by Owusu *et al*. (2012) who reported a positive relationship between increase in temperature and increase in *L** value. Though unlikely, this was associated with decrease in browning reactions with increase in temperature.

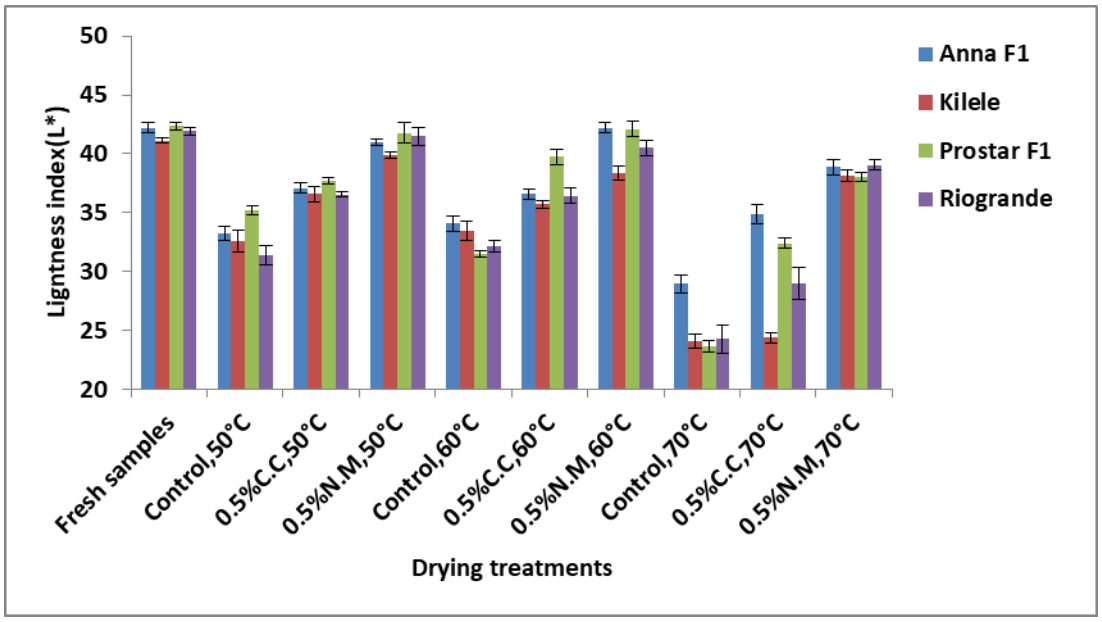


Figure 4.14: Effect of pretreatment on the L* value during vacuum-oven drying on four selected tomato varieties. Plotted data are mean values ± standard error of three replicates

c) Effect of pretreatment on lightness value during solar drying

The effect of pretreatment on the L* value after solar drying is shown in Figure 4.15. Overall, decrease in *L**value was reported to occur after solar drying in our study in the order 0.5% N.M<0.5% C.C< control. ANCOVA analysis demonstrated that the interaction effect between variety and pretreatment on the lightness value was not significant (P>0.05). Variety as a main effect was not significant (P>0.05). However, the effect of pretreatment as a main effect was significant (P<0.05). Maximum *L**values (36.73-37.07) were reported in 0.5% N.M pretreatment while minimum values were reported in the control (29.25-29.71) across the four varieties studied. Thus the effect of sodium metabisulphate preceding solar drying was most effective in decreasing color change in the tomato quarters under this study. This further implies that browning reactions were less prevalent in the 0.5%N.M samples as compared to the control and

0.5% C.C. pretreated samples. Ghavidel and Davoodi, (2010) reported that during dehydration of fruits, non-enzymatic browning produces dark pigments that eventually lead to decrease in *L** values and undesirable color changes.

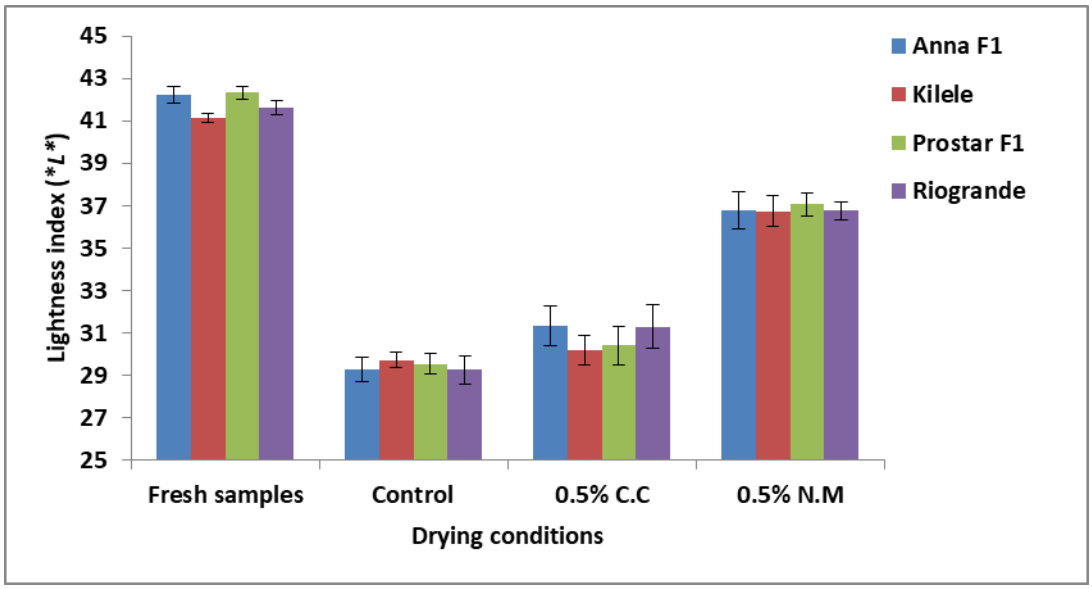


Figure 4.15: Effect of pretreatment on the L* value during solar drying in four selected tomato varieties. Plotted data are mean values ± standard error of three replicates

d) Effect of pretreatment on lightness value during freeze drying

Figure 4.16 shows the *L**value in fresh and freeze dried tomatoes. An interaction effect between variety and treatment was found to be significant on the *L** value ($P<0.05$). It was also observed that the value of *L** in freeze dried tomato samples were significantly higher ($P<0.05$) than those of the fresh samples. It is possible that the freezing and crystallization process involved during the freeze drying process may have led to the pronunciation of the brightness value.

Therefore, freeze dried samples exhibited higher luminance (52.4-56.04) values than the fresh samples (41.61-42.33). As a result, they appeared whiter than their fresh counterparts. Furthermore, the pores formed in the dried samples after freeze drying may have led to more light being dispensed hence the increase in *L** values after drying. It can also be inferred that milliard reactions and pigment degradation were minimized during freeze drying hence the increase in luminance. The low temperatures and vacuum conditions employed during freeze drying (Shofian *et al*., 2011) may have led to minimized tissue darkening. Higher luminance has also been reported in freeze dried papaya compared to the fresh fruits (Serna-cock *et al*., 2015).

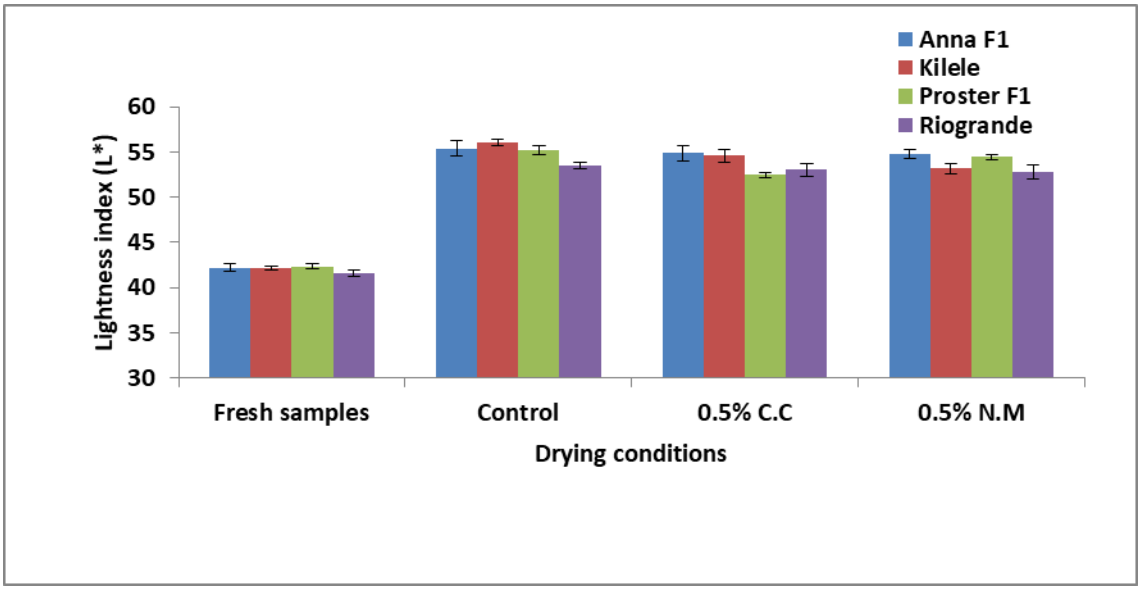


Figure 4.16: Effect of pretreatment on the L* value during freeze drying on four selected tomato varieties. Plotted data are mean values ± standard error of three replicates.

2) Effect of pretreatment on redness value during drying

The redness value in the tomato samples in this study was estimated based on the color coordinate *a** during oven-air, vacuum-oven, solar and freeze drying.

In this study, *a** coordinate in the fresh samples before drying was found to be significantly different between the four varieties ($P<0.05$) and ranged 21.46 to 26.55. Maximum *a** value in the fresh samples was found to be in Riogrande while the minimum value was found in Kilele variety which corresponded with the maximum (198.25 mg/100 g dw) and minimum (108.46 mg/100g dw) lycopene content respectively. The differences in the redness value between the varieties may be associated with differences in the lycopene pigmentation that impart the observed color. It has been reported that color properties of a material may depend on the chemical properties as well as the physical attributes of the material (Zielinska & Markowski, 2012).

a) Effect of pretreatment on redness value during oven–air drying of tomatoes

The effect of pretreatment on the redness value in oven-air dried samples is shown on Figure 4.17. Overall the interaction effect between variety, temperature and treatment on *a** value after oven-air drying was found to be insignificant ($P>0.05$). However, the interaction between temperature and treatment was found to be significant ($P<0.05$). The interaction effect between treatment and drying temperature was found to be significant in Anna F1 ($P<0.05$) and Prostar F1 ($P<0.05$). On the other hand, in Kilele ($P>0.05$) and Riogrande ($P>0.05$) varieties, the interaction effect was not significant. However the main effects in Kilele including drying temperature ($P<0.05$) and treatment ($P<0.05$) were significant. A similar phenomenon was also observed in Riogrande variety where drying temperature and treatment were significant ($P<0.05$). Maximum *a** values after oven-air drying was 25.43, 26.44, 27.80 and 28.58 in Anna F1, Kilele, Prostar F1 and Riogrande respectively. This occurred after drying at 60°C in all the four varieties combined with 0.5% N.M pretreatment. Overall, *a** value occurred in the range of 16.35-22.75, 17.51-23.98, and 21.39-28.58 in the control, 0.5% C.C and 0.5% N.M respectively across all the varieties under study. This indicated that better color was in 0.5% N.M samples as compared to the control and 0.5% C.C samples. This showed that 0.5% N.M offered better protective effect against lycopene degradation during oven-air drying. Sulphates have been associated with reduced oxidation of carotenoids which

impart the red color in tomatoes (Sablani & Sablani, 2006) thus leading to better color retention during thermal drying. In addition, samples pretreated with 0.5% N.M and dried at 60°C had significantly higher *a** values compared to the fresh. It is possible that pretreatment with 0.5%N.M led to higher expression of redness in the dried samples. A similar phenomenon was reported by Chaethong *et al*. (2012) in chilli pretreated with sodium metabisulphate.

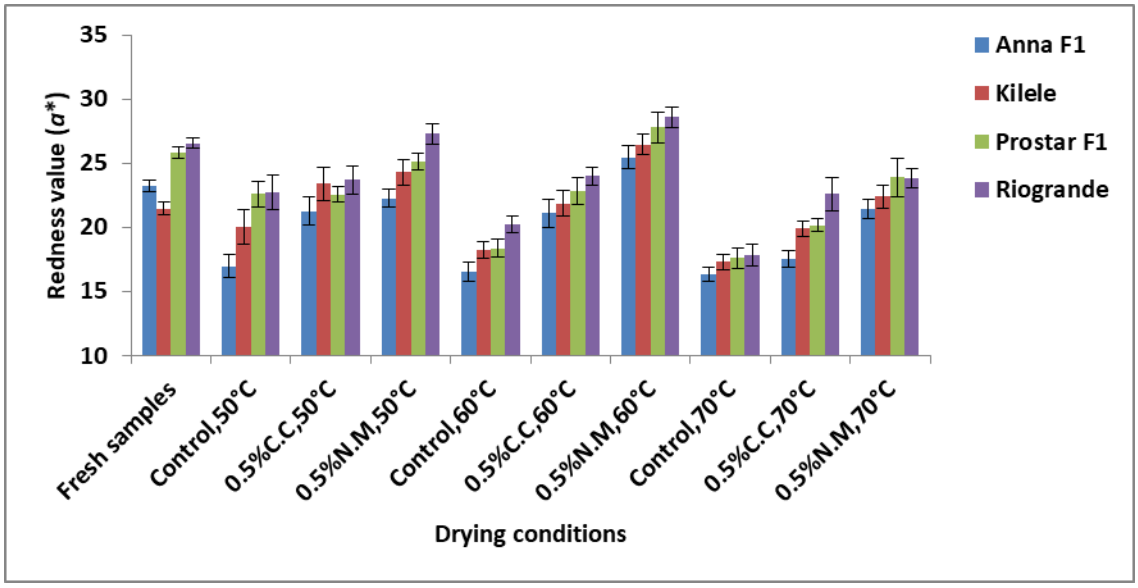


Figure 4.17: Effect of pretreatment on the redness value in four tomato varieties after oven-air drying. Plotted data are mean values ± standard error of three replicates.

b) Effect of pretreatment on redness value during vacuum-oven drying

During vacuum-oven drying (Figure 4.18), the interaction effect between temperature, pretreatments and variety was not significant (P>0.05). However, the interaction effect between temperature and treatment was found to be significant (P<0.05). A significant interaction effect between treatment and drying temperature was observed in Anna F1 (P<0.05) and in Prostar F1 (P<0.05). However, in Kilele (P>0.05) and Riogrande varieties (P>0.05) the interaction effect between the treatments and drying temperatures

were not significant. As main effects, temperature ($P<0.05$) and pretreatment ($P<0.05$) were significant in Kilele variety. Similarly, in Riogrande variety, temperature ($P<0.05$) and pretreatment ($P<0.05$) were also significant as main effects on *a** value in the vacuum-oven dried samples. The redness value ranged between 18.02-26.36, 19.29-28.95, 19.96-28.55 and 21.7-30.22 in Anna F1, Kilele, Prostar F1 and Riogrande respectively. In the control, 0.5% C.C and 0.5% N.M samples, redness value was 17.87-24.43, 18.02-30.00, and 22.17-30.22 respectively. Marginal differences in the redness value of the dried samples after vacuum-oven drying was observed between the varieties under study. Maximum *a** value (30.22) was observed in the Riogrande variety after drying at 60°C accompanied with 0.5% N.M pretreatment. The lowest *a** value (17.87) was observed in the control samples dried at 70°C in Anna F1 variety. Therefore better color retention was observed in the pretreated samples as compared to the control. This indicates that there was possible higher oxidation reactions in the control compared to the pretreated samples resulting in splitting of lycopene thus higher color loss. Sulfites reduce color loss in food materials during drying through oxygen depletion thus enhance the color quality of the dried material (Ahmed *et al*., 2010). Moreover, increase in temperature from 60°C to 70°C in all the four varieties under this study negatively impacted the redness value in the dried samples. As a result, the maximum *a** values was determined to be 30.22 and 25.86 at 60°C and 70°C, respectively. In a separate study, Joshi *et al*. (2009) reported a positive association of temperature increase with increase in color decrease. Elsewhere, redness value was reported to decrease with increase in drying temperature (Sahin *et al*., 2011).

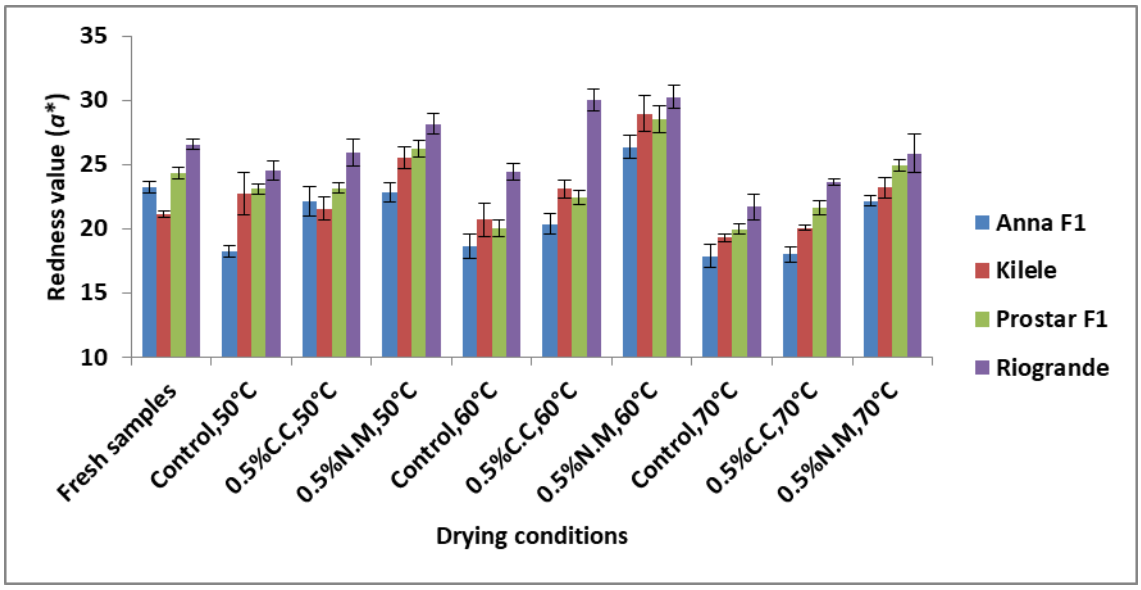


Figure 4.18: Effect of pretreatment on the redness value in four tomato varieties during vacuum-oven drying. Plotted data are mean values ± standard error of three replicates.

c) Effect of pretreatment on redness value during solar drying

During solar drying (Figure 4.19) the final *a** value was highly influenced by the pretreatment applied. The control samples had significantly lower redness value 17.48-20.03 as compared to 0.5% C.C 20.35-23.76 and 0.5% N.M 26.5-29.05. Since lycopene imparts the characteristic red color in tomatoes (Shi & Qu, 2004), it can be concluded that higher lycopene content was retained in the pretreated samples compared to the control.

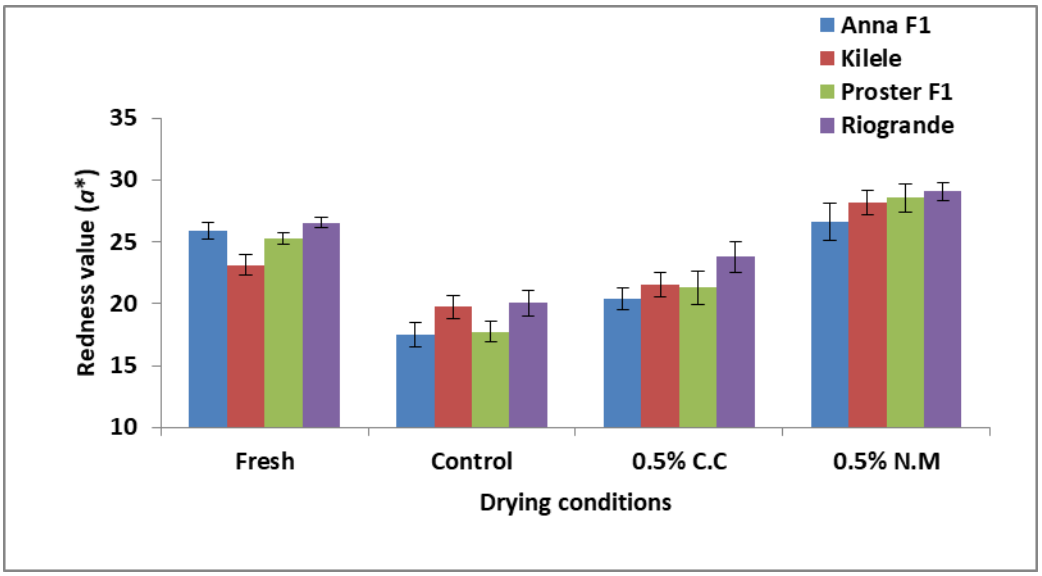


Figure 4.19: Effect of pretreatment on the redness value in four tomato varieties during solar drying. Plotted data are mean values ±standard error of three replicates.

d) Effect of pretreatment on redness value during freeze drying

Figure 4.20 shows the effect of pretreatment on the redness value during freeze drying. ANCOVA analysis showed that the interaction effect between variety and treatment on *a** value in the freeze dried samples was found to be significant ($P<0.05$). However, treatment as a main effect was not significant ($P>0.05$) on the redness value. This indicates that pretreatment did not have any effect in maintaining the redness quality in the freeze dried samples. Therefore the low temperatures applied during freeze drying are adequate in maintaining the color quality of the dried samples.

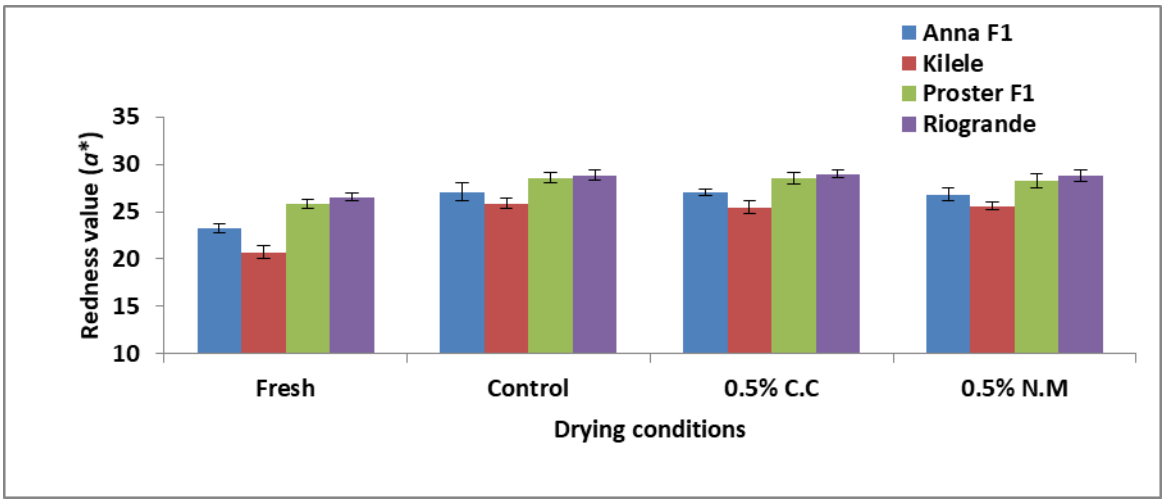


Figure 4.20: Effect of pretreatment on the redness value in four tomato varieties during freeze drying. Plotted data are mean value ±standard error of three replicates.

4.3 The effect of pretreatment on the microbiological growth of dried tomatoes during six month storage duration

1) Effect of pretreatment on the bacterial growth during storage

Microbiological growth is commonly used to determine the shelf life and acceptability of dried plant-based foods (Dauda *et al*., 2019). Some microbes are destroyed during the drying process but some are process survivors (Dauda *et al*., 2019).

Figure 4.21, 4.22, 4.23 and 4.24 shows the total bacterial counts in oven-air, vacuum-oven, solar and freeze dried tomato samples during six months storage at 25°C, respectively. Bacterial growth was found to be present in all the dried samples irrespective of the drying method and pretreatment applied. However, the total bacterial infection levels in all the dried samples did not exceed the allowable limit (2×10^4 cfu/g) set for dried fruits by Kenya bureau of standards (KEBS, 2018) during the entire storage period. This shows that drying methods used in this study were effective enough to

maintain bacterial counts under the allowable limits during the entire six month storage period.

Since dried tomatoes are sometimes consumed without further processing or cooking, the presence of *Salmonella* and *Escherichia coli* were tested. Results showed they were absent in all the samples during the entire storage duration. *Escherichia coli* is regarded as an indicator organism for sanitary and hygiene conditions during food handling and processing (Victor *et al*., 2017). Therefore, its absence in dried tomatoes in this study indicates that there was no contamination as adequate hygiene was practiced during the drying process. *Salmonella* on the hand is of health concern due to its pathogenicity and has been associated with many dried vegetables, spices and fruits (Li *et al*., 2016). Its absence during the storage period signifies microbial quality and safety of the dried tomato product for the period studied.

a) Effect of pretreatment during oven-air drying on the total bacterial growth during storage

At onset, (0months) the total bacterial counts were significantly different between the control and the pretreated samples ($P<0.05$) in the oven-air dried samples (Figure 4.21). However, there was no significant difference between the 0.5% C.C and 0.5%N.M samples ($P>0.05$). This shows that when heat is combined with chemical pretreatment during drying, inactivation of bacterial microbes in tomatoes was higher than when heat alone was used. Pretreatment during drying has been reported to have antimicrobial effect by affecting the cellular components of microbes therefore reducing their numbers in the final product (Latapi, 2006). Also shorter drying time (Table 4.1) observed in the pretreated samples compared to the control during oven-air drying may have resulted in reduced bacterial infection in the dried samples. Shorter drying duration has been reported to be detrimental in terms of microbial inactivation (Li *et al*., 2016). It was observed that the bacterial infection levels in the control and 0.5% C.C samples changed significantly throughout the six month storage duration reaching five and four fold levels in the respective treatments at the end of the storage period respectively. However, in

0.5% N.M samples, the bacterial growth remained fairly constant and did not change significantly during the entire storage period as shown in Figure 25. At the end of the storage period, the bacterial count was 30×10^1, 15.5 $\times10^1$ and 2.5 $\times10^1$ cfu/g in the control, 0.5% .CC and 0.5 %N.M, respectively. This indicated that when tomatoes are pretreated prior to drying, they may have a longer shelf life than the untreated samples. In a separate study, tomatoes pretreated with acetic acid prior to drying was reported to have increased inactivation of microbes in the dried product (Li *et al*., 2016). Dauda *et al*. (2019) reported that oven dried tomato samples contain total bacterial count of 0.8 to 1.1×10^1 cfu/g after drying. This shows that bacterial level in a food sample is largely influenced by the storage duration as well as pretreatment applied. As storage progresses, so does the level of bacterial growth (Kadam *et al*., 2011). This is associated with availability of better growth conditions as storage time progresses. In addition, bacterial growth is accelerated once conditions favorable for bacterial growth are available (Li *et al*., 2016).

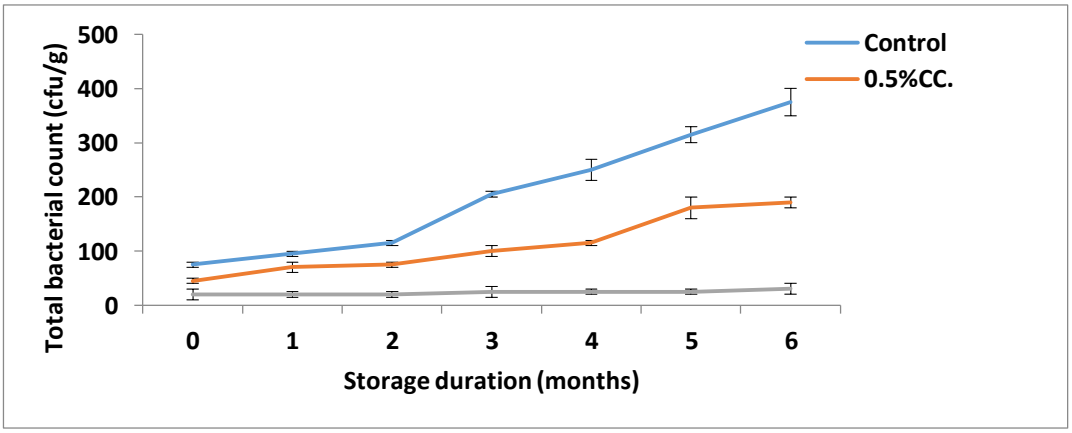


Figure 4.21: Effect of pretreatment on the total bacterial count in oven-air dried tomato samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

b) Effect of pretreatment during vacuum-oven drying on the bacterial growth during storage

In vacuum-oven dried samples (Figure 4.22), the interaction effect between pretreatment and storage months on the total bacterial count was found to be highly significant ($P<0.05$). It was observed that the initial (0 months) bacterial count was not significantly different between the control and the pretreated tomato samples ($P>0.05$). This shows that the stress caused by the vacuum and heat applied created an even inactivation of microbes in all the samples. As storage duration progressed (1-6 months) notable differences on the total bacterial levels was observed in the control, 0.5% C.C and 0.5%N.M samples. Higher infection levels were observed in the control samples (4.5×10^1 -30.0×10^1cfu/g) as compared to the 0.5%C.C (3.5×10^1-17.0×10^1 cfu/g) and 0.5%NM.(2.0×10^1-2.5×10^1 cfu/g) throughout the entire storage period. This implies that the use of 0.5% N.M on tomatoes prior to vacuum drying inhibited the growth of bacteria better as compared to the control and in the 0.5% C.C. Therefore, tomatoes pretreated with 0.5%N.M can be successfully stored for six months with minimal bacterial infection. However, the microbial safety in 0.5% C.C (17.0×10^1cfu/g) was better than the control (30.0×10^1cfu/g). Salts are reported to slow or stop microbial growth in foods by inactivating enzyme systems of microbes (Latapi, 2006). Presences of microbes in the dried products show that it is possible for microbes to survive the drying conditions. This has been associated with the presence of many compounds in vegetables such as carboxylic acid, amino acids, sugars and sucrose that promote microbial survival (Li *et al*., 2016).

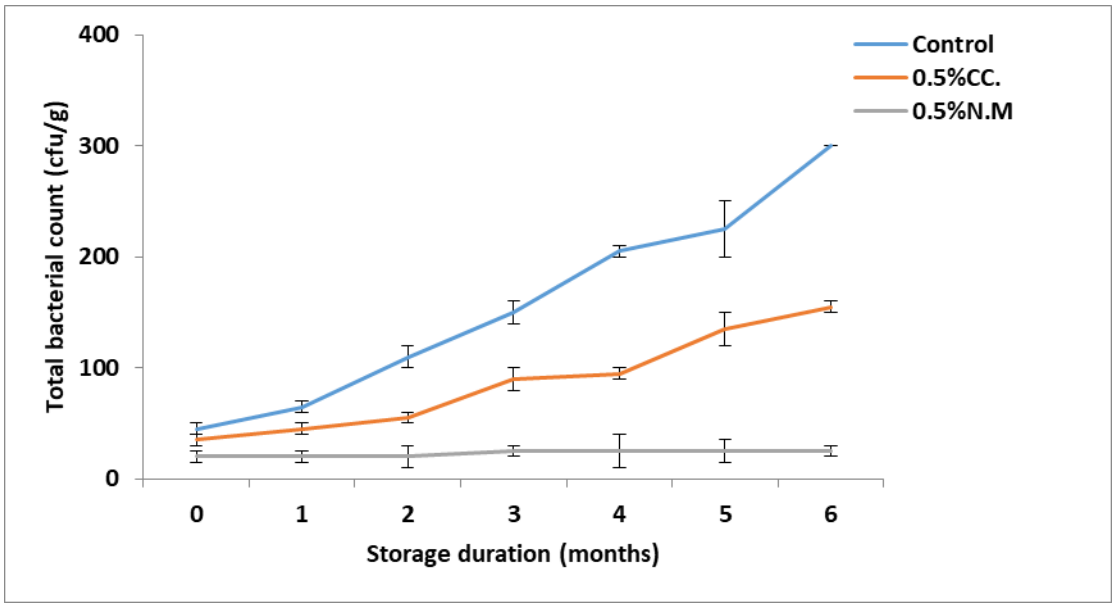


Figure 4.22: Effect of pretreatment on the total bacterial count in vacuum-oven dried tomato samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

c) Effect of pretreatment during solar drying on the bacterial growth during storage

In the solar dried tomatoes (Figure 4.23), the initial bacterial load in the pretreated samples was lower (3.0×10^1-8.5×10^1 cfu/g) as compared to the control (11.0×10^1 cfu/g). However, bacterial count in the control and 0.5% C.C samples was not significantly different ($P>0.05$) at onset, first ($P>0.05$) and second months ($P>0.05$) of storage. This implies that the stress effect of 0.5% C.C did not significantly lower microbial growth more, from onset to second month of storage when compared with the control. Lower bacterial counts (<13cfu/g) were reported by Isiaka, (2013) after solar drying of 15-25mm tomato flakes. It is possible that the lower count may be due to reduced drying time in drying of flakes as compared to quarters as was the case in this study. Shorter drying time retards activities of bacteria in foods (Victor *et al*., 2017). Elsewhere, mesophilic bacterial counts >2cfu/g have been reported in solar dried (indirect drying) Roma tomatoes (Li *et al*., 2016). A significant difference in the bacterial levels from

second to sixth months of storage in this study was observed in the control, 0.5% C.C and 0.5%N.M. At the end of the storage period maximum bacterial growth reached 49.0×10^1, 21.5×10^1 and 6.0×10^1 cfu/g in the control, 0.5% C.C and 0.5% N.M respectively. This shows that samples pretreated with 0.5%N.M may be safer than the control and 0.5%C.C samples. Generally, solar dried tomatoes recorded a higher bacterial load (6.0×10^1-49.0×10^1 cfu/g) at the end of the drying process as compared to the other drying methods applied (2.5×10^1-37.5×10^1 cfu/g). This may be due to possible higher contamination from the drying air during solar drying. Solar dried foods have been found to have a higher microbial population due to exposure to wind, insects and dust (Li *et al*., 2016). Also the drying process was slow (5days) and thus increased the chances of microbial contamination. The fall of temperatures at night may have also allowed bacterial growth to continue before the samples were fully dried (Li *et al*., 2016). Therefore microbial proliferation was possible at night after a daytime of heat stress.

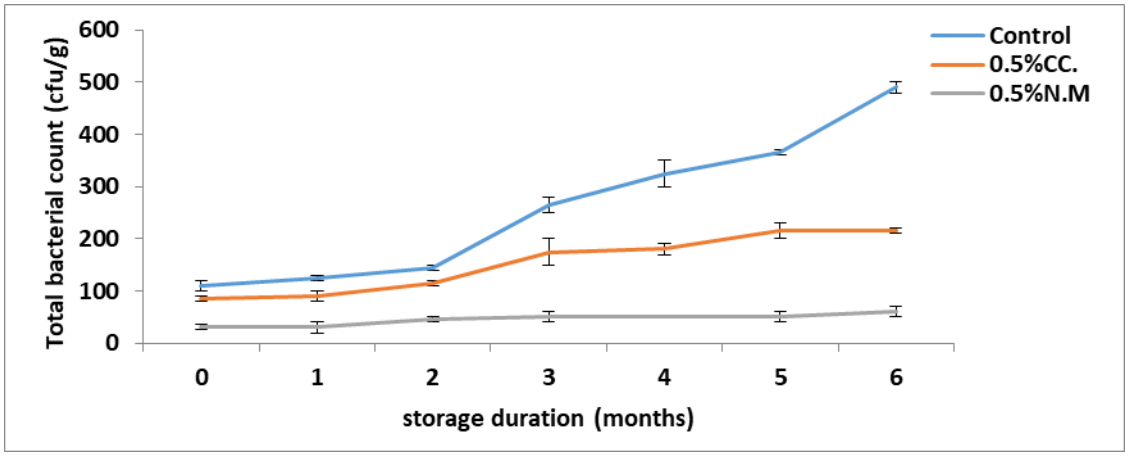


Figure 4.23: Effect of pretreatment on the total bacterial count in solar dried samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

d) Effect of pretreatment during freeze drying on the bacterial growth during storage

Bacterial growth progression during storage in freeze dried samples is shown in figure 4.24. Interaction effect between storage duration and the pretreatment applied was significant for total bacterial count ($P<0.05$). Although during freeze drying cells are frozen and dried (Li *et al*., 2016), bacteria survival was observed after the drying process The initial bacterial levels in the control and 0.5% C.C did not differ significantly ($P>0.05$) as well as between 0.5%C.C and 0.5%N.M ($P>0.05$) at onset. The lowest initial bacterial counts at 0 months were observed in the 0.5% N.M (2.0×10^1cfu/g) while the highest (7.5×10^1cfu/g) were observed in the control samples. During the six months storage duration the bacteria levels in the 0.5% N.M samples remained relatively low reaching maximum levels of 4.0×10^1cfu/g at the end of the storage period. However, in the 0.5% C.C samples, a slower increase in bacterial growth compared to the control was observed. In this case, a two fold increase in bacterial growth representing 19.5×10^1 cfu/g was noted at the end of the six month storage period in 0.5% C.C. On the contrary, a higher bacterial level was observed in the control samples as compared to the pretreated samples. These results suggest that pretreatment during freeze drying with 0.5% N.M and 0.5% C.C was more detrimental to bacteria than in the control in freeze dried tomatoes. The lower bacterial count in the pretreated samples may be associated with the wash out effect experienced during sample pretreatment. It has been reported that microbial reduction during osmotic pretreatment is associated with the wash out effect during pretreatment of the samples (Li *et al*., 2016). In addition use of salts has been associated with antimicrobial effect in dried tomatoes. Salts inactivate enzymes systems that are important to the cell, therefore slowing or stopping microbial growth (Latapi, 2006). In this case, bacterial levels reached a maximum of 36.0×10^1 cfu/g in the control at the end of the storage period. Generally an increase in bacterial count as storage progressed was observed in all the dried samples. It is possible that as storage progressed, the conditions for bacterial growth became more favorable. Victor *et al*.

(2017), mentions that microbial growth increases when favorable environment for their growth such as water and adaptation to the environment is attained.

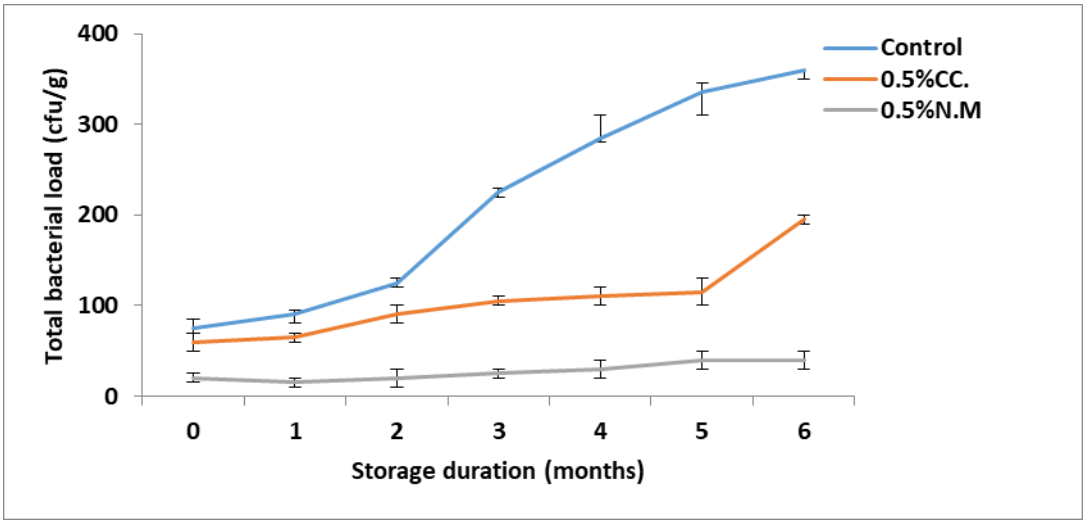


Figure 4.24: Effect of pretreatment on the total bacterial count in freeze dried tomato samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

2) Effect of pretreatment during drying on the total fungal growth

Figure 4.25, 4.26, 4.27 and 4.28 shows total fungal counts in pretreated tomatoes after oven-air, vacuum-oven, solar and freeze drying, respectively .Generally, fungal growth was found to be present in all the dried samples irrespective of the drying method and pretreatment applied. However, the total fungal counts generally remained below the allowable limit (100 cfu/g) (KEBS, 2018) set by the Kenya Bureau of standards for dried fruits during the first three months storage duration in all the dried samples.

a) **Effect of pretreatment during oven-air drying on the fungal growth during storage**

The total fungal count during oven-air drying is shown in Figure 4.25. ANCOVA analysis showed that the interaction effect between pretreatment and storage duration was significant ($P<0.05$). At onset, the total fungal count was 4.5×10^1, 2.5×10^1 and 1×10^1cfu/g in the control, 0.5% C.C and 0.5%N.M, respectively. This shows that the total fungal count in the pretreated samples were significantly lower in the pretreated samples as compared to the control. Metabisulphate and calcium chloride have been reported to have antimicrobial effect on the growth of fungi (Chaethong *et al*., 2012; Latapi, 2006). These compounds alter the cellular integrity of microbes therefore causing slowed multiplication and fungal death. In a another study, oven-air dried tomatoes were found to contain 1.0×10^1-3.0×10^1 cfu/g total fungal count immediately after drying (Adejo *et al*., 2015). At the end of the storage period, the fungal counts in the samples in this study averaged 14.0×10^1, 7.0×10^1 and 3.0×10^1 cfu/g in the control, 0.5% C.C and 0.5%N.M respectively. In this case a higher level of fungal count was observed in the control as compared to the pretreated samples. This shows that the pretreated samples exhibited better fungicidal effect as compared to the control. It was also observed that despite the low moisture content (13%) in the oven-air dried samples, fungal growth was observed in all the oven-air dried samples. It has been reported that fungi are able to grow under conditions of low water content (Njoroge *et al*., 2015). Therefore, progression of fungal growth during storage may largely be influenced by pretreatment applied to the samples before drying (Latapi, 2006).

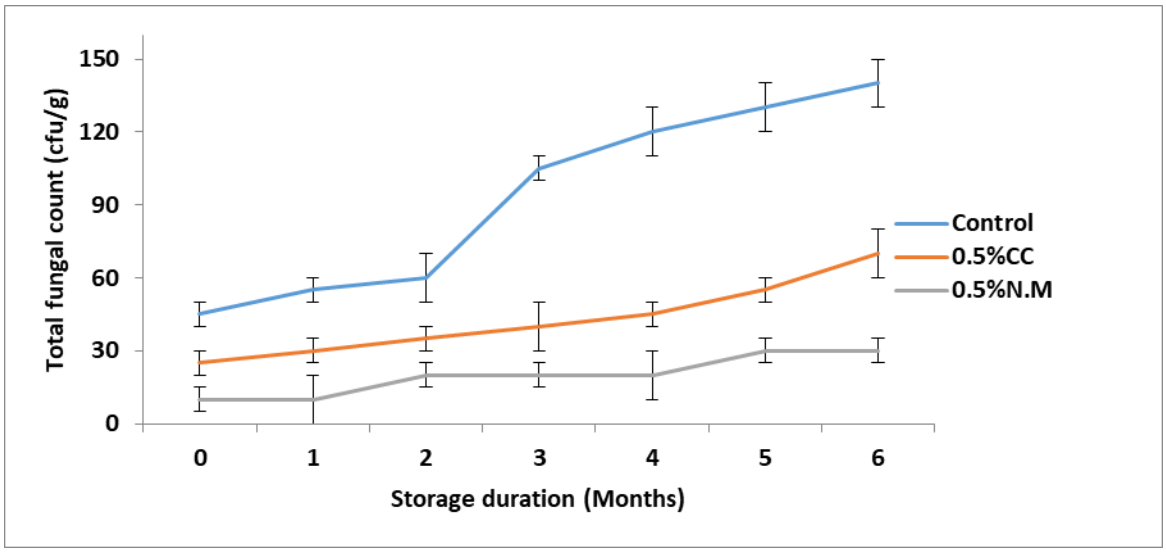


Figure 4.25: Effect of pretreatment on the total fungal count in oven-air dried tomato sample stored at 25°C for 6months. Plotted data are mean values ± standard error of three replicates.

b) Effect of pretreatment during vacuum-oven drying on the fungal growth during storage

Figure 4.26 shows the total fungal counts in the vacuum-oven dried samples over six months of storage. It was generally observed that fungal count increased with storage time in all the pretreatments and the control applied. This indicates that as storage progressed, favorable conditions for fungal growth were available. It has been reported that fungal proliferation continues during storage (Ghamdi *et al*., 2019) when conditions for growth become favorable (Li *et al*., 2016). ANCOVA analysis showed that the interaction effect between pretreatment and storage months was significant ($P<0.05$). At the initial stage (0 months), the fungal load varied significantly between the control and the 0.5%N.M samples ($P<0.05$). The presence of fungal counts in the dried samples indicates that drying is not lethal enough for the growth of fungi (Li *et al*., 2016). During the second, third and fourth months of storage, the fungal counts in the 0.5% C.C and 0.5 % N.M did not differ significantly and ranged 2.5×10^1-3.5×10^1 and 1.5×10^1 -

2.5×10^1 cfu/g in the respective pretreatments. This shows that anti fungicidal effect in the 05%C.C and 0.5%N.M pretreatment was similar in both pretreatments between second and fourth months of storage. Therefore, the rate of fungal growth was similar. In the fifth and sixth months of storage, the counts varied significantly between the control and the pretreated samples reaching a maximum of 12.5×10^1, 8.5×10^1 and 2.5×10^1 cfu/g in the control, 0.5% C.C and 0.5%N.M, respectively at the end of the storage period. Therefore, higher fungal counts were observed in the control as compared to the pretreated samples. It is possible that fungal growth was inhibited by 0.5%C.C and 0.5% N.M as a result lower total fungal count was observed during storage. It has been reported that calcium chloride produce calcification that strengthens cell wall thus causing tissue resistance hence reduced fungal growth (Prakash *et al*., 2007). In addition sulphites have antimicrobial effect in foods thus limiting fungal growth (Sarkar *et al*., 2015). The fungal count at the end of storage indicates that shelf life of tomatoes may depend on the pretreatment applied during drying (Camargo *et al.*, 2010). From the final fungal count, it is evident that pretreatment limits fungal growth better than the control in vacuum-oven dried tomatoes. In addition, shorter drying period observed in the pretreated samples (Table 4.2) as compared to the control may have resulted in reduced fungal count. Growth of microbes in foods is lowered under shorter periods of drying (Li, 2016). Also, pretreatment may have offered better antimicrobial effect than the control.

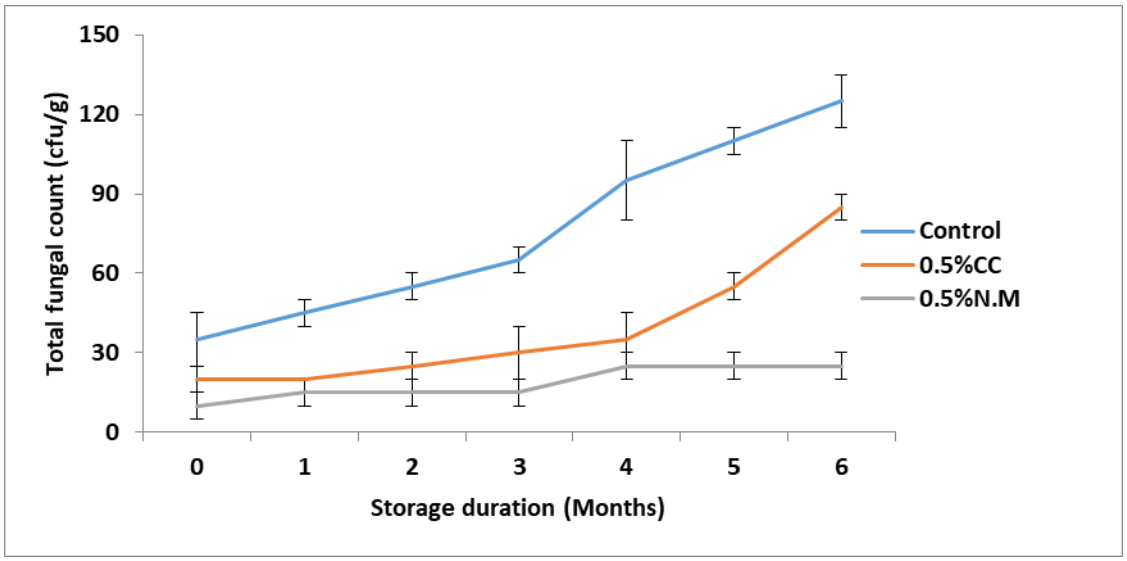


Figure 4.26: Effect of pretreatment on the total fungal count in vacuum-oven dried samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

c) **Effect of pretreatment during solar drying on the fungal growth during storage**

The results of total fungal counts in solar dried samples during storage are presented on Figure 4.27. In solar dried samples, ANCOVA results showed that the interaction effect between storage duration and pretreatment was significant ($P<0.05$). At onset, the total fungal count in the control was significantly higher than the pretreated samples ($P<0.05$). The presence of fungal counts after solar drying (0 months) indicate that heat and UV radiation during solar drying only induced a limited inactivation of microbes. Fungal growth (<10cfu/g) has also been reported in sun dried tomatoes before storage (Latapi & Barrett, 2006). From the first to the fifth month of storage, the counts in the control and 0.5% C.C did not differ significantly. This shows that antimicrobial effect of pretreatment with 0.5% calcium chloride did not have any significant difference from the control. However, throughout the entire storage period the fungal counts in

0.5%N.M were the lowest (<5.0×10^1cfu/g) while the control presented the highest counts (<17.5×10^1 cfu/g). At the end of the sixth month, counts in 0.5% C.C reached a maximum of 12.5×10^1 cfu/g. This indicates that samples pretreated with sodium metabisulphate had the lowest fungal growth as compared to the control and 0.5%C.C pretreatment. Therefore, 0.5%N.M pretreated samples would have a longer shelf life as compared to the control and 0.5%C.C samples. It was also observed that the final counts were higher in solar dried samples than in the other drying methods (2.5×10^1-15.0×10^1 cfu/g) in this study. This was indicative of possible higher contamination levels during solar drying from the environment as compared to the other drying methods. In a separate study, lower fungal growth (<0.8 ×10^1 cfu/g) has been reported in solar drying tomato flakes (Isiaka, 2013). Increase of fungal growth with storage has also been reported by (Latapi & Barrett, 2006) in pretreated tomato samples after solar drying.

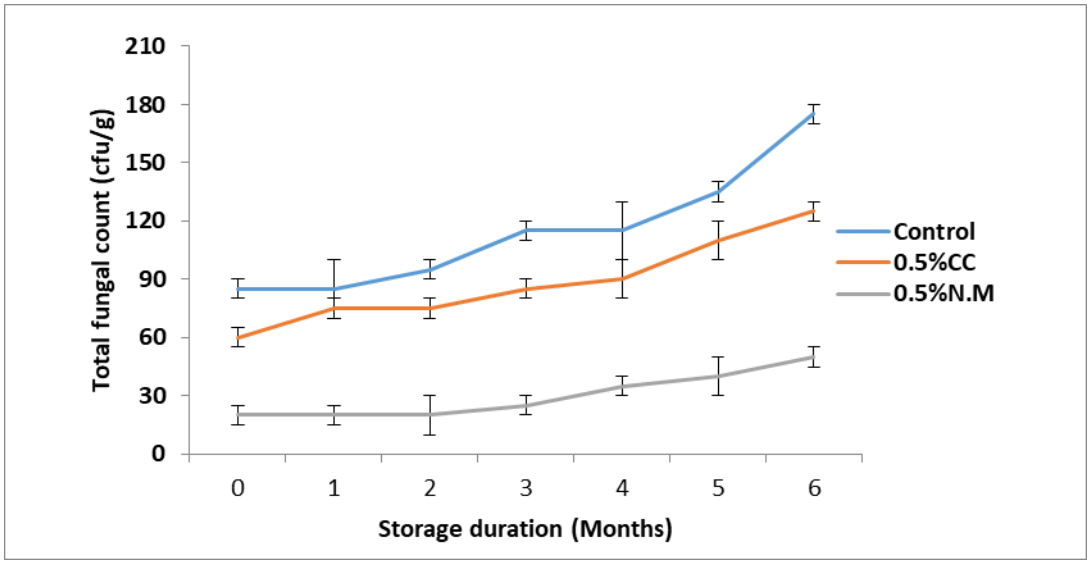


Figure 4.27: Effect of pretreatment on the total fungal count in pretreated tomato samples stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

d) Effect of pretreatment during freeze drying on the fungal growth during storage

The progression of total fungal growth in freeze dried samples during storage is shown in Figure 4.28. ANCOVA analysis showed that the interaction effect between storage duration and pretreatment was significant ($P<0.05$). At onset, the fungal load in the control and the 0.5%C.C did not differ significantly ($P>0.05$). This phenomenon was also observed in the first, second and third months of storage where fungal infection levels in the control (6.5×10^1-9.5×10^1cfu/g) and 0.5%C.C (5.5×10^1-9.0×10^1 cfu/g) were not significantly different ($P>0.05$). This shows that fungicidal effect of 0.5%C.C and the control from 0 to third month of storage was not significantly different. It is possible that the fungi were able to survive, grow and multiply in the presence of calcium chloride. On the contrary, the fungal levels in 0.5%N.M remained unchanged from onset to the second month (1.5×10^1 cfu/g). This indicates that 0.5%N.M pretreatment best prevented fungal growth during storage in freeze dried samples. At the end of the storage period, the lowest fungal levels (3.0×10^1 cfu/g) in the freeze dried were observed in the 0.5% N.M samples while the highest levels were in the control (15.0×10^1 cfu/g). Intermediated levels were observed in the 0.5%C.C (12.0×10^1 cfu/g). However, the final fungal counts in the control and 0.5% C.C were not significantly different ($P>0.05$). This demonstrated that the growth conditions were less conducive for fungal growth in the 0.5% N.M samples as compared to the other treatments. Therefore, better microbial quality than in the control and 0.5% C.C.

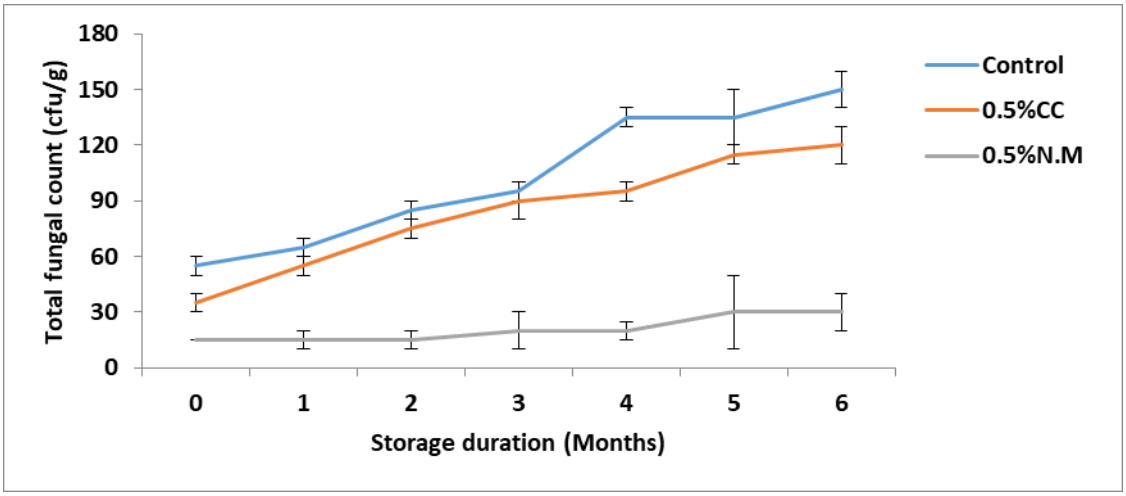


Figure 4.28: Effect of pretreatment on the total fungal count in pretreated tomato samples after freeze drying and stored at 25°C for 6 months. Plotted data are mean values ± standard error of three replicates.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Dehydration is a common method of preservation. However, due to detrimental changes associated with heat, pretreatment of tomato quarters before drying provide a better addition to drying so as to achieve dried tomato products of better quality. In this study, the initial moisture content in the fresh tomato varieties studied ranged between 94.2-94.6%. Treated Riogrande samples dried at 70°C and pretreated with 0.5% sodium metabisulphate took the shortest drying time while the control samples dried at 50°C in Anna F1 took the longest time to achieve stable moisture content (13%) after oven-air and vacuum-oven drying.

Lycopene content, β-carotene and total phenolic was best preserved in Riogrande accompanied with 0.5%sodium metabisulphate pretreatment after oven air, vacuum-oven, solar and freeze drying. In addition, maximum retention of lycopene content, β-carotene and total phenolic was observed after freeze drying in all the varieties studied. However, during freeze drying the effect of pretreatment on total phenolics, lycopene and β-carotene was not significant in enhancing better retention in the four varieties studied. Maximum retention of total phenolic compounds, lycopene and β-carotene phenolics was observed at 70, 60 and 50°C, respectively after oven-air and vacuum-oven drying. Ascorbic acid was only present in the freeze dried samples and absent in the samples that were oven-air, solar and vacuum-oven dried.

Salmonella and *Escherichia.coli* were found to be absent in all the dried tomato samples during the entire storage duration. The total fungal and bacterial count growth during storage followed the order: 0.5%N.M<0.5%C.C<control. From this study it was observed that pretreatment before drying of tomatoes may be used as a technique to

prevent postharvest losses, ensure maximum shelf stability and quality of tomatoes grown in Kenya.

5.2 Recommendations

1. Since dried tomatoes may be stored for several months on the shelf before consumption, further research is needed to establish the effect of storage time on the antioxidants, rehydration and color quality of pretreated tomatoes.
2. Cost analysis of the different drying methods and pretreatment in tomatoes will help in making of appropriate economic decisions during tomato drying.

REFERENCES

Abano, E. E., Ma., H., & Qu, W. (2011). Influence of Air Temperature on the Drying Kinetics and Quality of Tomato Slices. *Journal of Food Processing & Technology*, *2*(5), 1–9.

Adams, S. R. (2015). The effect of periods of high temperature and manipulating fruit load on the pattern of tomato yields. *The Journal of Horticultural Science and Biotechnology*, *77*(4), 461–466.

Adams, S. R., & Fenlon, J. S. (2015). The impact of changing light levels and fruit load on the pattern of tomato yields. *The Journal of Horticultural Science and Biotechnology*, *76*(3), 368–373.

Addo, J. K., Osei, M. K., Mochiah, M. B., Bonsu, K. O., Choi, H. S., & Kim, J. G. (2015). Assessment of farmer level postharvest losses along the tomato value chain in three agro-ecological zones of Ghana. *International Journal of Research In Agriculture and Food Sciences*, *2*(9), 15–23.

Adejo, G. O., Agbali, F. A., & Otokpa, O. S. (2015). Antioxidant , Total Lycopene , Ascorbic Acid and Microbial Load Estimation in Powdered Tomato Varieties Sold in Dutsin-Ma Market. *Open Access Library Journal*, *2*, 1–7.

Agar, I. T., & Sabir, K. F. (2011). Effects of 1-Methylcyclopropene and Modified Atmosphere Packing on Postharvest Life and Quality in Tomatoes. *Journal of Food Quality*, *34*(2), 111–118.

Aguayo, E., Escalona, V., & Artes, F. (2004). Quality of fresh-cut tomato as affected by type of cut , packaging , temperature and storage time. *European Food Research and Technology*, *219*(4), 492–499.

Aherne, S. A., Jiwan, M. A., Daly, T., & Brien, N. M. O. (2009). Geographical Location

has Greater Impact on Carotenoid Content and Bioaccessibility from Tomatoes than Variety. *Plant Foods for Human Nutrition*, *64*(4), 250–256.

Ahmed, F., Islam, Z., Sarker, S. H., & Hasan, S. M. K. (2016). Development and Performance Study of Controlled Atmosphere for Fresh Tomato. *World Journal of Engineering and Technology.*, *4*, 168–175.

Ahmed, M., Sorifa, A. M., & Eun, J. B. (2010). Effect of pretreatments and drying temperatures on sweet potato flour. *International Journal of Food Science & Technology*, *45*, 726–732.

Aidoo, R., Danfoku, R. A., & Mensah, J. O. (2014). Determinants of postharvest losses in tomato production in the Offinso North district of Ghana. *Journal of Development and Agricultural Economics*, *6*(8), 338–344.

Ainsworth, E. A., & Gillespie, K. M. (2007). Estimation of total phenolic content and other oxidation substrates in plant tissues using Folin – Ciocalteu reagent. *Nature Protocols*, *2*, 875–877.

Akbarian, M., Ghasemkhani, N., & Moayedi, F. (2014). Osmotic dehydration of fruits in food industrial. *International Journal of Biosciences*, *6655*, 42–57.

Akhtar, A., Abbasi, N. A., & Hussain, A. (2010). Effect of Calcium Chloride Treatments on Quality Characteristics of Loquat Fruit During Storage. *Pakistan Journal of Botany*, *42*(1), 181–188.

Aldrich, H. T., Salandanan, K., Kendall, P., Stushnoff, C., Bunning, M., Stonaker, F., & Oktay, K. (2010). Cultivar choice provides options for local production of organic and conventionally produced tomatoes with higher quality and antioxidant content. *Journal of the Science of Food and Agiculture*, *90*(15), 2548–2555.

Alibas, I. (2009). Microwave, vacuum, and air drying characteristics of collard leaves.

Drying Technology, *27*(11), 1266–1273.

An, K., Li, H., Zhao, D., Ding, S., Tao, H., An, K., … Wang, Z. (2013). Effect of Osmotic Dehydration with Pulsed Vacuum on Hot-Air Drying Kinetics and Quality Attributes of Cherry Tomatoes. *Drying Technology An*, *31*(6), 698–706.

Andrés, A., Fito, P., Heredia, A., Rosa, E. M., Fito, P., Heredia, A., … Andre, A. (2007). Combined Drying Technologies for Development of High-Quality Shelf-Stable Mango Products. *Drying Technology ISSN:*, *25*(11), 1857–1866.

Andrew, I., Ormerod, P., Gb, B., Ralfs, J. D., & Michael, C. (2004). Freezing Vegetables. United States.

Antal, T. (2015). Comparative study of three drying methods : freeze , hot air- assisted freeze and infrared-assisted freeze modes. *Agronomy Research*, *13*(4), 863–878.

Anthon, G. E., & Barrett, D. M. (2011). Changes in pH , acids , sugars and other quality parameters during extended vine holding of ripe processing tomatoes. *Journal of the Science of Food and Agiculture*, *91*(7), 1175–1181.

Appliqu, B., Appliqu, B., & Appliqu, B. (2014). Antioxidant Activity of Eight Tomato (Esculentum L.) Varieties Gown in Algeria. *Journal of Food Technology Research*, *1*(3), 133–145.

Ara, N., Bashar, M. K., Begum, S., & Kakon, S. S. (2007). Effect of spacing and stem pruning on the growth and yield of tomato. *International Journal of Sustainable Crop Production*, *2*(3), 35–39.

Arah, I. (2015). An overview of post-harvest challenges facing tomato production in Africa. In *Diversity and Development* (pp. 1–21).

Arah, I. (2015). An Overview of Post-Harvest Losses in Tomato Production in Africa : Causes and Possible Prevention Strategies. *Journal of Biology, Agriculture and*

Healthcare, *5*(16), 78–88.

Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K., & Amaglo, H. (2016). Postharvest Handling Practices and Treatment Methods for Tomato Handlers in Developing Countries. *Advances in Agriculture*, *2016*, 1–8.

Arah, I. K., Amaglo, H., Kumah, E. K., & Ofori, H. (2015). Preharvest and Postharvest Factors Affecting the Quality and Shelf Life of Harvested Tomatoes. *International Journal of Agronomy*, *6*, 1–6.

Arun, S., Ayyappan, S., & Sreenarayanan, V. V. (2014). Experimental and Comparison Studies on Drying Characteristics of Sliced Cut Tomatoes and Cube Cut Tomatoes. *International Journal of Recent Technology and Engineering*, *internatio*(4), 25–31.

Association of Official Analytical Chemists. (2000). *Official Methods of Analysis*. Arlington,VA,USA.

Athanasia, G., & Konstantinos, A. (2010). Kinetic Models of β-Carotene Degradation During Air Drying of Carrots. *Drying Technology*, *28*(6), 752–761.

Ayandiji, A, O. R., Adeniyi, Omidiji, D. (2011). Determinant Post Harvest Losses among Tomato Farmers in Imeko-Afon Local Government Area of Ogun State, Nigeria. *Global Journal of Science Frontier Research*, *11*(5), 23–28.

Azevedo, V. F. De. (2010). Row Spacing and Pruning Regimes on Organically Grown Cherry Tomato. *Horticultura Brasileira*, *28*(4), 389–394.

Azoubel, M., & Oliveira, F. (2008). Optimisation of osmotic dehydration of “Tommy Atkins” mango fruit. *International Journal of Food Science and Technology*, *43*, 1276–1280..

Bala, S. J. B. K. (2012). Solar Drying Technology. *Food Engineering Reviews*, *4*, 16–54.

Barba, A. I. O., & Ferna, V. (2006). Application of a UV – vis detection-HPLC method for a rapid determination of lycopene and β-Carotene in vegetables. *Food Chemistry*, *95*, 328–336.

Barrett, D. M., Lloyd, B., Barrett, D. M., & Lloyd, B. (2012). Advanced preservation methods and nutrient retention in fruits and vegetables. *Journal of Food Science and Agriculture*, *92*, 7–22.

Bayili, R. G., Bayili, R. G., Abdoul-latif, F., Kone, O. H., Diao, M., & Imael, H. (2011). Phenolic compounds and antioxidant activities in some fruits and vegetables from Burkina Faso. *African Journal of Biotechnology*, *10*(62), 13543–13547.

Beckles, D. (2012). Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. *Postharvest Biology and Technology*, *63*, 129–140.

Ben-gal, A., & Shani, U. (2002). Yield , transpiration and growth of tomatoes under combined excess boron and salinity stress. *Plant and Science*, *247*(2), 211–221.

Ben-oliel, G., Kant, S., Naim, M., Rabinowitch, H. D., Gary, R., Buttery, R. G., … Gary, R. (2005). Effects of Ammonium to Nitrate Ratio and Salinity on Yield and Fruit Quality of Large and Small Tomato Fruit Hybrids. *Journal of Plant Nutrition*, *27*(10), 1795–1812.

Bertin, B. N., Buret, M., & Gary, C. (2015). Insights into the formation of tomato quality during fruit development. *The Journal of Horticultural Science and Biotechnology*, *76*(6), 786–792.

Bertin, N. (2005). Analysis of the Tomato Fruit Growth Response to Temperature and Plant Fruit Load in Relation to Cell Division , Cell Expansion and DNA Endoreduplication. *Annals of Botany 95:*, *95*, 439–447.

Bico, S. L. S., Raposo, M. F. J., Morais, R. M. S. C., & Morais, A. M. M. B. (2009). Combined effects of chemical dip and / or carrageenan coating and / or controlled atmosphere on quality of fresh-cut banana. *Food Control*, *20*, 508–514.

Boon, C. S., Mcclements, D. J., Weiss, J., Decker, E. A., Boon, C. S., Mcclements, D. J., … Weiss, J. (2010). Factors Influencing the Chemical Stability of Carotenoids in Foods. *Critical Reviews in Food Science and Nutrition*, *50*(6), 515–532.

Boonkasem, P., Sricharoen, P., Techawongstein, S., & Chanthai, S. (2015). Determination of Ascorbic Acid and Total Phenolics Related to The Antioxidant Activity of Some Local Tomato (Solanum lycopersicum) varieties. *Der Pharma Chemica*, *7*(4), 66–70.

Botineștean, C., Hădărugă, N. G., Hădărugă, D. I., & Jianu, I. (2012). Fatty acids composition by gas chromatography-mass spectrometry (GC-MS) and most important physical-chemicals parameters of tomato seed oil. *Journal of Agroalimentary Processes and Technologies*, *18*(1), 89–94.

Brooks, M. S., Abou El-Hana, N. H., & Ghaly, A. E. (2008). Effects of tomato geometries and air temperature on the drying behavior of plum tomato. *American Journal of Applied Sciences*, *5*(10), 1369–1375.

Camargo, G. A., Grillo, S. L. M., Mieli, J., & Moretti, R. H. (2010). Shelf Life of Pretreated Dried Tomato. *Food and Bioprocess Technology*, *3*, 826–833.

Capanoglu, E., Beekwilder, J., Boyacioglu, D., Vos, R. C. H. De, Hall, R. D., Capanoglu, E., … Vos, R. C. H. De. (2010). The Effect of Industrial Food Processing on Potentially Health-Beneficial Tomato Antioxidants. *Critical Reviews in Food Science and Nutrition*, *15*(10), 919–930.

Catalano, P., Fucci, F., Giametta, F., Penna, A. La, & Fianza, G. La. (2013). Experimental System and Tests to Optimize a Tomato Drying Process. *The Open*

Agriculture Journal, *7*, 73–79.

Cesare, L. F. D. I., Migliori, C., Viscardi, D., Parisi, M., Unità, C. R. A. A. A., & Venezian, V. G. (2010). Quality of tomato fertilized with nitrogen and phosphorus. *Italian Journal of Food Science*, *22*(2), 186–192.

Chaethong, K., Tunnarut, D., & Pongsawatmanit, R. (2012). Quality and Color Parameters of Dried Chili and Chili Powder Pretreated by Metabisul fi te Soaking with Different Times and Concentrations. *Kasetsart Journal of Natural Sciences*, *46*, 473–484.

Chaignon, V., Bedin, F., & Hinsinger, P. (2002). Copper Bioavailability and Rhizosphere pH Changes as Affected by Nitrogen Supply for Tomato and Oilseed Rape Cropped on an Acidic and a Calcareous Soil. *Plant and Soil*, *243*, 219–228.

Charles, Ni., Jude, O., Obiegbuna, J., & Ezike, T. (2014). Effect of Thermal Processing on Lycopene, beta-carotene and vitamin C Content of Tomato [Var . UC82B]. *Journal of Food and Nutrition Sciences*, *2*(3), 87–92.

Chauhan, K., Sharma, S., Agarwal, N., & Chauhan, B. (2011). Lycopne of Tomato Fame : Its Role in Health and Disease. *International Journal of Pharmaceutical Sciences Review and Research*, *10*(1), 99–115.

Chawla, C., Kaur, D., Oberoi, D. P. S., Sogi, D. S., Chawla, C., Kaur, D., … Sogi, D. S. (2008). Drying Characteristics , Sorption Isotherms , and Lycopene Retention of Tomato Pulp. *Drying Technology*, *26*(10), 1257–1264.

Chen, C. H. L. B. H. (2005). Stability of carotenoids in tomato juice during processing. *European Food Research Technology*, *221*, 274–280.

Dadalı, G., Kılıç Apar, D., & Özbek, B. (2007). Color Change Kinetics of Spinach Undergoing Microwave Drying. *Drying Technology*, *25*(5), 925–936.

Dalben, C., Campos, M., Carla, A., Sato, K., & Tonon, R. V. (2012). Effect of Process Variables on the Osmotic Dehydration of Star-fruit Slices. *Ciência E Tecnologia de Alimentos*, *32*(2), 357–365.

Dauda, A., Abiodun, O., Salami, T., & Akintayo, O. (2019). Chemical and Microbiological Evaluation of Dried Tomato slices for Nigerian System. *Global Journal of Nutrition & Food Science*, *1*(5), 1–4.

Demiray, E., Tulek, Y., & Yilmaz, Y. (2013). Degradation Kinetics of Lycopene, β-Carotene and Ascorbic acid in Tomatoes During Hot Air Drying. *Food Science and Technology*, *50*(1), 172–176.

Demırhan, E., & Özbek, B. (2011). Color Change Kinetics of Celery Leaves Undergoing Microwave Heating. *Chemical Engineering Communications*, *198*(10), 1189–1205.

Dipak kumar paul, R. K. S. (2004). Nutrients, Vitamins and Minerals Content in Common Citrus Fruits in the Northern Region of Bangladesh. *Pakistan Journal of Biological Sciences*, *7*, 238–242.

Djamel, F., Miloud, L., Houcine, B., & Samir, M. (2009). Effect of osmotic dehydration on the freeze drying kinetics of apricots. *Journal of Food Agriculture and Environment*, *7*(2), 117–121.

Dorais, M., Ehret, Æ. D. L., & Papadopoulos, Æ. A. P. (2008). Tomato (Solanum lycopersicum) health components : from the seed to the consumer. *Phytochemistry Reviews*, *7*, 231–250.

Doymaz, B. (2014). Mathematical Modelling Of Drying of Tomato Slices. *Journal of Food Processing and Preservation*, *38*, 389–396.

Dumas, Y., Dadomo, M., Lucca, G. Di, & Grolier, P. (2003). Effects of Environmental Factors and Agricultural Techniques on Antioxidant Content of Tomatoes. *Journal*

of the Science of Food and Agriculture, *83*, 369–382.

Eldahshan, O. A., & Singab, A. N. B. (2013). Carotenoids. *Journal of Pharmacognosy and Phytochemistry*, *2*(1), 225–234.

Elkhodiry, M. A., Suwaidi, S. R., Taheri, M., Elwalid, H., Elbaba, D., & Qasim, M. (2015). Drying Kinetics of Eggplant (Solanum melongena) in a Fluidized Bed Dryer : Experimental Evaluation and Modelling. *Journal of Food Processing*, 1–10.

Emana, B., Sefa, V. A., Nenguwo, N., Ayana, A., Kebede, D., & Mohammed, H. (2017). Characterization of pre - and postharvest losses of tomato supply chain in Ethiopia. *Agriculture & Food Security*, *6*(3), 1–11.

Faisal, S., Tabassum, R., & Kumar, V. (2013). Performance Evaluation and Process Optimization of Potato Drying using Hot Air Oven. *Journal of Food Processing and Technology*, *4*(10), 2–9.

Fanasca, S., Martino, A., Heuvelink, E., & Stanghellini, C. (2007). Effect of electrical conductivity, fruit pruning, and truss positionon quality in greenhouse tomato fruit. *Journal of Horticultural Science and Biotechnolgy*, *82*(3), 488–494.

FAOSTAT. (2014). *Global tomato production in 2012*. Rome, Italy. Retrieved from http://www.faostat.org

Fernández-garcí, N., Martínez, V., Cerdá, A., & Carvajal, M. (2004). Fruit quality of grafted tomato plants grown under saline conditions. *The Journal of Horticultural Science and Biotechnology*, *79*(6), 995–1001.

Flores, P., Carvajal, M., Cerdá, A., & Martínez, V. (2001). Salinity and Ammonium/Nitrate Interactions on Tomato Plant Development,Nutrition and Metabolites. *Journal of Plant Nutrition*, *24*(10), 1561–1573.

Food and Agriculture Organisation(FAO). (2012). *statistical database*. Retrieved from

http://www.faostat.org

Food and Agriculture Organisation(FAO). (2018). *Post-harvest management of tomato for quality and safety assurance. Guidance for horticultural supply chain stakeholders*.

Foolad, M. R. (2004). Recent Advances in Genetics of Salt Tolerance in Tomato. *Plant Cell Tissue and Organ Culture*, *76*(2), 101–119.

Freeman, B. B., & Reimers, K. (2010). Tomato Consumption and Health : Emerging Benefits. *American Journal of Lifestyle Medicine*, 1–10.

Gagliardi, J. V, & Karns, J. S. (2002). Persistence of Escherichia coli O157 : H7 in soil and on plant roots. *Environmental MIcrobiology*, *4*(2), 89–96.

Garcia, E., & Barrett, D. M. (2006). Evaluation of Processing Tomatoes From Two Consequtive Growing Seasons: Quality Attributes, Peelability and Yield. *Journal of Food Processing and Preservation*, *30*(1), 20–36.

Gari, Y. (2010). Drying Kinetics of Tomato Slices in Solar Cabinet Dryer Compared with Open Sun. *Madras Agriculture Journal*, *97*(7–9), 287–295.

Gassem, M. A. A. (2002). A microbiological Study of Sobia : a Fermented Beverage in the Western Province of Saudi Arabia. *World Journal of Microbiology and Biotechnology*, *18*(3), 173–177.

Gaware, T. J., Sutar, N., Thorat, B. N., Gaware, T. J., Sutar, N., & Thorat, B. N. (2010). Drying of Tomato Using Different Methods : Comparison of Dehydration and Rehydration Kinetics. *Drying Technology*, *28*(5), 651–658.

Geoffrey, S. K., Hillary, N. K., Antony, M., Mariam, M., & Mary, M. C. (2014). Challenges and Strategies to Improve Tomato Competitiveness along the Tomato Value Chain in Kenya. *International Journal of Business and Management*, *9*(9),

205–212.

Georgé, S., Tourniaire, F., Gautier, H., Goupy, P., Rock, E., & Caris-veyrat, C. (2011). Changes in the Contents of Carotenoids , Phenolic Compounds and vitamin C During Technical Processing and Lyophilisation of Red and Yellow Tomatoes. *Food Chemistry*, *124*, 1603–1611.

Ghaly, A., Hammouda, A., & Hattab, M. Al. (2015). Biotechnological Advancements Influence of Low Temperature and Geometry on the Drying Behavior and Quality Parameters of Strawberry. *International Journal of Bioprocess & Biotechnological Advancements*, *1*(1), 18–30.

Ghamdi, F. L. Al, Bokhari, F. M., & Aly, M. M. (2019). Toxigenic fungi associated with dried Fruits and fruit-based products collected from Jeddah province. *Journal Of Pharmacy And Biological Sciences*, *14*(1), 10–20.

Gharezi, M., Joshi, N., & Sadeghian, E. (2012). Effect of Post Harvest Treatment on Stored Cherry Tomatoes. *Journal of Nutrition and Food Sciences*, *2*(8), 1–10.

Ghavidel, R. A., & Davoodi, M. G. (2010). Studies on Physiochemical Properties of Tomato Powder as Affected by Different Dehydration Methods and Pretreatments. *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, *4*(9), 700–709.

Gouda, G. P., & Nidoni, U. (2014). Dehydration of Onions with Different Drying Methods. *Current Trends in Technology and Science*, *3*(3), 210–216.

Goula, A. M., Adamopoulos, K. G., Goula, A. M., & Adamopoulos, K. G. (2012). A New Technique for Spray-Dried Encapsulation of Lycopene A New Technique for Spray-Dried Encapsulation of Lycopene. *Drying Technology*, *30*(6), 641–652.

Groot, C. C. D. E., Marcelis, L. F. M., Boogaard, R. vanden, & Lambers, H. (2001).

Growth and Dry-mass Partitioning in Tomato as Affected by Phosphorus Nutrition and Light. *Plant, Cell and Environment*, *24*(12), 1309–1317.

Gruda, N., & Gruda, N. (2005). Impact of Environmental Factors on Product Quality of Greenhouse Vegetables for Fresh Consumption Impact of Environmental Factors on Product Quality. *Critical Reviews in Plant Sciences*, *24*(3), 227–247.

Gümüsay, O. A., Zoran, I. S., Ercal, N., & Demirkol, O. (2015). Drying effects on the antioxidant properties of tomatoes and ginger. *Food Chemistry*, *173*, 156–162.

Hafeznia, M., Mashayekhi, K., Ghaderifar, F., & Javad, S. (2014). Tomato morphological and biochemical characteristics in response to foliar applying of Salicylic acid. *International Journal of Bioscience*, *6655*, 237–243.

Hanson, P. M., Yang, R., Wu, J., Chen, J., Ledesma, D., Tsou, S. C. S., & Lee, T. (2004). Variation for Antioxidant Activity and Antioxidants in Tomato. *Journal of the American Society for Horticultural Science*, *129*(5), 704–711.

Hathan, S. B. K. and B. . (2014). Effect of Blanching and Drying Air Temperature on Quality Characteristics of Beetroot (Beta Vulgaris L .) Leaves Powder. *International Journal of Engineering and Management Research*, *4*(5), 213–219.

Herna, M. (2008). Chemical composition of tomato (Lycopersicon esculentum) from Tenerife , the Canary Islands. *Food Chemistry*, *106*, 1046–1056.

Hii, C. L., Law, C. L., & Cloke, M. (2008). Modelling of Thin Layer Drying Kinetics of Cocoa Beans During Artificial and Natural Drying. *Journal of Food Engineering*, *3*(1), 1–10.

Hong, L. (2014). Isomerisation and degradation of lycopene during heat processing in simulated food system. *International Food Research Journal*, *21*(1), 45–50.

Hossain, M. A., Amer, B. M. A., Gottschalk, K., Hossain, M. A., Amer, B. M. A., &

Gottschalk, K. (2008). Hybrid Solar Dryer for Quality Dried Tomato. *Drying Technology*, *26*(12), 1591–1601.

Hossain, M. A., & Gottschalk, K. (2009). Single Layer Drying Characteristics of Half Fruit Tomato. *International Journal of Food Properties*, *12*(4), 871–884.

Idah, P. A., Musa, J. J., & Abdullahi, M. (2010). Effects of Storage Period on Some Nutritional Properties of Orange and Tomato. *AU Journal of Technology*, *13*(3), 181–185.

Ioannou, I. (2013). Prevention of Enzymatic Browning in Fruit and Vegetables. *European Scientific Journal*, *9*(30), 310–341.

Isack, M. E., & Lyimo, M. (2013). Effect of Postharvest Handling Practices on Physicochemical Composition of Tomato. *Journal of Agricultural Technology*, *9*(6), 1655–1664.

Isiaka, M. (2013). Quality Assessment of Solar Dried Tomato Flakes. *Arid Zone Journal of Engineering, Technology and Environment*, *9*, 1–7.

Jacob, K., Garcia-Alonso, F. J., Ros, G., & Periago, M. J. (2010). Stability of Carotenoids, Phenolic Compounds, Ascorbic acid and Antioxidant Capacity of Tomatoes During Thermal Processing. *Archivos Latinoamericanos de Nutricion*, *60*(2), 192–198.

Joshi, N., Orsat, V., & Raghavan, G. S. V. (2009). Physical Attributes of Different Cuts of Tomatoes during Hot Air Drying. *Fresh Produce*, *3*(1), 32–36.

Kadam, D. M., Rai, D. R., Patil, R. T., Wilson, R. A., Kaur, S., & Kumar, R. (2011). Original article Quality of fresh and stored foam mat dried Mandarin powder. *International Journal of Food Science and Technology*, *46*, 793–799.

Kamiloglu, S., Toydemir, G., Boyacioglu, D., Beekwilder, J., Hall, R. D., & Capanoglu,

E. (2016). A Review on the Effect of Drying on Antioxidant Potential of Fruits and Vegetables. *Critical Reviews in Food Science and Nutrition*, *56*, 110–129.

Karaki, G. N. Al. (2000). Growth , water use efficiency , and sodium and potassium acquisition by tomato cultivars grown under salt stress. *Journal of Plant Nutrition*, *23*(1), 1–8.

Karuku, G. N., Kimenju, J. W., Verplancke, H., Karuku, G. N., Kimenju, J. W., & Verplancke, H. (2016). Farmers â€™ perspectives on factors limiting tomato production and yields in Kabete , Kiambu County , Kenya. *East African Agricultural and Forestry Journal*, *82*(1), 70–89.

Kaya, C., Kirnak, H., Higgs, D., Kaya, C., Kirnak, H., & Higgs, D. (2001). Emhancement of growth and normal growth parameters by foliar application of potassium and phosphorus in tomato cultivars grown at high(NaCl) salinity. *Journal of Plant Nutrition*, *24*(2), 357–367.

Kennedy, J. F. (2007). Optimisation of osmotic dehydration of carrot cubes in sucrose-salt solutions using response surface methodology. *European Food Research and Technology*, *225*, 157–165.

Kenya Bureau of Standards. (2018). *Kenya Standard for Dried fruits -Specifications*.

Kerkhofs, N. S., Lister, C. E., & Savage, G. P. (2005). Change in colour and antioxidant content of tomato cultivars following forced-air drying. *Plant Foods for Human Nutrition*, *60*(3), 117–121.

Khoo, H., Prasad, K. N., Kong, K., Jiang, Y., & Ismail, A. (2011). Carotenoids and Their Isomers: Color Pigments in Fruits and Vegetables. *Molecules*, *16*, 1710–1738.

Koh, J., Kim, Y., & Oh, J. (2010). Chemical Characterization of Tomato Juice

Fermented with Bifidobacteria. *Journal of Food Science*, *75*(5), 428–432.

Koning, D. (2001). Effect of Temperature on the Growth and Development of Tomato Fruits. *Annals of Botany*, *88*, 869–877.

Latapi, G., & Barrett, D. (2006). Influence of Pre-drying treatments on Quality and Safety of Sun-dried Tomatoes . Part II . Effects of Storage on Nutritional and Sensory Quality of Sun-dried Tomatoes Pretreated with Sulfur , Sodium Metbisulfite , or Salt. *Journal of Food S*, *71*(1), 1–6.

Latapi G., B. D. M. (2006). Influence of pre-drying treatments on quality and safety of sun-dried tomatoes. Part II. Effects of storage on nutritional and sensory quality of sun-dried tomatoes pretreated with sulfur, sodium metabisulfite, or salt. *Journal of Food Science*, *71*(1), 32–37.

Lemma, Z., Dawit, W., Negari, M., Chaka, A., & Selvaraj, T. (2014). Identification of post-harvest rotting microorganisms from tomato fruits (Solanum esculentum Mill) in Toke Kutaye District of West Shoa Zone , Ethiopia. *Journal of Stored Products and Postharvest Research*, *5*(3), 14–19.

Lemmens, L., Tchuenche, E. S., Loey, A. M. Van, & Hendrickx, M. E. (2013). Beta-carotene isomerisation in mango puree as influenced by thermal processing and high-pressure homogenisation. *European Food Research and Technology*, *236*, 155–163.

Leonardi, C., Ambrosino, P., Esposito, F., Fogliano, V., Tecnologie, O., Valdisavoia, V., … Gussone, P. (2000). Antioxidative Activity and Carotenoid and Tomatine Contents in Different Typologies of Fresh Consumption Tomatoes. *Journal of Agricultural and Food Chemistry*, *48*(10), 4723–4727.

Lewicki, P. P. (2006). Design of hot air drying for better foods. *Trends in Food Science & Technology*, *17*(4), 153–163.

Li, D., Rajkovic, A., Devlieghere, F., & Uyttendaele, M. (2016a). Performance of Drying Technologies to Ensure Microbial Safety of Dried Fruits and Vegetables. *Food Science and Food Safety*, *15*, 1056–1066.

Li, D., Rajkovic, A., Devlieghere, F., & Uyttendaele, M. (2016b). Performance of Drying Technologies to Ensure Microbial Safety of Dried Fruits and Vegetables. *Comprehensive Reviews in Food Science and Food Safety*, *15*, 1056–1066.

Lozel, S., Bico, S., Manuel, R., & Costa, S. (2010). Chemical dips and edible coatings to retard softening and browning of fresh-cut banana. *International Journal of Postharvest Technology and Innovation*, *2*(1), 13–24.

Luengwilai, K., & Beckles, D. M. (2013). Effect of low temperature storage on fruit physiology and carbohydrate accumulation in tomato ripening-inhibited mutants. *Journal of Stored Products and Postharvest Research*, *4*(3), 35–43.

Luengwilai, K., Beckles, D. M., & Saltveit, M. E. (2012). Postharvest Biology and Technology Chilling-injury of harvested tomato (Solanum lycopersicum L .) cv . Micro-Tom fruit is reduced by temperature pre-treatments. *Postharvest Biology and Technology*, *63*(1), 123–128.

Lues, J. F. R., Rasephei, M. R., Venter, P., Theron, M. M., Lues, J. F. R., Rasephei, M. R., … Theron, M. M. (2006). Assessing food safety and associated food handling practices in street food vending. *International Journal of Environmental Health Research*, *16*(5), 319–328.

Lumpur-, K. (2008). Effect of Stages of Maturity and Ripening Conditions on the Biochemical Characteristics of Tomato. *American Journal of Biochemistry and Biotechnology*, *4*(4), 336–344.

Luterotti, S., Bicanic, D., & Markovi, K. (2014). Carotenes in processed tomato after thermal treatment. *Food Control*, *40*, 4–11.

Luthria, D. L., Mukhopadhyay, S., & Krizek, D. T. (2006). Content of total phenolics and phenolic acids in tomato (Lycopersicon esculentum Mill .) fruits as influenced by cultivar and solar UV radiation. *Journal of Food Composition and Analysis*, *19*, 771–777.

Majidi, H., Minaei, S., Almassi, M., & Mostofi, Y. (2014). Tomato quality in controlled atmosphere storage , modified atmosphere packaging and cold storage. *Journal of Food Science and Technology*, *51*(9), 2155–2161.

Maqsood, S., Omer, I., & Eldin, A. K. (2015). Quality attributes, moisture sorption isotherm, phenolic content and antioxidative activities of tomato (Lycopersicon esculentum L.) as influenced by method of drying. *Journal of Food Science and Technology*, *52*(11), 7059–7069.

Marouelli, W. A., & Silva, W. L. C. (2007). Water tension thresholds for processing tomatoes under drip irrigation in Central Brazil. *Journal of Irrigation Science*, *25*, 411–418.

Marques, L. G., Silveira, A. M., Freire, J. T., Marques, L. G., & Silveira, A. M. (2006). Freeze-Drying Characteristics of Tropical Fruits. *Drying Technology*, *24*(4), 457–463.

Maršić, N. K., Osvald, J., & Jakše, M. (2005). Evaluation of ten cultivars of determinate tomato (Lycopersicum esculentum Mill .), grown under different climatic conditions. *Acta Agriculturae Slovenica*, *85*(2), 321–328.

Martínez-romero, D., Bailén, G., Serrano, M., Guillén, F., Valverde, J. M., Zapata, P., … Valero, D. (2007). Tools to Maintain Postharvest Fruit and Vegetable Quality through the Inhibition of Ethylene Action. *Critical Reviews in Food Science and Nutrition*, *47*(6), 543–560.

Matteo, A. Di, Sacco, A., Anacleria, M., Pezzotti, M., Delledonne, M., Ferrarini, A., …

Barone, A. (2010). The ascorbic acid content of tomato fruits is associated with the expression of genes involved in pectin degradation. *Plant Biology*, *10*(163), 2–11.

Michael Edwin Kuehn, Esparto, CA ; Court Nicholas, Hollister, C. (2005). Inbred Tomato Line 294. United States Patent.

Ministry of agriculture Kenya (MOA). (2012). *statistics*. *National Horticultural Policy,2012 Kenya.*

Ministry of Agriculture Livestock and Fisheries (MOALF). (2015). *Republic of kenya*. *Republic of Kenya. 2015 Annual Report*.

Mtchell, A., Hong, Y.-J., Koh, E., & Barrett, D. (2007). Ten-Year Comparison of the Influence of Organic and Conventional Crop Management Practices on the Content of Flavonoids in Tomatoes. *Journal of Agricultural and Food Chemistry*, *55*(15), 6154–6159.

Mujumdar, A. S., & Law, C. L. (2010). Drying Technology : Trends and Applications in Postharvest Processing, 843–852.

Mulholland, B. B. J., Edmondson, R. N., Fussell, M., Basham, J., & Ho, L. C. (2003). Effects of high temperature on tomato summer fruit quality. *The Journal of Horticultural Science and Biotechnology*, *78*(3), 365–374.

Mwende, R., Owino, W., & Imathiu, S. (2018). Effects of pretreatment during drying on the antioxidant properties and color of selected tomato varieties. *Food Science & Nutrition*, *6*, 503–511.

Nisha, P., Singhal, R. S., & Pandit, A. B. (2011). Kinetic Modelling of Colour Degradation in Tomato Puree (Lycopersicon esculentum L .). *Food Bioprocess Technology*, *4*, 781–787.

Njoroge, E. W., Matofari, J. W., Mulwa, R. M. S., & Anyango, J. O. (2015). Effects of

blanching time / temperature combination coupled with solar-drying on the nutritional and microbial quality of indigenous leafy vegetables in Kenya. *African Journal of Food Science and Technology*, *6*(7), 209–219.

Noor Atiqah, A. A. K., Maisarah, A. M. and * Asmah, R. (2014). Comparison of antioxidant properties of tamarillo (Cyphomandra betacea), cherry tomato (Solanum lycopersicum var . cerasiform) and tomato (Lyopersicon esulentum). *International Food Research Journal 21(6):*, *21*(6), 2355–2362.

Obire, O., Anyanwu, E. C., Obire, O., & Anyanwu, E. C. (2009). Impact of various concentrations of crude oil on fungal populations of soil. *International Journal of Environmental Science and Technology*, *6*(2), 211–218.

Ochida, C. O., & Itodo, A. U. (2018). A Review on Postharvest Storage , Processing and Preservation of Tomatoes (Lycopersicon esculentum Mill). *Asian Food Science Journal*, *6*(2), 1–10.

Ochilo, W. N., Nyamasyo, G. N., Kilalo, D., Otieno, W., Otipa, M., Chege, F., … Lingeera, E. K. (2018). Characteristics and production constraints of smallholder tomato production in Kenya. *Scientific African*, *2*, e00014.

Olaniyi, J. O., Akanbi, W. B., Adejumo, T. A., & Akande, O. G. (2010). Growth , fruit yield and nutritional quality of tomato varieties. *African Journal of Food Science*, *4*(6), 398–402.

Olufemi, A., Pamela, T. A., Ibitoye, E., & Olubunmi, D. (2009). Lycopene Content in Tomatoes (Lycopersicon esculentum Mill): Effect of Thermal Heat and its Health Benefits. *Fresh Produce*, *3*(1), 40–43.

Omodamiro, O. D., & Amechi, U. (2013). The phytochemical content, antioxidant, antimicrobial and anti-inflammatory activities of *Lycopersicon esculentum* (Tomato). *Asian Journal of Plant Science and Research*, *3*(5), 70–81.

Ongeri, B. O. (2014). Small Scale Horticultural farming along the Kenyan Highways and Local economic development : Exploring the effect of factor prices. *International Review of Research in Emerging Markets and the Global Economy*, *1*(3), 102–119.

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., & Abdan, K. (2016). Modeling the Thin-Layer Drying of Fruits and Vegetables. *Comprehensive Reviews in Food Science and Food Safety*, 15, 599-618.

Orak, H. H., Aktas, T., Yagar, H., Selen, S., & Ekinci, N. (2011). Effects of hot air and freeze drying methods on antioxidant activity , colour and some nutritional characteristics of strawberry tree (Arbutus unedo L) fruit. *Food Science and Technology International.*, *18*(4), 391–402.

Ordoñez-santos, L. E., & Ledezma-realpe, D. P. (2013). Lycopene Concentration and Physico-Chemical Properties of Tropical Fruits. *Food and Nutrition Sciences*, *4*, 758–762.

Owino, W., Sefa, V., & Nenguwo, N. (2015). Postharvest Loss Assessment of Vegetables in Kenya. In *Proceedings of the First International Congress on Postharvest Loss Prevention* (pp. 4–5). Rome, Italy.

Owureku-asare, M., Agyei-amponsah, J., Saalia, F., Alfaro, L., Espinoza-rodezno, L. A., & Sathivel, S. (2014). Effect of pretreatment on physicochemical quality characteristics of a dried tomato (Lycopersicon esculentum). *African Journal of Food Science*, *8*(5), 253–259.

Owusu, J., Wang, Z., & Amissah, A. (2012). Effect of Drying Methods on Physicochemical Properties of Pretreated Tomato (lycopersicon esculentum mill .) Slices. *Croatian Journal of Food Technology, Biotechnology and Nutrition*, *7*(1–2), 106–111.

Pandharipande, S. L., Paul, S., & Tech, B. (2012). Modeling of Osmotic Dehydration Kinetics of Banana Slices using Artificial Neural Network. *International Journal of Computer Applications*, *48*(3), 26–31.

Paran, I. and Vander Knaap, E. (2007). Genetic and molecular regulation of fruit and plant domestication traits in tomato and pepper. *Journal of Experimental Botany*, *58*(14), 3841–3852.

Parnell, T. L., Suslow, T. V, & Harris, L. J. (2004). *Tomatoes : Safe Methods to Store, Preserve, and Enjoy*. *ANR Publication 8116* (Vol. 8116). Oakland.

Pascale, B. S. D. E. (2001). Irrigation with Saline Water Improves Carotenoids Content and Antioxidant Activity of Tomato. *The Journal of Horticultural Science and Biotechnology*, *76*(4), 447–453.

Passam, H. C., Karapanos, I. C., Bebeli, P. J., & Savvas, D. (2007). A Review of Recent Research on Tomato Nutrition , Breeding and Post-Harvest Technology with Reference to Fruit Quality. *The European Journal of Plant Science and Biotechnology*, *1*(1), 1–21.

Perera, C. O. (2005). Selected Quality Attributes of Dried Foods. *Drying Technology*, *23*(4), 717–730.

Periago, J., Provan, G., & Chesson, A. (2002). Phenolic compounds , lycopene and antioxidant activity in commercial varieties of tomato (*Lycopersicum esculentum*). *Journal of the Science of Food and Agriculture*, *330*, 323–330.

Perkins-veazie, P., Roberts, W., Collins, J. K., Roberts, W., Lycopene, J. K. C., Perkins-veazie, P., & Collins, J. K. (2007). Lycopene Content Among Organically Produced Tomatoes Lycopene Content Among Organically Produced Tomatoes. *Journal of Vegetable Science*, *12*(4), 93–106.

Phomkong, W., Soponronnarit, S., & Thammarutwasik, P. (2010). Chemical Pretreatments Affecting Drying Characteristics of Chilli (cv . Huarou Yon). *Drying Technology*, *28*, 1466–1476.

Pila, N., Gol, N. B., & Rao, T. V. R. (2010). Effect of Post harvest Treatments on Physicochemical Characteristics and Shelf Life of Tomato (Lycopersicon esculentum Mill .) Fruits during Storage. *American-Eurasian Journal of Agriculture & Environmental Science*, *9*(5), 470–479.

Prakash, A., Chen, P., Pilling, R. L., Johnson, N., & Foley, D. (2007). 1% Calcium Chloride Treatment in Combination with Gamma Irradiation Improves Microbial and Physicochemical Properties of Diced Tomatoes. *Foodborne Pathogens and Disease*, *4*(1), 89–98.

Purkayastha, M. Das, & Nath, A. (2013). Thin layer drying of tomato slices. *Journal of Food Science and Technology*, *50*(4), 642–653.

Quintero-ramos, A., Bourne, M., Barnard, J., Domõ, R., Jime, J., & Anzaldu, A. (2001). Texture of rehydrated dried bell peppers modified by low-temperature blanching and calcium addition. *International Journal of Food Science and Technology*, *36*, 523–527.

Rajkumar, P., Kulanthaisami, S., Raghavan, G. S. V, Gariépy, Y., Orsat, V., Kulanthaisami, S., … Orsat, V. (2007). Drying Kinetics of Tomato Slices in Vacuum Assisted Solar and Open Sun Drying Methods. *Drying Technology*, *25*(7–8), 1349–1357.

Rao, A. V, & Rao, L. G. (2007). Carotenoids and human health. *Pharmacological Research*, *55*, 207–216.

Rausch, F., Leonardo, F. Æ., Albuquerque, C. De, Britto, L. De, Leonardo, G. Æ., Boiteux, S., … A, A. C. De. (2008). Diversity and prevalence of Brazilian bipartite

begomovirus species associated to tomatoes. *Virus Genes*, *36*, 251–258.

Rico, D., & Henehan, G. T. M. (2007). Calcium for extending the shelf life of fresh whole and minimally processed fruits and vegetables : a review. *Trends in Food Science & Technology*, *18*, 210–218.

Ringeisen, B., Barrett, D. M., & Stroeve, P. (2014). Energy for Sustainable Development Concentrated solar drying of tomatoes. *Energy for Sustainable Development*, *19*, 47–55.

Ruiz-garcía, Y., & Gómez-plaza, E. (2013). Elicitors: A Tool for Improving Fruit Phenolic Content. *American Journal of Plant Sciences*, *3*, 33–52.

Ruttoh, J. K., Bett, E. K., & Nyairo, N. (2018). Empirical analysis of structure and conduct of tomato marketing in Loitoktok , Kajiado County , Kenya. *International Scholars Journal*, *6*(4), 628–638.

Sablani, S. S., Andrews, P. K., Davies, N. M., Walters, T., Saez, H., Bastarrachea, L., … Vernon, M. (2011). Effects of Air and Freeze Drying on Phytochemical Content of Conventional and Organic Berries. *Drying Technology*, *29*, 205–216.

Sablani, S. S., & Sablani, S. S. (2006). Drying of Fruits and Vegetables : Retention of Nutritional / Functional Quality Drying of Fruits and Vegetables . *Drying Technology*, *24*(2), 123–135.

Sacilik, K. (2007). The Thin-Layer Modelling of Tomato Drying Process. *Agriculturae Conspectus Scientificus*, *72*(4), 343–349.

Sahin, F. H., Aktas, T., Orak, H., Ulger, P., Sahin, H., Aktas, T., … Ulger, P. (2011). Influence of Pretreatments and Different Drying Methods on Color Parameters and Lycopene Content of Dried Tomato. *Bulgarian Journal of Agricultural Science*, *17*(6), 867–881.

Samuel, O., & Orji, M. U. (2015). Fungi Associated with the Spoilage of Post-harvest Tomato Fruits Sold in Major Markets in Awka , Nigeria. *Universal Journal of Microbiology Research*, *3*(2), 11–16.

Santamaria, P., Cantore, V., Conversa, G., & Serio, F. (2004). Effect of night salinity level on water use , physiological responses , yield and quality of tomato. *The Journal of Horticultural Science and Biotechnology*, *79*(1), 59–66.

Santos-Sánchez, N. F., Valadez-Blanco, R., Gómez-Gómez, M. S., Pérez-Herrera, A., & Salas-Coronado, R. (2012). Effect of rotating tray drying on antioxidant components, color and rehydration ratio of tomato saladette slices. *Food Science and Technology*, *46*(1), 298–304.

Santos, P. H. S., Silva, M. A., Santos, P. H. S., & Silva, M. A. (2008a). Retention of Vitamin C in Drying Processes of Fruits and Vegetables. *Drying Technology*, *26*(12), 1421–1437.

Santos, P. H. S., Silva, M. A., Santos, P. H. S., & Silva, M. A. (2008b). Retention of Vitamin C in Drying Processes of Fruits and Vegetables. *Drying Technology*, *26*(12), 1421–1437.

Sarkar, S., Kumar, D., Roy, D., Siddik, A. B., & Das, K. (2015). Effect of Chemical Preservatives and Storage Conditions on the Nutritional Quality of Tomato Pulp. *Gida The Journal of Food*, *3*(4), 90–100.

Satoi, S., M, K., T, I., N, M., Furukawa, H., & Ikeda, H. (2006). Moderate Increase of Mean Daily Temperature Adversely Affects Fruit Set of Lycopersicon esculentum by Disrupting Specific Physiological Processes in Male Reproductive Development. *Annals of Botany*, *97*, 731–738.

Serna-cock, L., Vargas-muñoz, D. P., & Aponte, A. A. (2015). Structural , physical , functional and nutraceutical changes of freeze-dried fruit. *African Journal of*

Biotechnology, *14*(6), 442–450.

Sgroppo, S. C., Vergara, L. E., & Tenev, M. D. (2010). Effects of sodium metabisulphite and citric acid on the shelf life of fresh cut sweet potatoes. *Spanish Journal of Agricultural Research*, *8*(3), 686–693.

Sharma, K. D., & Karki, S. (2012). Chemical composition , functional properties and processing of carrot. *Journal of Food Science and Technology*, *49*(1), 22–32.

Shi, J., Maguer, M. Le, Shi, J., & Maguer, M. Le. (2000). Lycopene in Tomatoes : Chemical and Physical Properties Affected by Food Processing. *Critical Reviews in Biotechnology*, *20*(4), 293–334.

Shi, J., & Qu, Q. I. N. (2004). Stability and Synergistic Effect of Antioxidative Properties of Lycopene. *Critical Reviews in Food Science and Nutrition*, *44*(7–8), 559–573.

Shirzadeh, E., Rabiei, V., & Sharafi, Y. (2011). Effect of calcium chloride (CaCl 2) on postharvest quality of apple fruits. *African Journal of Agricultural Research*, *6*(22), 5139–5143.

Shishehgarha, F., Makhlouf, J., & Ratti, C. (2002). Freeze-Drying Characteristics of Strawberries. *Drying Technology*, *20*(1), 131–145.

Shofian, N. M., Hamid, A. A., Osman, A., & Saari, N. (2011). Effect of Freeze-Drying on the Antioxidant Compounds and Antioxidant Activity of Selected Tropical Fruits. *International Journal of Molecular Sciences*, *12*, 4678–4692.

Simonne, A. H., Fuzeré, J. M., Simonne, E., Hochmuth, R. C., Marshall, M. R., Fuzeré, J. M., … Marshall, M. R. (2007). Effects of Nitrogen Rates on Chemical Composition of Yellow Grape Tomato Grown in a Subtropical Climate. *Journal of Plant and Nutrition*, *30*(6), 927–935.

Slimestad, R., & Verheul, M. (2009). Review of flavonoids and other phenolics from fruits of different tomato (Lycopersicon esculentum Mill .) cultivars. *Journal of the Science of Food and Agriculture*, *89*(8), 1255–1270.

Tan, H., Thomas-Ahner, J.M., E.M., wan, L., Francis, D.M., Schwatz, S.J., ErdmanJr J.W ., StevenK.Clinton, S. . (2010). Tomato based food products for prostrate cancer prevention,What have we learned.Cancer metastasis. *Cancer Metastasis Reviews*, *29*(3), 553–568.

The Horticultural crops directorate of the Agriculture and food authority. (2016). *Horticulture validated report 2015-2016*.

Tigist, M., & Workneh, T. S. (2013). Effects of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology*, *50*(3), 477–486.

Tola, Y., & Ramaswamy, H. (2015). Temperature and high pressure stability of lycopene and vitamin C of watermelon Juice. *African Journal of Food Science*, *9*(5), 351–358.

Tosun, B. N. (2008). Influence of commercial freezing and storage on vitamin C content of some vegetables. *International Journal of Food Science and Technology*, *43*(2), 316–321.

Ukponmwan, I. (2015). Preservation of Tomatoes. In *5th International Conference on Biomedical Engineering and Technology: Preservation of Tomatoes* (Vol. 81, pp. 85–88). Nigeria: IACSIT Press, Singapore.

United States Department of Agriculture. (1997). *United States Standards for Grades of Fresh Tomatoes*.

Valerie, N., Chong, W., Pindi, W., Chye, F., Shaarani, S., & Lee, J. (2015). Effects of

Drying Methods on the Quality of Dried Sea Cucumbers from Sabah – A Review. *International Journal of Novel Research in Life Sciences*, *2*(4), 49–64.

Vergeldt, F. J., Dalen, G. Van, Duijster, A. J., Voda, A., Khallou, S., Vliet, L. J. Van, … Sman, R. G. M. Van Der. (2014). Rehydration kinetics of freeze-dried carrots. *Innovative Food Science and Emerging Technologies*, *24*, 40–47.

Victor, N., Peter, C., Raphael, K., Tendekayi, G. H., Jephris, G., Taole, M., & Portia, P. R. (2017). Microbiological quality of selected dried fruits and vegetables in Maseru , Lesotho. *African Journal of Microbiology Research*, *11*(5), 185–193.

Vikram, V. B., Ramesh, M. N., & Prapulla, S. G. (2005). Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. *Journal of Food Engineering*, *69*(1), 31–40.

Visa, S., Cao, C., Mcspadden, B., & Knaap, E. Van Der. (2014). Modeling of tomato fruits into nine shape categories using elliptic fourier shape modeling and Bayesian classification of contour morphometric data, 429–439.

Voda, A., Homan, N., Witek, M., Duijster, A., Dalen, G. Van, Sman, R. Van Der, … Duynhoven, J. Van. (2012). The impact of freeze-drying on microstructure and rehydration properties of carrot. *Food Research International*, *49*(2), 687–693.

Wachira, J. M., Mshenga, P. M., & Saidi, M. (2014). Comparison of the Profitability of Small-scale Greenhouse and Open-field Tomato Production Systems in Nakuru-North District, Kenya. *Asian Journal of Agricultural Sciences*, *6*(2), 54–61.

Wang, Y., Huang, S., Liu, R., & Jin, J. (2007). Effects of nitrogen application on flavor compounds of cherry tomato fruits. *Journal of Plant Nutrition and Soil Science*, *170*(4), 461–468.

Wilhelmina, K. (2005). Effects of Production and Processing Factors on Major Fruit and

Vegetable Antioxidants. *Journal of Food Science*, *70*(1), 11–19.

Workneh, T. S., Raghavan, V., & Gariepy, Y. (2011). Microwave Assisted Hot Air Ventilation Drying of Tomato Slices, *9*, 150–161.

Xue, Z., Li, J., Yu, W., Lu, X., & Kou, X. (2015). Effects of nonthermal preservation technologies on antioxidant activity of fruits and vegetables : A review. *Food Science and Technology International*, *22*(5), 440–458.

Yadav, A. K., & Singh, S. V. (2014). Osmotic dehydration of fruits and vegetables : a review. *Journal of Food Science and Technology*, *51*(9), 1654–1673.

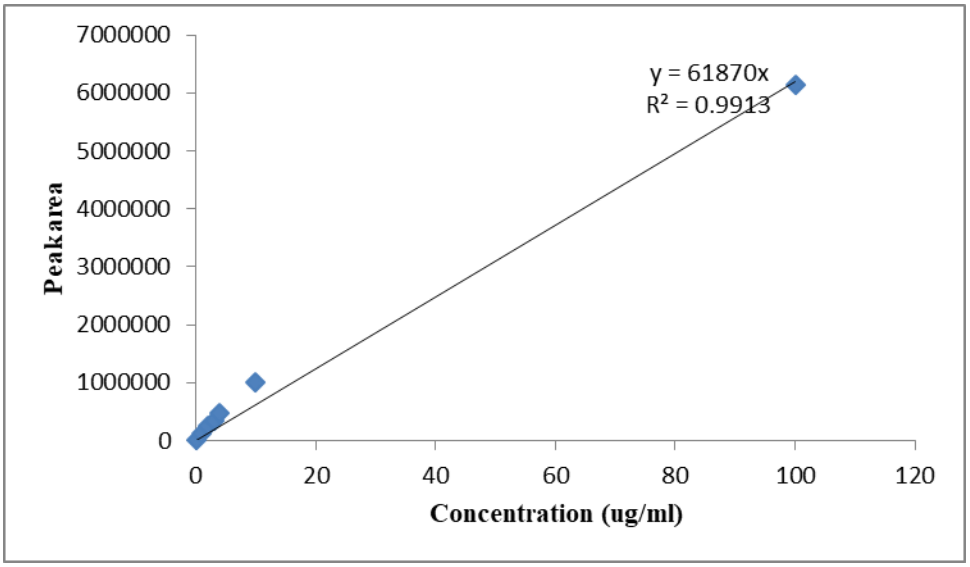
Yahaya, S., & Mardiyya, A. (2019). Review of Post-Harvest Losses of Fruits and Vegetables. *Biomedical Journal of Scientific & Technical Research*, 10192–10200.

Zhang, M., Tang, J., Mujumdar, A. S., & Wang, S. (2006). Trends in microwave- related drying of fruits and vegetables. *Trends in Food Science & Technology*, *17*(10), 524–534.

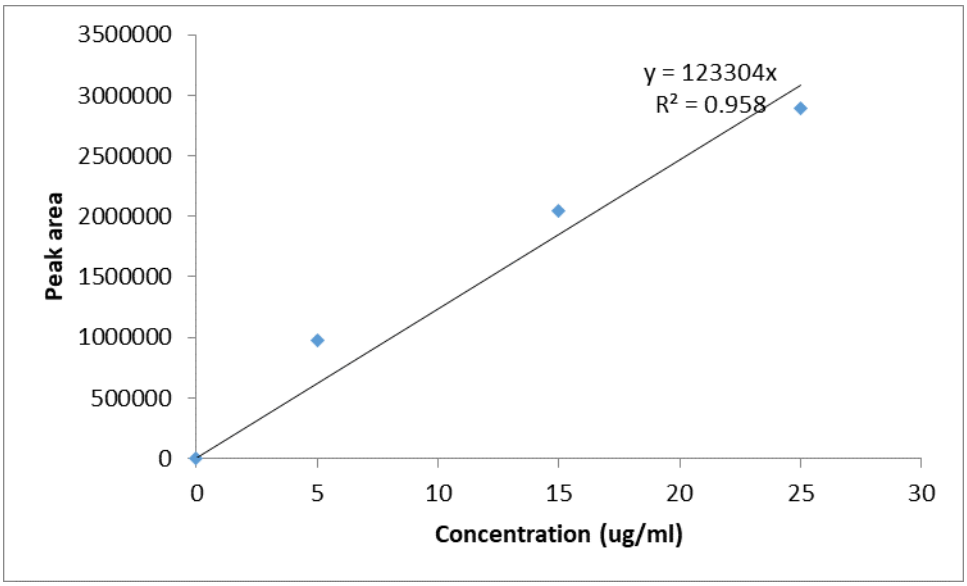
Zielinska, M., & Markowski, M. (2012). Color Characteristics of Carrots : Effect of Drying and Rehydration. *International Journal of Food Properties*, *15*(2), 450–466.

APPENDICES

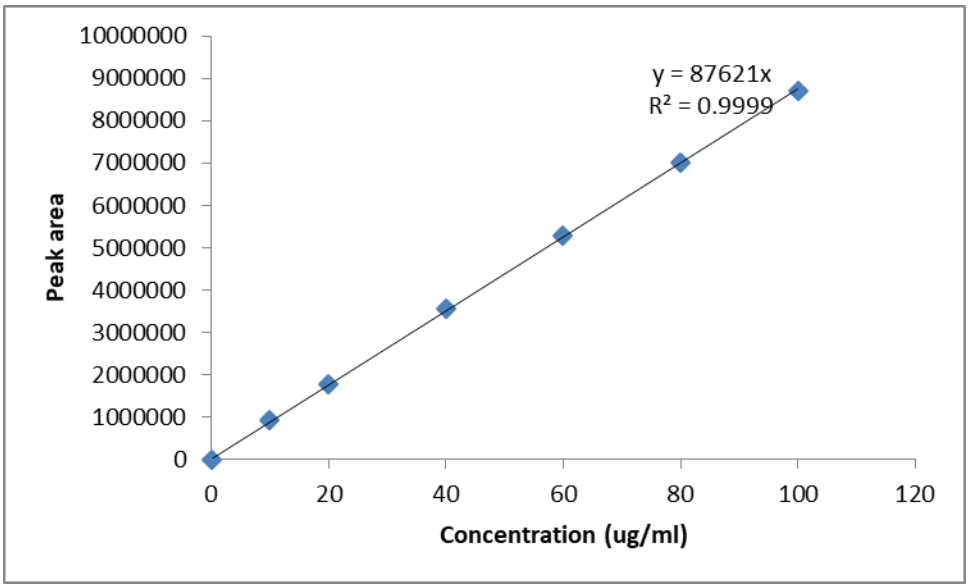
Appendix I: β carotene standard curve



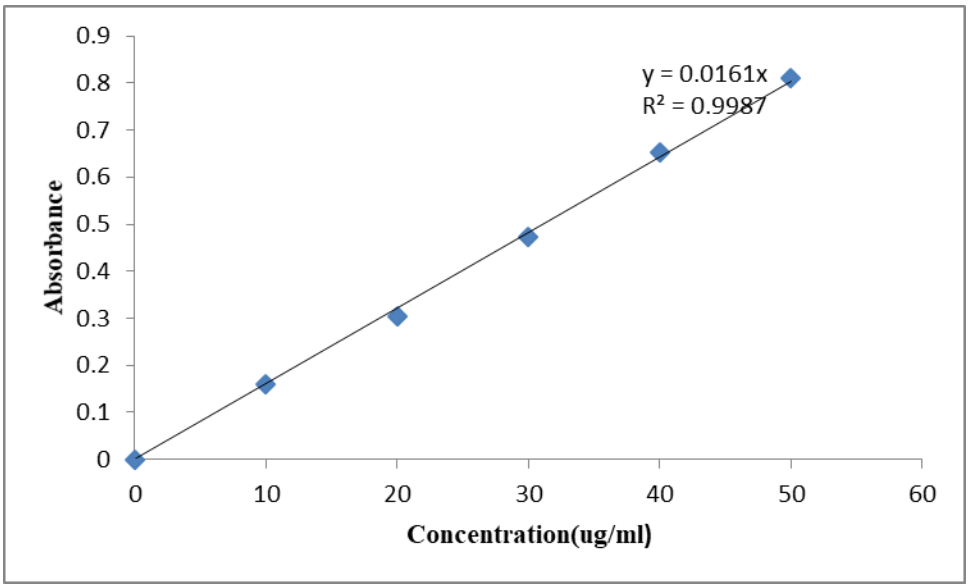
Appendix II: Lycopene standard curve



Appendix III: Vitamin C standard curve



Appendix IV: Total phenolic content standard curve



Appendix V: Pictorials of dried tomatoes (Riogrande variety)


Oven dried- 60°C
Control.


Oven dried- 60°C.
CaCl2 Treated.


Oven dried - 60°C.
Na2S2O5 Treated.


Riograude.
Solar Dried.
Control.


Solar Dried.
Na2S2O5 Treated.