# Evaluation of Growth, Yield, Storage and Processing Characteristics of Selected Tomato (*Lycopersicon esculenta* Mill) Varieties

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**A Thesis submitted in partial fulfilment for the Degree of Master of Science Degree in Horticulture in the Jomo Kenyatta University of Agriculture and Technology**

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# DECLARATION

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

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# DEDICATION

This thesis is dedicated to my late father, my mum, my beloved wife, Grace, my two sons, Chikondi and Chimwemwe and my daughter, Charity.

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## LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AI** | Adequate intake |
| **ANOVA** | Analysis of Variance |
| **AOAC** | Association of Analytical Chemists |
| **ARO** | Agricultural Research Organization |
| **ASL** | Above Sea Level |
| **ATCC** | Agricultural Technology Clearing Committee |
| **AVRDC** | Asian Vegetable Research & Development Centre |
| **BER** | Blossom-end rot |
| **Ca** | Calcium |
| **$Ca(NO_3)_2$** | Calcium Nitrate |
| **CAN** | Calcium Ammonium Nitrate |
| **CRD** | Completely Randomized Design |
| **CTA** | Technical Centre for Agricultural and Rural Cooperation |
| **DAP** | Diammonium phosphate |
| **DARS** | Department of Agricultural Research Services |
| **DMRT** | Duncan‘s Multiple Range Test |
| **DTF** | Days to flowering |
| **DTM** | Days to fruit maturity |

| | |
|---|---|
| **EC** | Emulsifiable Concentrates |
| **FAO** | Food and Agriculture Organization |
| **GAP** | Guide to Agricultural Production |
| **$H_3BO_3$** | Boric acid |
| **Ha** | Hectare |
| **HCl** | Hydrochloric acid |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **K** | Potassium |
| **KARI** | Kenya Agricultural Research Institute |
| **Kcal** | Kilo calorie |
| **$K_2O$** | Potassium Oxide |
| **$K_2SO_4$** | Potassium Sulphate |
| **LSD** | Least significant difference |
| **Mg** | Magnesium |
| **$mgCO_2/Kgh$** | Milligrams of carbon dioxide per kilogramme per hour |
| **MoAFS** | Ministry of Agriculture and Food Security |
| **mt** | Metric tonnes |
| **N** | Nitrogen |
| **NAFIS** | National Farmers Information Service |
| **NaOH** | Sodium hydroxide |

| | |
|---|---|
| **$NH_3$** | Ammonia |
| **NPK** | Nitrogen Phosphorous and Potassium |
| **$^0$Brix** | Degrees Brix |
| **PET** | Potential evaporation |
| **pH** | Hydrogen/ion concentration |
| **ppm** | Parts per million |
| **RDA** | Recommended Daily Allowance |
| **RUE** | Radiation Use Efficiency |
| **VF** | Verticillium and Fusarium wilts |
| **TCA** | Trichloroacetic acid |
| **TYLC** | Tomato Yellow Leaf Curl Virus |
| **ww** | Wet Weight |

# ABSTRACT

The study was carried out in order to determine growth and development, yield and storage characteristics of selected processing tomato varieties under similar growth and storage conditions and to determine the processing characteristics of the selected varieties with regard to product yield and quality. Seedlings of Roma VF, M82-1-8-VF and Cal-J tomato varieties were planted in pots laid out in a Completely Randomized Design (CRD), under external environment. Each treatment was replicated four times. The study was carried out between September 2008 and June 2009.

Data on plant height, number of main branches, number of leaves, number of fruits and average fruit weight was collected from each plant. Fresh fruits from each treatment were selected and stored at average room temperature of 25°C and relative humidity 85 to 90% for a period of 31 days. The fruits were weighed at 5 day interval in order to assess the rate of deterioration of fresh fruits and pictures showing the physical condition of the fruits were taken on 16 and 31days of storage. The other fruits were processed into tomato paste, sauce and ketchup and data on pulp to fruit weight ratio, proportion of product to pulp weight, degrees Brix, pH, vitamin C content and protein content were collected.  All data was subjected to Analysis of Variance (ANOVA) to determine whether the treatment effects were significant at 5%, 1% or 0.1%. Means were separated using Duncan‘s Multiple Range Test (DMRT). Correlation analysis among growth parameters and yield was also done to determine their relationships.

Six weeks after planting, Roma VF had significantly higher leaf area and leaf area index compared to Cal J and M82-1-8-VF. Roma VF also had significantly higher number of leaves per plant and plant height than Cal J but had no significant differences with M82-1-8-VF. In number of main branches per plant, Roma VF was significantly higher than M82-1-8-VF but not significantly different from Cal J. Roma VF was significantly higher in all yield parameters than Cal J and M82-1-8-VF but was significantly lower in fruit weight than the other two varieties. M82-1-8-VF had significantly lower fruit weight loss compared to Cal J and Roma VF. There were no significant differences among all the varieties in the proportion of pulp to fruit weight, proportion of product to pulp volume (%) and degrees Brix ($^0$Brix) in all the three products. Cal J had significantly higher protein content in tomato sauce and tomato paste compared to the other two varieties while in tomato ketchup, it was Roma VF that had significantly higher protein content than the other two varieties. There were no significant differences in product pH and Vitamin C content among all the varieties.

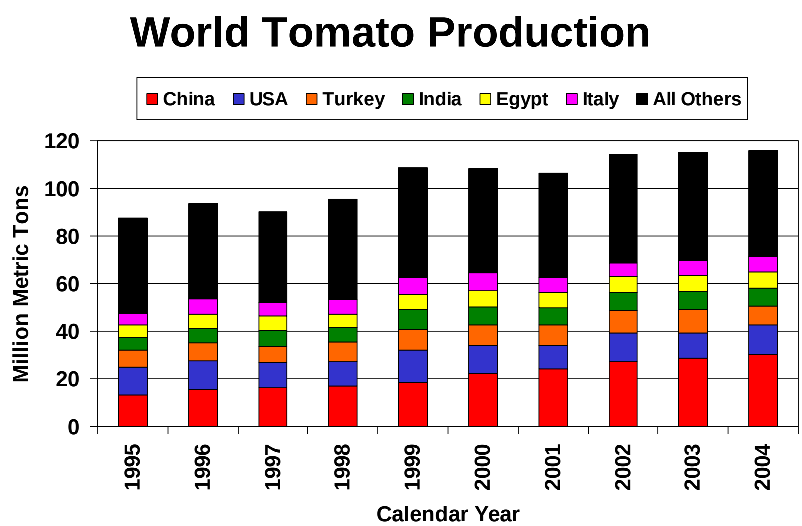
Based on the results, it is concluded that Roma VF was a better variety in plant growth and fresh fruit yield compared to the other two varieties. Fresh fruits of M82-1-8-VF had better storage characteristics at 25$^0$C and relative humidity of 85 to 90 %. No variety was significantly better than the other in processing characteristics while in product quality characteristics, Cal J was a significantly better variety in protein content in tomato sauce and tomato paste than the other two varieties while Roma VF was a significantly better variety with regard to protein content in tomato ketchup. No variety was better than the other in product pH and Vitamin C content.

Roma VF is recommended as the best processing variety for farmers to cultivate due to its good growth characteristics as well as high fresh fruit yield. However, due to its poor fruit storage characteristics it is recommended that the fruits should be processed as soon as they are ripe and not be kept for long periods. On the other hand, M82-1-8-VF is recommended as a dual purpose variety both for processing and for fresh market. This is because of its good storage characteristics that could allow farmers to keep it for a longer period before marketing as well as where processing capacity is very low.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Tomato, *Lycopersicon esculentum* Mill, belongs to the family Solanaceae and is one of the most widely grown vegetables in the world. Tomato is an important source of essential nutrients, including beta carotene and ascorbic acid (AVRDC, 1990). Leading tomato producing countries are China, India, Commonwealth of Independent States (formerly Soviet Union), Turkey, Egypt, United States and Italy. The world tomato production in 2001 was about 105 million metric tonnes of fresh fruit from an estimated 3.9 million hectares with world exports of fresh tomato fruits estimated at 4 million metric tonnes, valued at 3000 million US$ (van der Vossen et al., 2004). According to FAO (2005), by the year 2004, the world production was estimated to be 118 million metric tonnes (Plate 1) grown on 4,311,000 ha with average yield of 26,286 kg/ha. The area used for tomato production in tropical Africa is about 300,000 ha with an estimated annual production of 2.3 million metric tonnes and yields of 7,667 kg/ha (van der Vossen et al., 2004).




Source: Food and Agriculture Organization (FAO) of the United Nations

**Plate 1: World tomato production**

In Malawi there are a total of 4,000 ha under tomato crop, producing 35,000 mt with average yields of about 8,750 kg/ha (Ministry of Agriculture & Food Security, Malawi, 2006). The crop is grown throughout the year and of the total production, 20% is used for home consumption, 75% sold fresh and 5% used for processing by very few companies available in Malawi. Small-scale processing is almost absent. There are many tomato varieties which were introduced in Malawi and were released through the Agricultural Technology Clearing Committee (ATCC) in collaboration with the Department of Agricultural Research Services (DARS) of the Ministry of Agriculture and Food Security (MoAFS). Some of the tomato varieties grown in Malawi include moneymaker, red khaki, Roma, Mbambande, Khama, Rodade, Rommittel, Heinze 1370, Heinze 1350 and Rossol. However, their fruit processing characteristics have not been well established.

## 1.2 Problem statement

Vegetable farmers in Malawi produce a diversified range of tomato varieties that are suitable for processing that include Roma VF, Rossol, Heinze 1350, M82-1-8-VF and Cal J. In most cases, varieties that are meant for processing are sold as fresh market tomatoes. According to the Ministry of Agriculture and Food Security (2006), the major problem in Malawi is that out of 35,000 mt of tomato produced, more than 40% is lost both during and after harvest. The varieties meant for processing are sold fresh on the local market and small-scale processing is almost absent. Farmers also lack knowledge on the available processing technologies and appropriate storage conditions for fresh fruits. More than 80% of tomato products in Malawi are imported while a lot of tomatoes are produced locally. Product yields of the processing varieties as well as quality attributes of the products processed from different tomato varieties are not well established in Malawi (Ministry of Agriculture and Food Security, 2006). The purpose of the study was therefore to establish the yield, quality attributes and losses associated with production, storage and processing of some selected processing tomato varieties.

## 1.3 Objectives of the study

### 1.3.1 Overall objective

To evaluate the performance and processing characteristics of three processing tomato varieties.

### 1.3.2 Specific objectives

1.3.2.1 To determine growth, yield and storage characteristics of three processing tomato varieties (Roma VF, M82-1-8-VF and Cal-J) under similar plant growth and storage conditions.

1.3.2.2 To determine the processing characteristics of the selected varieties with regard to product yields and quality.

## 1.4 Null Hypothesis

- There are no differences in growth, yield and storage characteristics of the three processing tomato varieties under similar plant growth and storage conditions: Roma VF, M82-1-8-VF and Cal-J.
- There are no differences in the processing characteristics of the three processing tomato varieties

## 1.5 Justification

The study was to help establish the yield, quality attributes and losses associated with production, storage and processing of the selected tomato varieties. The results were to provide useful information that would assist farmers in Malawi and other African countries to make appropriate choice of suitable processing tomato varieties, enhance local processing of tomato products and hence reduce importation of such products and empower farmers economically and reduce post-harvest losses through processing and proper storage.

# CHAPTER TWO: REVIEW OF LITERATURE

## 2.1 Introduction

Tomato originated in the South American Andes, from central Ecuador through Peru to northern Chile. Archaeological and linguistic evidence suggest that tomato was domesticated in Mexico, outside its centre of origin. Tomato was introduced from Europe to southern and eastern Asia in the $17^{th}$ century and subsequently to the United States, Africa and the Middle East and has become one of the most important vegetables worldwide (van der Vossen et al., 2004).

It is a perennial plant, but often grown outdoors in temperate climates as an annual plant. Typically reaching to a height of 1 to 3 m, it has a weak, woody stem that often vines over other plants (Edmond et al., 1997). The leaves are 10 to 25 cm long, odd pinnate, with 5 to 9 leaflets on petioles. Each leaflet grows up to 8 cm long, with a serrated margin and both the stem and leaves are densely glandular-hairy (Rick, 1978; Vaughan et al. 1998; van der Vossen et al., 2004). Tomato is one of the most widely grown vegetables in the world and the fruit is the main edible portion. Tomato fruits are berries with different forms and dimensions. Sugars constitute 65 to 70% of total soluble solids in a tomato fruit, and an accurate estimate of this can be made using a refractometer. The tomato is regarded as a fruit because fruits are the edible part of the plant that contains the seeds. The fruit consists of the external layer called the pepicarp, the pulpy part formed by cells with thin round walls called the mesocarp and the thicker tissue that divides and limit the pulp sections called the endocarp (Plate 2b) (Adams et al., 1993; Hobson and Grierson, 1993).

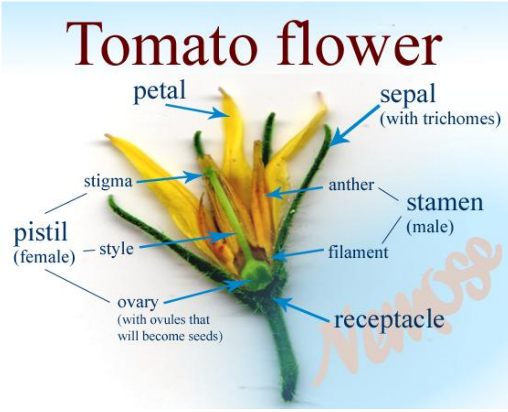



**Plate 2a: Tomato flower**

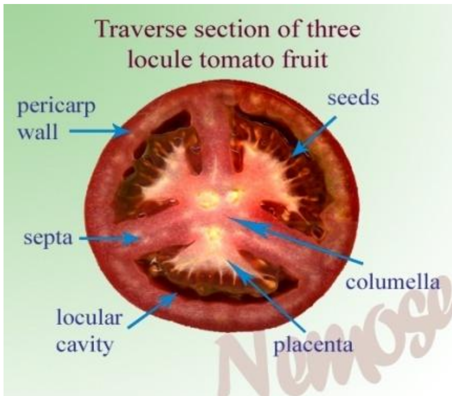



**Plate 2b: Cross section of a tomato fruit**

Source: Hobson and Grierson (1993)

**Plate 2: Botanical characteristics of tomato flower and fruit**

Tomato is an important source of nutrients. On the average, 100 grammes of the edible portions of fresh raw tomato comprise 94% water, 19 Kcal energy, 0.9 g protein, 0.2 g fat, 4.3 g carbohydrate, 0.5 g fiber, 7 mg calcium, 23 mg phosphorous, 8 mg sodium, 0.5 mg iron and 207 mg potassium (AVRDC, 1990; van der Vossen et al., 2004). It also contains a wide range of vitamins that include beta-carotene, thiamine, riboflavin, niacin, ascorbic acid and B6 (Lorenz and Maynard, 1988). New medical research also suggests that having lycopene in a diet may help prevent cancer. Investigators established those patients with prostate cancer when treated with lycopene supplements had smaller tumors and the cancer was more frequently restricted to the prostate, which means the cancer did not spread to nearby tissue and organs (La Vecchia, 1998; Giovannucci, 1999; CTA, 2008). The contents of soluble solids such as fructose, glucose and sucrose, organic acids such as citric, malic, galacturonic and pyrrolidone carboxylic as well as the sugar/acid ratio, are important determinants of taste and can be assessed by standard analytical methods (van der Vossen et al., 2004).

## 2.2 Tomato varieties and growth characteristics

### 2.2.1 Available tomato varieties

According to van der Vossen et al. (2004), there are hundreds of tomato varieties available with fruits coming in a number of shapes, sizes and colours. Tomato plants are also produced as early, main or late season crop and the cultivars have to be adapted to the growers' seasons. Some varieties are resistant to nematodes and certain diseases, such as verticillium wilt and fusarium wilt. This resistance to verticillium wilt and fusarium wilt diseases is usually indicated by letters following the varieties' name e.g. Roma VF (Sprittstoesser, 1984). According to Hanson et al. (2000), recommended tomato varieties are divided into two main categories that include fresh market varieties; Money maker, Marglobe, Manapal, Zest and Homestead that are indeterminate; Rodade and Floradade that are semi-determinate and Heinz 1370, Red khaki, Sixpack and Zeal, which are determinate varieties. The other category is that of processing varieties that include Roma VF, Rossol and Heinze 1350 which are all determinate varieties.

Based on what Barrett and Kader (2002) wrote, selection of varieties for specific purpose of processing is different from selecting strictly for fresh market. This is because varieties meant for processing may be exposed to mechanical harvesting, rigorous cleaning, peeling and size reduction operations as well as high or low temperature preservation methods. Varieties may differ in peeling ability, texture integrity, colour stability, flavour retention and nutritional value (Kinet and Peet, 1997). It is important, therefore, to evaluate not only the raw material but also the intended processed product when selecting processing varieties.

A number of factors have to be considered in selection of varieties to be grown. Varieties can be selected based on whether they are for fresh market or processing (Edmond et al., 1997). This factor is important in the selection of varieties for a specific purpose based on the attributes that they have in order to maximize the benefits. Plant growth habit can also another factor used in variety selection. This is selection based on whether it is determinate or indeterminate. Determinate varieties are short and bushy, grow to a fixed mature size and all fruits ripen in a short period of usually about two weeks (Edmond et al., 1997). Indeterminate tomato varieties, on the other hand, continually produce new leaves and flowers and can grow very tall and set fruit over a longer period. This longer harvest period is an advantage if market prices fluctuate, because income tends to even out (Scholberg et al., 2000a). Farmers usually prefer the determinate varieties due to early maturity and ease of management for fresh market even though they are meant for processing.

Another factor used in selection of a tomato variety is fruit characteristics such as size, shape, colour and storage life. The weight of a tomato fruit varies from 1 g to 100 g with colour ranging from yellow to deep red. Tomato is considered a low respiration crop and its physiological ripeness can be identified by changes in colour and texture and at this stage most cultivars show a dark red colour and the tissue is softened (Weichmann, 1987). The fruit shape may be round, longish or even ribbed. It has an average water content of 95% and highest freezing point of -1.0$^0$C (Weichmann, 1987).

Fruit quality is established by all characteristics and attributes involved in satisfying the demands, needs and expectations of the grower, wholesaler, retailer and consumer (Gould, 1983; Garcia and Barrett, 2006). Post-harvest qualities of tomato fruits partly depend on pre-harvest factors such as cultural practices, genetic and environmental conditions. For instance, cultural practices such as nutrient and water supply and harvesting method affect quality of tomato both before and after harvest (Hobson, 1964; Fischer and Richter, 1986; Pretorius, 2003). Processing tomato fruits are popular in market gardens in the tropics because their firmer fruit better Processing tomato fruits have thicker walls and are firmer than most fresh market cultivars, maintain their shape when cooked and withstand long-distance transportation better than fresh market varieties.

A high ratio of water insoluble solids to total solids in processing tomato varieties is also important in ketchup and other consistency tomato products (Peet, 2001). According to Gould (1983), requirements for ideal tomato from a processing stand point include:

- Uniform set and uniform ripening with ability to set fruits over a wide range of temperature and other climatic conditions.
- Resistance to diseases, pests and disorders
- Adaptation to mechanical harvesting and bulk handling
- Freedom from blossom-end scars and crack resistant
- Stemless when removed from the vines with stem scars of less than 6 mm in diameter
- Round to oval in shape
- Uniform fruit size averaging 65 to 80 g
- High solids content (5.5 to 7.0%)
- High acid content (0.35 to 0.55%)
- Low pH (maximum 4.4, preferably all fruits with pH 4.1 below)
- High Vitamin C content (minimum 20 mg/100 g)
- For canning as peeled tomato, the skin or peel should be easily and readily removed
- After juice making, it should retain thick consistency and the juice should not separate
- After processing, produce colour should be bright red with high gloss

### 2.2.2 Processing tomato varieties

**Cal J tomato variety**

The variety has an average fruit weight of about 57 to 68 g, maturity period of approximately 120 days and average yield of between 73 and 77 tonnes per hectare. It is susceptible to disease and usually grown for processing (Sindi, 2009; KARI, 1991). Growth and development of direct-seeded tomato 'Cal J' were studied on a sandy soil at Coruche, Portugal, from 1976 till 1978. Cultural practices were standard under irrigation in the area. Final number of fruits was 38 ± 8 per plant with average fruit weight of 55 g (Calado et al., 2001). Cal J is a compact determinate variety of processing type but also a good table tomato. It has a tremendous vigor and is highly productive. Though susceptible to some diseases, it is tolerant to verticillium and fusarium wilts. The variety is very suitable at lower warmer areas (Calado et al., 2001; Sindi 2009).

**M82-1-8-VF tomato variety**

This processing variety has a maturity period of approximately 120 days, fruit weight of about 75 grammes and an average fresh fruit yield of 57 tonnes per hectare. It is susceptible to disease and usually grown for processing (Sindi, 2009). It is a variety that is increasing in popularity due to earliness in maturity and high yields. Has determinate plant growth habit, resistant to verticillium and fusarium wilts and mainly grown as a processing variety with square firm deep red fruits (Sindi, 2009).

**Roma VF tomato variety**

The variety has a maturity period of 75 days and is open-pollinated. Has a regular leaf shape, resistant to verticillium and fusarium wilts and grows to a height of 120 cm with a red or pink coloured fruit with an average weight of 113 g. Roma is a plum tomato which is commonly found in supermarkets. It has an average yield of 83 tonnes per hectare. The tomato is a meaty, egg or pear-shaped fruit that is available in red and yellow colours. It has few seeds and is a good canning and sauce tomato. The vines are determinate and fruit heavily, making it a popular variety to gardeners who do a lot of home canning. While Roma is an open-pollinated variety rather than a hybrid, it has been steadily improved to the point where most Roma tomato vines are fusarium wilt and verticillium resistant (thus the VF in the name). Most commercial plum tomatoes sold in markets in the Western Hemisphere are Roma or related types. It is tolerant to cracking and a high uniform yielder (Sindi, 2009).

Although the growth, yield and fruit characteristics for these varieties are well established from the studies carried out in various parts of the world, these characteristics have not been well established under agro-ecological conditions of most African countries, including Kenya and Malawi.

## 2.3 Transplanting of tomato seedlings

A good seedling ready for transplanting should be at the four or five-leaf stage, vigorous and stocky. Transplanting should be done in the late afternoon or on a cloudy day to minimize transplant shock. Tall and thin seedlings should be buried deeper (Peet, 2001).

Tomatoes should be transplanted at within-row spacing of 35 to 75 cm depending on the vigor of the cultivar and on how severely it will be pruned and at between-row spacing of 135 to 180 cm (Ahmad and Singh, 2006). Some growers space plants widely in the row and prune very lightly or not at all. The soil should be pressed firmly around the root and water should be applied around the base of the plant to settle the soil as soon as transplanting is done. Plant spacing also depends on cropping system, soil type and plant growth habit (AVRDC, 1990; Peet, 2001).

## 2.4 Soil and nutrient management of tomato plants

Tomato can be grown in many soil types, from sandy loam to clay-loam soils that are rich in organic matter. It is sensitive to water logging and flooding and prefers well-drained soils. The optimum soil pH range is 6.0 to 7.0 as higher or lower pH can cause mineral deficiencies or toxicities (van der Vossen et al., 2004). Three major nutrients important in satisfactory development of tomatoes are Nitrogen, Phosphorous and Potassium. Minor nutrients include calcium, magnesium and sulphur while trace elements are boron and manganese (Keeney and Bremner, 1967). Nutrition plays a major role in increasing productivity and fertilizer for tomato should be fairly rich in phosphorus. Excess nitrogen is associated with excessive vegetative growth, fruit puffiness and blossom-end rot (Garcia et al., 2000; Riahi et al., 2009). The amount of fertilizer and the timing of its applications vary with soil type and cultivar. In tropical Africa, fertilizer recommendations include 80 to 180 kg N, 80 to 200 kg P, 80 to 200 kg K and 25 tonnes of farmyard manure per ha (Wood, 1986; Peet, 2001; van der Vossen et al., 2004). It is recommended that half of the fertilizer be applied as a basal dose and the remaining fertilizer be added at first fruit-set (Reid, 2002). The amount of NPK already in the soil can be estimated through a laboratory soil test (Reid, 2002). The addition of fertilizer is needed to make up the difference between the NPK requirement for the target yield and the NPK available in the soil. However, fertilizer uptake efficiency by a crop is highly variable and depends upon many factors, including fertilizer form and placement as well as irrigation and other management practices (Keeney and Bremner, 1967; Scholberg et al., 2000b; Garcia et al., 2000).

## 2.5 Water management in a tomato crop

For maximum yield, adequate water levels need to be maintained throughout fruit development while for maximum flavour, a slight water stress during fruit development is sometimes recommended (Alvino et al., 1980). The most important consideration in watering tomatoes is consistency as a tomato crop can be very sensitive to too much or too little water. If too much water is supplied, nutrients are leached out of the root zone, oxygen content of the soil can decrease sharply and crop growth may stop temporarily, thereby resulting in reduced yield (Garcia et al., 2000, Hara and Saha, 2000).

Tomato needs adequate irrigation during the early plant growth, fruit set and fruit enlargement stages. About 20 mm of water per week is needed under cool conditions while about 70 mm is needed during hot and dry periods. Constancy of water supply plays a major role in attaining uniform maturity and reducing the incidence of blossom-end rot, a physiological disorder associated with irregular water supply and the resulting calcium deficiency in the fruit during its enlargement (van der Vossen et al., 2004). One of the first signs of water logging is wilting of leaves due to lack of oxygen in the root zone which decreases the ability of the roots to take up water to supply the leaves. If those conditions persist then plants may die, especially in low-lying areas. This can occur at any stage of crop growth (Kent and Theodore, 1982; Poysa, 1987). However, mild water stress during late stages of fruit growth can increase brix levels in the pulp and therefore decrease processing costs, without having any noticeable effect on overall yield (Reid, 2002). Decrease in irrigation frequencies leads to higher values of sugars and solids without any effects on colour and pH (Alvino et al., 1980).

## 2.6 Staking and pruning of tomato plants

Staking can increase fruit yield and size, reduce fruit rot and make spraying, harvesting and other cultural practices easier. Determinate varieties should be staked in the wet season to prevent fruit contact with the soil (Ahmad and Singh, 2006). Pruning, which involves selective removal of side shoots to limit plant growth, can cause fruits to mature earlier and grow to greater size and uniformity (van der Vossen et al., 2004). Pruning improves air circulation within the canopy, which reduces foliar diseases and facilitates spraying and harvesting. Indeterminate varieties should always be pruned so that they do not produce too much vegetative growth. The degree of pruning varies according to season (Chen and Lal, 2000).

## 2.7 Tomato diseases, insect pests and physiological disorders

The most common diseases of tomato include late blight (*Phytophthora infestans*), early blight (*Alternaria solani*), tomato yellow leaf curl, bacterial spot (*Xanthomonas campestris* pv. Vesicatoria), fusarium wilts (*Fusarium oxysporum* f. sp. Lycopersici) and bacterial wilts (*Ralstonia solanacearum)* (AICAF, 1995; Hanson et al., 2000; Kumwenda, 2007; Sindi, 2009).

The common insect pests of tomatoes are tobacco white fly (*Bemisia tabaci*), red spider mites (*Tetranychus evansi*), aphids and tomato fruit worm (*Helicoverpa armigera*) (Hanson et al., 2000; Kumwenda, 2007). Tomato plants are also affected by root-knot nematodes (*Meloidogyne incognita)* and some disorders such as blossom end-rot (BER) (KARI, 1996). Some varieties are resistant to a wide range of diseases. Information of a variety's disease resistance can often be found on the seed packet label For instance, Roma VF, M82-1-8-VF and Cal J are all resistant to verticillium and fusarium wilts (Kokalis-Burelle, 2002 and Kumwenda, 2007).

## 2.8 Harvesting of tomatoes

Generally, the time from transplanting to first harvest of tomatoes is 70 to 75 days for cherry types, 75 to 80 days for the plum types and 80 to 90 days for the large fruited tomatoes. Tomato fruits mature in about 25 to 30 days after fertilization. Maturity is correlated with increased fruit size, weight, specific gravity, total acidity and hydrogen concentration. Fruit category sizes for tomatoes are 205 g, 150 g and 115 g for large, medium and small respectively (Grierson and Kader, 1986). Fresh-market tomato fruits are often harvested at different stages of ripeness, from mature green to pale pink, depending upon distance and time needed to market the fruit while processing fruits are picked when fully ripe. Generally, fruits harvested at pre-ripe stages tend to have lower soluble solids, ascorbic acid and reducing sugars than fruits ripened on the plant (van der Vossen et al., 2004). Tomato fruit maturity stages are categorized into several classes based or ripeness (Table 1).

**Table 1: Tomato fruit maturity stages**

| **Class** | **Description** |
|---|---|
| Green | Entirely light to dark green but mature |
| Breaker | First appearance of external pink, red or tarnish yellow colour, not more that 10% |
| Turning | Over 10% but not more than 30% red pink or tarnish yellow |
| Pink | Over 30% but not more than 60% pinkish or red |

| | |
|---|---|
| Light red | Over 60% but not more than 90% red |
| Red | Over 90% red desirable table ripeness |

Note: All percentages refer to colour, distribution and intensity

Source: Grierson and Kader, 1986

## 2.9 Storage and processing of horticultural crops

Fresh fruits and vegetables are living organisms. However, the act of removing fruit or vegetables (harvesting) from the plant on which it was produced causes many changes to occur. Produce begins dying from the moment of harvest. Handling procedures after harvest determine its useful life. The goal in post harvest handling is to keep the produce in good condition until it is consumed (Ross and Bramlage 1990; Barrett and Kader, 2002).The storage life of tomato fruits depends on the maturity stage at which they were picked and on the desired quality. Quality is highest when completely ripe, whether ripened artificially or on the plant. Ideally mature-green tomatoes should be stored for 7 - 10 days at 13 - 18°C with 85 - 90% relative humidity to ripen properly. Humidities close to 100 percent may cause excessive growth of microorganisms by giving them a wet surface to get established on. Surface cracking may occur on some produce, such as tomatoes (Ross and Bramlage 1990; van der Vossen et al., 2004). The objective of proper storage is therefore to retain the fresh state of the tomato fruit, thereby avoiding deterioration which is mainly caused by water loss and respiration. Amount of water lost by a vegetable crop before becoming unsalable varies with species and varieties within a species. For tomatoes, the maximum permissible loss is 7% of original weight before becoming unsalable (Grierson and Kader, 1986).

Consumers like to obtain and consume fruits and vegetables when they are fresh. Unfortunately most producers are unable to maintain supply of fresh products all year round and their production tends to be seasonal (Barrett and Kader, 2002). The primary goal of food processing and packaging is to minimize wastage by preventing undesirable changes in the food, extend seasonality, prolong product shelf life, improve nutritional quality and add value among others. (Bishop et al., 1982; Barrett and Kader, 2002). According to Dauthy (1995), there are a number of processing systems based on the complexity and level of investment that include small-scale processing that is practiced by small-scale farmers either for personal consumption or for sale in nearby markets. Intermediate-scale processing is practiced by either a group of small-scale processors who pool their resources together or done by individuals and is based on improving the technology used by small-scale processors while large-scale processing is highly mechanized and requires a substantial supply of raw materials for economic operation.

## 2.10 Tomato products and their quality characteristics

### 2.10.1 Tomato products

Tomatoes are widely grown and used in Eastern Africa. During the peak season most farmers sell their tomatoes at throw-away prices and substantial quantities go to waste because they are highly perishable. To avoid this, farmers can process tomatoes into various products for storage and use at home or as value-added products for income generation (CTA, 2008).

Tomato ketchup is generally a term applied to a mashed tomato, whose main ingredients are tomato puree, together with salt, sugar, onion, mustard, vinegar, pepper, mushrooms and other herbs and spices. Recipes vary according to the regulations in each country. The minimum solids (dry matter) are normally around 35%. Its nutritional composition includes water, mineral salts, proteins, fats, sugars, acids, dietary fiber and vitamins. The wide range of components and their different properties require very efficient mixing, which cannot be achieved with traditional agitators, as they do not produce a sufficiently stable mix of the suspended particles and tend to separate. For this and other reasons, high pressure homogenizers have been used for a number of years in the processing of ketchups and other similar sauces (Boriss, 2005).

Tomato sauce includes any of a very large number of sauces made primarily out of tomatoes and served as part of a dish. Tomatoes are ideal for sauces because they have a rich flavour, very soft flesh and the right composition to thicken up into a sauce when cooked. It consists just of chopped tomato flesh (skins and seeds optionally removed), cooked in a little olive oil, until it loses its raw flavour and seasoned with salt. Water, stock or wine is added to keep it from too much drying. Onion and garlic are always added and other seasonings include some spicy red or black pepper (Boriss, 2005).

The product constitutes a thick paste made from ripe tomatoes with skin and seeds removed. It is used to make either ketchup or tomato juice, depending on manufacturing conditions (Boriss, 2005)

### 2.10.2 Tomato product quality characteristics

Fruit quality is a decisive factor in the production of canned tomatoes. Some of the major parameters determining the quality of a tomato product are concentration of soluble solids (degree Brix), acidity (pH), vitamin C levels and protein content..
Degrees Brix ($^{0}$Bx) is a measurement of the dissolved sugar to water mass ratio of a liquid and is measured using a refractometer. It is a summation of the quantities of sucrose, fructose, vitamins, minerals, amino acids, proteins, hormones and other solids in one hundred units of any particular plant juice (de la Torre et al., 1999, Garcia and Barrett, 2006). There are a number of factors that determine the Brix level in a tomato product. One of the factors is the harvesting stage of the fruits in that harvesting tomatoes before full ripeness has an effect not only on peak sugar content but also on full flavour spectrum, which affects consumer acceptability Gourd (1983). Garcia and Barrett (2006) also reported that accumulation of soluble solids largely depends on the rate of starch accumulation during rapid growth phase of development. Tomatoes harvested at the pink or red stage produced thicker pastes with greater serum viscosity and titratable acidity than tomatoes harvested at the more red stage and that soluble solids levels also increased with maturity.

Regarding other factors affecting brix, de la Torre et al., (1999) reported that the effects of classical ingredients such as starch, sunflower oil, citric acid and salt at different concentrations on the Brix value of tomato paste have been measured separately. The results have been used to develop first formulae describing their effect in ketchup. It was reported that the effect of different ingredients on the Brix value of the final products varies. For instance, in ketchup, the addition of salt and acetic acid increases the Brix value more than the addition of citric acid and sugar.   There are positive correlations between $^{o}$Brix and soil available potassium (K), calcium (Ca), magnesium (Mg), lime, organic matter and pH, whereas there are negative correlations with salt and available Na contents. In presence of high available K and Mg content in soil, decreasing irrigation and yield were the most effective factors on increasing Brix of processing tomato (Aydin and Yoltas, 2003). Gourd (1983) indicated the ideal brix values for tomato sauce, ketchup and paste are $18^0$ to $20^0$, $25^0$ to $29^0$ and $29^0$ to $31^0$ respectively.

Vitamin C, also known as ascorbic acid, abounds in nature and is highly labile. It is a water-soluble vitamin that is lost in large amounts during food processing and its prescribed requirement across cultures is not uniform. For example, the prescribed requirement of vitamin C in Great Britain is 30mg/day, while in the U.S.A. it is 60mg/day and 100mg/day in Japan (Walingo, 2005)

Vitamin C plays significant functions in the body that enhance its role in the health status of the human body. The biochemical functions of vitamin C include: stimulation of certain enzymes, collagen biosynthesis, hormonal activation, antioxidant, detoxification of histamine, phagocytic functions of leukocytes, formation of nitrosamine, and proline hydroxylation amongst others. These functions are related to the health effects of vitamin C status in an individual. In human health, vitamin C has been associated with reduction of incidence of cancer, blood pressure, immunity, and drug metabolism and urinary hydroxyproline excretion, tissue regeneration (Gaby and Singh, 1991; Walingo, 2005). Epidemiological data have revealed the preventive and curative role of vitamin C on certain disease conditions in the body though controversies still persist. Vitamin C is effective in protecting against oxidative damage in tissues and also suppresses formation of carcinogens like nitrosamines. There is an inverse relationship with blood pressure and both plasma vitamin C and Vitamin C. Vitamin C has a lowering effect on blood pressure, especially on systolic pressure more than a diastolic pressure. Low levels of plasma vitamin C are associated with stroke and with an increased risk of all cause mortality. Increased consumption of ascorbic acid raises serum ascorbic levels and could decrease the risk of death (Walingo, 2005). It was reported by Gourd (1983) that Vitamin C is easily destroyed by cooking and exposure to light and easily oxidized in air. Tomato sauce, ketchup and paste are required to contain 16 mg/100 g, 49 mg/100 g and 15 mg/100 g of vitamin C, respectively.

Proteins are organic compounds made of amino acids arranged in a linear chain polymer and joined together by peptide bonds between the carboxyl and amino groups of adjacent amino acid residues. Shortly after or even during synthesis, the residues in a protein are often chemically modified by post-translational modification, which alter the physical and chemical properties, folding, stability, activity and ultimately, the function of the proteins. Proteins can also work together to achieve a particular function and they often associate to form stable complexes (Hu et al., 2000).

Like other biological macromolecules such as polysaccharides and nucleic acids, proteins are essential parts of organisms and participate in virtually every process within cells. Many proteins are enzymes that catalyze biochemical reactions and are vital to metabolism. Proteins also have structural or mechanical functions, such as actin and myosin in muscle and the proteins in the cytoskeleton, which form a system of scaffolding that maintains cell shape. Other proteins are important in cell signaling, immune responses, cell adhesion and the cell cycle. Proteins are also necessary in animal diets since animals cannot synthesize all the amino acids they need and must obtain essential amino acids from food that are used in metabolism. Protein is an important component of every cell in the body for instance hair and nails are mostly made of protein. Human body uses protein to build and repair tissues and to make enzymes, hormones and other body chemicals. Protein is an important building block of the bones, muscles, cartilage, skin and blood (Hu et al., 2000).

Acidity level in a food product is a controlling factor in regulating many chemical and microbiological reactions. It ranges from 1 to 14 and is measured using a glass electrode pH meter (Gould, 1983). It is considered that pH 4.6 is the dividing line between acid and non-acid foods. This means that when a product has pH 4.6 or less, germination of bacterial spores from organisms will be inhibited after proper sterilization. Important factors that affect product pH include cultivar, maturity, seasonal variations due to growing conditions, geographical areas, handling prior to processing, processing variables and salt (Gould, 1983). Garcia and Barrett (2006) also reported that pH is very important because acidity influences the thermal processing conditions required for producing safe products. The report indicated that although the pH of mature tomatoes may exceed 4.6, tomato products are generally classified as acid foods (pH 4.6), which require moderate conditions of processing to control microbial spoilage and enzyme inactivation. In addition, Hobson and Grierson (1993) reported that tomato product flavour is dependent on the accumulation and balance between sugar and organic acid content. Garcia and Barrett (2006) suggested 4.4 as the maximum desirable pH to avoid potential spoilage caused by thermophilic organisms and pH 4.25 as the optimum value for processing tomatoes.

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Study site

The research was carried out at Jomo Kenyatta University of Agriculture and Technology horticulture experimental yard, in the horticulture laboratory and in the food processing workshops between September 2008 and June 2009.

## 3.2 Planting material

Certified seeds of three selected processing tomato varieties were sourced from one of the agents of Kenya Seed Company and grown in pots laid out in the field at Jomo Kenyatta University of Agriculture and Technology (JKUAT) under irrigation. These varieties were Roma VF, M82-1-8-VF and Cal-J which are all determinate.

## 3.3 Experimental design

The experiment was laid down in a Completely Randomized Design (CRD) with three treatments. The treatments were processing tomato varieties namely Roma VF, M82-1-8-VF and Cal-J each replicated four times. Each treatment had a total of 16 plants planted in pots, representing a plot spaced at 50 cm apart. The spacing between plots was 1.0 m.

## 3.4 Crop management

### 3.4.1Sowing

The seed was sown in trays (Plate 3a) at the rate of 125 g per hectare and 0.5 cm depth. The growth media used was a mixture of soil and manure, in the ratio of 2:1. The seedlings were transferred into small pots at 18 days after sowing (Plate 3b).

**Plate 3a: Seedlings in tray and pots**

**Plate 3b: Seedlings in small pots**

**Plate 3: Tomato seedlings at vegetative growth stage**

### 3.4.2 Transplanting

Transplanting was done at 36 days after sowing in perforated polythene pots of 8 cm x 14 cm x 14 cm by volume. At this stage, the seedlings had an average of five true leaves (Plate 4). The medium used was a mixture of sandy clay soil and compost manure. The soil was collected at JKUAT and sterilized in the laboratory using a soil sterilizing chamber. Mulching was done in the pots using rice husks in order to reduce water loss since the experiment was laid out in the open.

**Plate 4: Growth stage at which seedlings were transplanted**

### 3.4.3 Watering

Watering was done three times a day and plants were provided, on average 900 ml of water per day depending on the prevailing weather conditions. This was maintained throughout the production period in order to supply adequate moisture to the plants since the experiment was laid in the open and hence prone to high evapo-transpiration.

### 3.4.4 Disease and pest control

Soon after seedling emergence, routine spraying with a fungicide, ridomil and a contact insecticide, cypermethrin was done at weekly intervals. Ridomil was sprayed at the rate of 20 g in 5 litres of water while cypermethrin was being sprayed at the rate of 10 ml in 20 litres of water. Later green copper and asaphat were used as fungicide and systemic insecticide respectively. The insecticides were used to control tobacco whitefly (*Bemisia tabaci*) that transmits Tomato Yellow Leaf Curl (TYLC), a tomato disease caused by Tomato Yellow Leaf Curl Virus. Foliar spray with Easy-gro calcium at a weekly interval was also carried out in order to control blossom end rot that affected almost 40% of the fruits.

### 3.4.5 Fertilizer application

At transplanting, DAP was applied as a basal fertilizer at the rate of 8 g per plant. The first dose of top dressing with Calcium Ammonium Nitrate (CAN) was applied at three weeks after transplanting and at two week intervals thereafter at the rate of 8 g per pot until flowering stage. Later CAN was replaced with NPK, 17:17:17 in order to supply phosphorous and potassium that were essential for flower and fruit development. To boost flowering and fruit set, easy-gro was also used as a foliar spray at the rate of 40 g in 20 litres of water.

### 3.4.6 Desuckering, staking and weeding

At the onset of flowering, all unwanted growing buds and drying leaves were removed from the plant in order to boost flowering and fruit set. The number of days taken from planting to the time when 50% of flower clusters on the plant had some flowers in bloom was recorded. Staking was done just before the flowers started to open in order to avoid the leaves and fruits touching the ground and therefore minimize the incidence of soil-borne diseases. This was done by tying each plant with strings supported by wooden poles (Plate 5). Weeding around the pots and in the pots was done as frequently as the weeds appeared and was a continuous activity during the entire production period.

**Plate 5: Staked tomato plants**

### 3.4.7 Harvesting

Harvesting was done for a period of almost six weeks for all varieties at varying intervals. For M82-18-VF and Cal J it started 66 days after transplanting with a total of nine harvests at varying frequencies depending on readiness of the fruits, while for Roma VF, harvesting started 69days after transplanting with a total of eight harvests also at varying frequencies. The period to fruit maturity was determined by the number of days taken, for the fruit that was uniformly green, to turn red at the bottom end. The fruits were harvested at the breaker stage (Plate 6), when not more than 10% of the mature fruit had turned red, just when the fruit started ripening (Plate 6). The fruits were then stored at 13 to 20°C with 85 to 90% relative humidity to finish ripening and then stored in the cold room at temperatures of between 15$^{O}$C and 20$^{O}$C. To prevent the fruits from deterioration, once the fruits from each harvest were ripe and in adequate quantities, pulp was extracted and stored under freezing conditions to avoid fermentation. From each harvest, the harvest date, number of fruits and weight of fruits were recorded and this data was the basis for fresh yield determination. This included all the fruits regardless of quality.

**Plate 6: Breaker stage of tomato ripening at which harvesting was done**

## 3.5 Data collection

### 3.5.1 Determination of plant growth characteristics of tomatoes

From each of the ten plants in all treatments and replicates, data on plant height and number of main branches was collected on weekly basis until the fruiting stage which was six weeks after planting. The maximum plant height and number of main branches per plant at six weeks of growth were recorded and used to determine the differences in plant growth characteristics. At this stage two plants were selected from each treatment, leaves were removed, counted and then plant leaf area was determined using a LI-COR, inc. Lincoln, Nebraska, USA area metre model number LI-3100. The average leaf area for each plant was divided by the ground area occupied by the plant to come up with the LAI.

#### 3.5.2 Determination of fresh fruit yield of tomatoes

Data on fresh fruit yield was collected from the same ten plants used for growth analysis at each harvest and included number of fruits per plant and average fresh weight of fruits per plant. This data was used to determine fresh fruit yield per plant which was converted to area yield.

#### 3.5.3 Determination of storage life of fresh tomato fruits

### Overall visual fruit quality

From each of the treatments, ten freshly harvested fruits were randomly selected and kept under room temperature of between 20 to 25°C with 85–90% relative humidity in order to assess the differences in the shelf life until extreme physical deterioration of the fruits beyond usable form was observed. A rating scale for overall visual quality for tomato fruits (Table 2) was used to assess physical deterioration of the fruits during the storage period at five day intervals. Pictures of the physical condition of the fruits were taken at days 16 and 31 of storage.

**Table 2: Rating scale for overall visual quality of tomato fruits**

| Rating | Description |
|---|---|
| 9 | Excellent, essentially no symptoms of deterioration |
| 7 | Good, with minor symptoms of deterioration not objectionable |
| 5 | Fair, deterioration evident but not serious |
| 3 | Poor, serious deterioration, limit of salability |
| 1 | Extremely poor, not usable |

Source: Grierson and Kader, 1986).

**Percentage loss in fruit weight over time**

The other parameter used to determine the storage characteristics of fresh fruits was the percent fruit weight loss over time. From the ten fruits randomly selected for visual quality deterioration assessment, data on average fruit weight was recorded at five day interval for a period of 31 days of storage and average fruit weight loss was used to determine the percentage fruit weight loss.

### 3.5.4 Determination of processing and product quality characteristics of tomatoes

**Pulp extraction**

Pulp extraction involved washing the fruits thoroughly, removing the pistil scars and then blanching the fruits by dropping the tomatoes into the rapidly boiling water for 60 seconds until the skins split. The fruits were then immediately removed from the water with a slotted spoon and dipped into cold water. After about a minute, they were removed from the water and blended into pulp.

The pulp was further sieved to remove skins and seeds (CTA, 2008). A total of 626, 441 and 393 tomato fruits weighing 17. kg, 14.2 kg and 14 kg of Roma VF, M82-1-8-VF and Cal J, respectively were used for extraction of pulp. The volume of pulp for each given number and weight of fruits was recorded for each treatment and used to determine the proportion of pulp to the weight of the fruits used. The pulp from each treatment was then partitioned into three parts for processing of tomato sauce, tomato ketchup and tomato paste.

**Product ingredients**

In sauce and ketchup processing, for each kilogramme of the pulp, the following ingredients were used; 7.5 g of sugar, 2.75 g salt, 0.3 g citric acid, 1.5 ml vinegar, 0.2 g mixed spices, 0.03 g xanthum gum, 0.05 g sodium benzoate, 1.8 g corn starch, 1.0 g onion and 0.5 g garlic**.** However, for paste processing only 2.75 g salt was added for each kilogramme of tomato pulp used.

**Processing procedure**

The pulp was boiled in a pot for about 5 minutes at a temperature range of between 85 and 95$^0$C after which sugar, salt and citric acid were added proportional to the pulp volume followed by corn starch (dissolved in water). As boiling continued, onion and garlic were crashed, mixed with spices and added to the pulp. For sauce, the pulp with the added ingredient was left to boil for a minimum of 20 minutes to achieve a desired concentration of $18^0$Brix, while for ketchup, boiling was done for at least 25 minutes to achieve the desired $25^0$Brix while a minimum of 25 minutes elapsed for tomato paste to achieve a desired target of $31^0$Brix. The brix level was measured using a refractometer.

After reaching the achievable (not necessarily the desired/ideal) brix for each product, vinegar and sodium benzoate were added. The final product was then left to cool to $70^0$C before being packed in sterilized bottles, sealed and stored in the cold room at between $15^0$C and $20^0$C. There were a total of 12 samples of each product processed i.e. three products (sauce, ketchup and paste) from each of the three varieties in all the four replicates.

#### 3.5.5 Determination of product quality

**Product pH**

During pH determination, 5 g of each product sample were dissolved in distilled water and stirred thoroughly to obtain the product solution. The pH was then measured using a glass electrode pH meter.

**Ascorbic acid (vitamin C) content**

This was done using visual titration with 2, 6, - Dichlorophenolindophenol solution (AOAC, 1996a). The reagents used included 10% trichloroacetic acid (TCA) solution that was prepared by dissolving 100 g of TCA in 1 litre of distilled water; standard ascorbic acid solution (1 mg/ml) prepared by dissolving 100 g of pure ascorbic acid in 10% TCA solution and made to 100 ml mark with distilled water in a volumetric flask and standard 2,6-dichlorophenolindophenol solution prepared by dissolving 42 mg of sodium carbonate in 50 ml of distilled water contained in a 200 ml volumetric flask, then dissolving 50 mg of 2, 6 – dichlorophenolindophenol (indophenol sodium) completely in the sodium carbonate solution and diluted to 200 ml mark with distilled water. The solution was filtered into a glass- stoppered brown bottle and kept in a refrigerator.

Standardization of 2, 6 – dichlorophenolindophenol solution was done by pipetting 5 ml of 10% TCA solution into 3 flasks, adding 2 ml of standard ascorbic acid solution to each of the flasks and then titrating with indophenol solution until pink colour appeared. A blank was also standardized by pippeting 7 ml of 10% TCA solution into 3 flasks, adding distilled water equivalent to the indophenol solution used in the titration above and then titrating with indophenol solution until a pink colour appeared.

The standard was calculated as:

$$\text{mg of ascorbic acid equiv. to 1.0ml. of indophenol solution} = \frac{\text{mg of asc. acid in 2 ml of std solution}}{\text{Titre of indophenol solution}}$$

Ascorbic acid content of the samples (Plate 7a) was carried out by weighing accurately 5 g of each product sample (Plate 7b), transferred into a 100 ml volumetric flask, rinsed and made to the 100 ml mark with 10% TCA (Plate 7c), mixed well and filtered (Plate d). 10ml of the solution was transferred into conical flasks (Plate 8e) and titrated with indophenol solution until pink colour appeared (Plate 7f). For the blank 10 ml of 10% TCA solution was pipetted, distilled water equivalent to the volume of indophenol solution that was used above added and then titrated with indophenol solution until the pink colour appeared.


**Plate 7a: Tomato ketchup product**

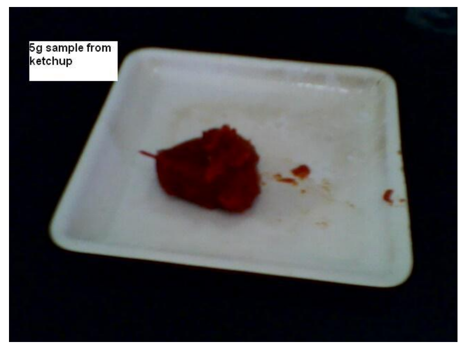



**Plate 7b: 5g sample of tomato ketchup**


**Plate 7c: Sample dissolved in 100ml of TCA**


**Plate 7d: Sample filtration in process**

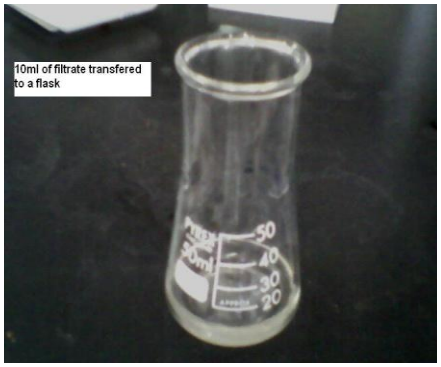



**Plate 7e: 10ml of filtered sample transferred to flask**

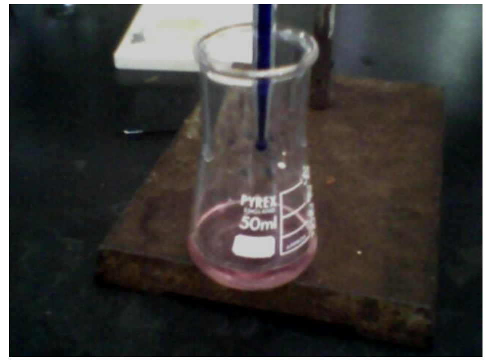


**Plate 7f: Filtrate changes colour to pink**

**Plate 7: Ascorbic acid determination procedure**

Vitamin C content (mg/100 g) was calculated using the formula:

$$(A - B) \times C \times \frac{100}{10} \times \frac{1}{S} \times 100$$

Where 100/10 = volume of extract used for determination

A = Volume in ml of the indophenol solution used for sample

B = Volume in ml of the indophenol solution used for blank

C = Mass in mg of ascorbic acid equivalent to 100 ml of standard indophenol solution

S = Weight of sample taken (g)

**Protein content**

This was done using Kjedahl's method (AOAC, 1996b). Firstly, digestion of each sample was done by mixing 5g of the sample with 15ml sulphuric acid and

15g of a catalyst. The catalyst was prepared by mixing 10 parts of potassium sulphate ($K_2SO_4$) with 1 part of copper-5-hydrate (cupric sulphate). The mixture was then digested by boiling using a block digester until the sample turned green or greenish blue. The sample was then transferred to a 100ml volumetric flask and made to the 100ml mark by adding distilled water. Then the sample was distilled where free ammonia was liberated from the solution in presence of excess alkali, sodium hydroxide (NaOH). The distillate was collected in a receiver (50ml conical flask) containing excess boric acid with drops of mixed indicator. The reagents used included 40% NaOH prepared by dissolving 400g NaOH in distilled water and then diluted to 1.0litre; 4% boric acid ($H_3BO_3$) prepared by dissolving 10g of boric acid in 1000ml distilled water and diluted to 1000ml and mixed indicator prepared by dissolving 0.009g blomocresol green, 0.066g methyl red and 0.011g thymol blue with shaking in 100ml ethanol. The steam distillation apparatus was set up and ammonia ($NH_3$) free distilled water was used wherever possible. 10ml of the sample digest was transferred to the reaction chamber of the distillation apparatus and added 10 ml NaOH. Steam distillation was carried out into 5 ml of 1% Boric acid containing 4 drops of mixed indicator. Distillation continued for about 2 minutes from the time the indicator turned green.

The distillate was then removed and titrated using 0.2 ml hydrochloric acid (HCl) until the indicator changed from green to a definite pink colour. This process was repeated for all the samples.

The % nitrogen was calculated using the following formula:

$$\% \text{ N in sample} = \frac{(\mathbf{a} - \mathbf{b})\ 0.2 \times \mathbf{v} \times 100}{1000 \times \mathbf{w} \times \mathbf{al}}$$

Where **a** = volume of the titre HCl for the sample, **b** = volume of the titre HCl for the blank, **v** = final volume of the digestion (100 ml), **w** = weight of the sample taken (5 g) and **al** = aliquot of the solution taken for analysis (10 ml). For example a sample that had a titre reading of 1.9 the following was the calculation for % nitrogen:

$$\% \text{ N in the sample} = \frac{1.9 \times 0.2 \times 100 \text{ ml} \times 100}{1000 \times 5 \text{ g} \times 10 \text{ ml}} = 0.076\% \text{ N}$$

So % N was calculated for each of the titre readings

Calculation of protein content (g/100 g) in the sample was based on the assumption that a food sample contains 16% protein.

$$\text{Protein content (g/100 g)} = \% \text{ N} \times \frac{100}{16} = \% \text{ N} \times 6.25$$

## 3.6 Data analysis

The data was subjected to Analysis of Variance (ANOVA) to establish if there were significant differences among the treatment effects at 5%, 1% or 0.1, using Genstat computer package. The means were separated using Duncan's Multiple Range Test (DMRT) to check for any significant differences among them. Correlation analysis among the growth parameters and fresh yield was also done.

# CHAPTER FOUR: RESULTS

## 4.1 Growth, yield and storage characteristics of tomatoes

### 4.1.1 Plant growth

The mean temperature at the study site averaged between 20 and 27$^0$C during the production period. Seed emergence occurred at 5 days after sowing with 75%, 100% and 84% emergence rate for Cal-J, Roma VF and M82-1-8-VF, respectively.

Analysis of plant growth parameters showed significant differences (P≤ 0.05) among the three varieties in all the parameters under growth characteristics i.e. number of main branches, plant height, number of leaves, leaf area and leaf area index (Table 3).

**Table 3: Tomato plant growth characteristics at 6 weeks after planting**

| Variety | No of main Branches/plant | Plant height (cm) | No of leaves per plant | Leaf area (cm$^2$/plant) | Leaf area index |
|---|---|---|---|---|---|
| Roma VF | 13.25a | 43.88a | 201b | 752.5b | 5b |
| M82-1-8-VF | 11.25b | 43.73ab | 162ab | 468.6a | 3a |
| Cal J | 11.75ab | 40.35b | 139a | 359.2a | 2a |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

As shown in Table 3 above, at six weeks after planting, Roma VF had a significantly higher (P≤ 0.05) leaf area and leaf area index compared to Cal J and M82-1-8-VF. As regards number of leaves per plant and plant height, Roma VF had significantly higher ($P \leq 0.05$) means than Cal J but there was no significant difference ($P > 0.05$) with M82-1-8-VF while in number of main branches per plant, Roma VF was significantly higher ($P \leq 0.05$) than M82-1-8-VF but not significantly different ($P > 0.05$) from Cal J.

Correlation analysis showed that 93.7% of the changes in leaf area may have been attributed to the number of leaves that the plant had. The number of main branches per plant may have accounted for only 11.9% of the achievement in the number of leaves per plant.

### 4.1.2 Fresh fruit yield

In fresh fruit yield, there were significant differences ($P \leq 0.05$) among the varieties in all the parameters of number of fruits per plant, average fruit weight, yield per plant and yield per hectare (Table 4).

**Table 4: Fresh fruit yields**

| Variety | No of fruits per plant | Average fruit weight (g) | Plant yield (g/plant) | Hectare yield (mt/ha) |
|---|---|---|---|---|
| Roma VF | 38.6b | 23.4a | 909.3b | 15.2b |
| M82-1-8-VF | 23.2a | 28.2b | 659.1a | 11.0a |
| Cal J | 26.4a | 27.7b | 725.7a | 12.1a |

**Note:** Means followed by the same letter are not significantly different ($P \leq 0.05$)

Roma VF had a highly significant ($P \leq 0.001$) mean in number fruits per plant, yield per plant and yield per hectare compared to Cal J and M82-1-8-VF. However, in average fruit weight, Roma VF recorded a significantly ($P \leq 0.05$) lower mean compared to the other two varieties. Cal J and M82-1-8-VF were not significantly different ($P > 0.05$) in all the yield parameters. Correlation analysis of plant growth characteristics and yield (Appendix VII) showed that 89% of the yield per plant may have been due to the number of fruits per plant. In the same manner, 70.7% of the achievement in the number of fruits per plant may have been contributed by leaf area per plant. However, the analysis showed that average fruit weight might not have any influence on the total plant yield as reflected by its negative correlation coefficient.

### 4.1.3 Storage characteristics of fruits under ambient conditions

**Percentage loss in fruit weight over time**

Determination of fresh fruit storage characteristics (Table 5) showed that there were significant differences ($P \leq 0.05$) among the varieties in the % fruit weight loss during all days of storage under similar ambient conditions apart from on day 16 where no significant differences ($P > 0.05$) were not observed.

**Table 5: Percentage loss in tomato fruit weight over time**

| Variety | % wt loss (day 6) | % wt loss (day 11) | % wt Loss (day 16) | % wt Loss (day 21) | % wt loss (day 26) | % wt loss (day 31) |
|---|---|---|---|---|---|---|
| **Roma VF** | 13.8b | 23.5b | 29.8a | 39.2b | 46.5b | 53.8b |
| **M82-1-8-VF** | 8.3a | 16.8a | 27.8a | 28.8a | 33.9a | 37.7a |
| **Cal J** | 11.5ab | 22.1b | 27.5a | 37.5b | 43.9b | 49.3b |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

On day 6 of storage, M82-1-8-VF recorded a significantly lower (P≤ 0.05) mean in fruit weight compared to Roma VF but was not significantly different (P>0.05) from Cal J. On days 11, 21, 26 and 31, M82-1-8-VF also recorded significantly (P≤ 0.05) lower average fruit weight losses compared to both Roma VF and Cal J. However, on day 16, there were no significant differences (P>0.05) in % fruit weight loss among all the varieties.

**Physical fruit texture changes over time**

Using a rating scale for overall visual quality of the tomato fruits by Grierson and Kader, (1986), results of physical fruit texture changes (Plates 7 to 9), showed that both at 16 and 31days fruits of Roma VF were deteriorating at the fastest rate while fruits of M82-1-8-VF were deteriorating at the slowest rate among all the varieties.



**Plate 8a: Fruits at day 16** **Plate 8b: fruits at day 31**

**Plate 8: Fresh fruit condition for Roma VF tomato variety**



**Plate 9a: Fruits at day 16** **Plate 9b: Fruits at day 31**

**Plate 9: Fresh fruit condition for M82-1-8-VF tomato variety**


**Plate 10a: Fruits at day 16** **Plate 10b: Fruits at day 31**

**Plate 10: Fresh fruit condition for Cal J tomato variety**

Despite no significant differences (P>0.05) in the % weight loss among the varieties, by the sixteenth ($16^{th}$) day of storage under ambient conditions, fresh fruits of M82-1-8-VF (Plate 8a) were still fairly good, with minor symptoms of deterioration and no objectionable storage (rating 7), fresh fruits of Cal J (Plate

9a) were fair, deterioration was evident but not serious (rating 5) while fresh fruits of Roma VF (Plate 7a) were poor with serious deterioration and limit of salability (rating 3). However, by day 31, fresh fruits of M82-1-8-VF (Plate 8b) were fair, deterioration was evident but not serious (rating 5), fresh fruits of Cal J (Plate 9) were poor with serious deterioration and limit of salability (rating 3) while fresh fruits of Roma VF (Plate 7b) were extremely poor and not usable (rating 1).

## 4.2 Processing and product quality characteristics of tomatoes

### 4.2.1 Processing characteristics

**Tomato sauce processing**

Analysis of tomato sauce processing characteristics (Table 6) showed that there were no significant differences (P>0.05) among all the three varieties in all the parameters under study.

**Table 6: Tomato sauce processing characteristics**

| Variety | Pulp: fruit wt ratio | Proportion product to pulp (%) | $^{O}$Brix |
|---|---|---|---|
| Roma VF | 0.6a | 50.6a | 10.8a |
| M82-1-8-VF | 0.7a | 52.4a | 12.3a |
| Cal J | 0.7a | 42.1a | 13.0a |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

**Tomato ketchup processing**

Just like with tomato sauce, results of tomato ketchup processing (Table 7) showed that there were no significant differences (P>0.05) among the three varieties in all the parameters under processing characteristics of tomato ketchup.

**Table 7: Tomato ketchup processing characteristics**

| Variety | Proportion product to pulp (%) | $^{O}$Brix |
|---|---|---|
| Roma VF | 33.7a | 19.0a |
| M82-1-8-VF | 38.4a | 20.8a |
| Cal J | 36.9a | 19.5a |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

**Tomato paste processing**

There were no significant differences (P>0.05) among all the varieties in proportion of product to pulp (%) and $^{O}$Brix.

**Table 8: Tomato paste processing characteristics**

| Variety | Proportion product to pulp (%) | $^{O}$Brix |
|---|---|---|
| Roma VF | 26.8a | 32.5a |
| M82-1-8-VF | 26.6a | 24.9a |
| Cal J | 22.5a | 29.0a |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

### 4.2.2 Product quality characteristics

**Tomato sauce**

In the analysis of quality characteristics of tomato sauce, results (Table 9) showed that there were no significant differences (P>0.05) among the three varieties in the pH level and Vitamin C content. The only significant difference (P≤ 0.05) was in protein content.

**Table 9: Tomato sauce quality characteristics**

| Variety | pH | Vitamin C content (mg/100 g) | Protein content (g/100 g) |
|---|---|---|---|
| Roma VF | 4.1a | 9.4a | 0.4a |
| M82-1-8-VF | 4.0a | 5.9a | 0.4a |
| Cal J | 4.3a | 4.9a | 0.7b |

**Note:** Means followed by the same letter are not significantly different (P≤ 0.05)

Ca J had a significantly higher (P≤ 0.05) protein content compared to Roma VF and M82-1-8-VF respectively.

**Tomato ketchup**

In the quality characteristics of tomato ketchup, results (Table 10) showed that there were no significant differences (P>0.05) among all the three varieties in all the parameters of pH, Vitamin C content and protein content.

**Table 10: Tomato ketchup quality characteristics**

| Variety | pH | Vit. C content (mg/100 g) | Protein content (g/100 g) |
|---|---|---|---|
| Roma VF | 4.0a | 6.0a | 0.8a |
| M82-1-8-VF | 4.0a | 9.4a | 0.4a |
| Cal J | 4.1a | 5.6a | 0.7a |

**Note:** Means followed by the same letter are not significantly different ($P \leq 0.05$)

**Tomato paste**

In the quality characteristics of tomato paste, results (Table 11) showed the same trend as in tomato sauce in that the only significant difference ($P \leq 0.05$) was observed in protein content while there were no significant differences ($P > 0.05$) in Vitamin C content and product pH.

**Table 11: Tomato paste quality characteristics**

| Variety | pH | Vit. C content (mg/100 g) | Protein content (g/100 g) |
|---|---|---|---|
| Roma VF | 4.1a | 5.9a | 0.7a |
| M82-1-8-VF | 4.2a | 5.6a | 0.8a |
| Cal J | 4.1a | 3.8a | 1.1b |

**Note:** Means followed by the same letter are not significantly different ($P \leq 0.05$)

Cal J had a significantly higher ($P > 0.05$) protein content compared to M82-1-8-VF and Roma VF.

# CHAPTER FIVE: DISCUSSION

## 5.1 Growth, yield and storage characteristics of tomatoes

### 5.1.1 Plant growth

Roma VF had a significantly higher ($P \leq 0.05$) leaf area and leaf area index compared to Cal J and M82-1-8-VF. As regards number of leaves per plant and plant height, Roma VF had significantly higher ($P \leq 0.05$) means than Cal J but there was no significant difference ($P>0.05$) with M82-1-8-VF while in number of main branches per plant, Roma VF was significantly higher ($P \leq 0.05$) than M82-1-8-VF but not significantly different ($P>0.05$) from Cal J.

Correlation analysis results for plant growth characteristics showed that 93.7% of the leaf area may have been attributed to increase in number of leaves. This explains why Roma VF, which had a significantly higher number of main branches, had significantly higher number of leaves/plant, leaf area (LA) per plant as well as leaf area index (LAI).

Norio (2001) reported that the best LAI for tomatoes, at a height of 2 metres, with high yield for the whole year, was a value of 4. The results indicated that although Roma VF had a high LAI of 5, the height was 0.4 metres which was too low compared to what was reported in the literature. This explains why the variety achieved a lower yield than its potential. It was also reported by Scholberg et al., (2000) that the estimated radiation use efficiency (RUE) for tomato averaged 1.05 g dry weight $MJ^{-1}$ $m^{-2}$, with 50 to 60% light interception in the crop production area at LAI values of 4 to 5 and that relationships between degree days, estimated cumulative intercepted radiation and fruit yield accounted for much of the variation in fruit yields. The significantly high LAI of 5.0 that Roma VF recorded compared to the other two varieties was therefore very ideal for better RUE and attainment of high fruit yield. Research work by Elattir (2003) comparing three different plant densities of two processing tomato varieties showed that when plant density increased, the number of clusters per square metre increased significantly with no difference between varieties. However, the fruit set percentage decreased from the first to the third cluster when plant density increased. However, Heuvelink et al. (2005) reported that although existing knowledge on the effects of growth factors on fruit yield of field-grown tomato is appreciable, detailed studies of crop and canopy characteristics appear to be lacking. He also reported that although results of some studies outlined some growth characteristics of field-grown tomato for one location and season, more detailed studies of crop and canopy characteristics are required to define general trends across seasons and locations, particularly in support of modeling approaches for field-grown tomato. Heuvelink et al. (2005) also reported that current understanding of growth characteristics for field-grown tomato appears to be lagging behind comparable knowledge for several other crops.

### 5.1.2 Fresh fruit yield

Roma VF had a highly significant ($P\leq0.001$) number of fruits per plant, yield per plant and yield per hectare compared to Cal J and M82-1-8-VF. However, on average fruit weight, Roma VF was significantly lower ($P\leq0.05$) than the other two varieties. Cal J and M82-1-8-VF were not significantly different ($P>0.05$) in all the yield parameters.

All the results, with regard to number of fruits per plant, average fruit weight and yield per hectare, were lower than earlier findings reported by the Sindi (2009) and KARI (1991). The results showed that the average number of fruits per plant for Roma VF, M-82-1-8-VF and Cal J were 38, 23 and 26 against the reported values of 52, 34 and 38 respectively, while the achieved fruit weight for the varieties averaged 23.4, 28.2 and 27.7 g against 113, 75 and 55 g respectively. Overall, the results showed that Roma VF, M82-1-8-VF and Cal J gave yields of about 15.2, 11 and 12.1 tonnes against the reported figures of 83, 57 and 77 tonnes per hectare against respectively. However, the results showed that Roma VF had a significantly lower average fruit weight and a significantly higher yield among the three varieties, which agrees with earlier results by Sindi (2009) and KARI (1991). However, results on yield per hectare agree with the earlier results that show that Roma VF had a higher value compared to the other two varieties. The differences in yield levels among the varieties could also be in line with what Gourd (1983) reported that genetic traits, environmental conditions, cultural practices, physiological disorders and fruit defects all contribute to productivity.

In both studies, Roma VF had a higher yield per hectare compared to Cal J and M82-1-8-VF. This higher yield might have come about due to its significant high leaf area that agrees with what was reported in literature by Gourd (1983), that tomato yield is positively related to quantity of solar radiation received by the crop in long season crops. Gourd (1983) also reported that carbon dioxide enrichment increases individual fruit weight and total yield and in addition, fruit size and yield, appear to be dependent on assimilate distribution within the fruiting plant, which is controlled by both sources and sinks. When assimilate availability is lower than total demand, competition between sinks becomes a determinant factor for assimilation distribution. The high yield in Roma VF variety might be attributed to its high leaf area, which lead to increased quantity of solar radiation received and carbon dioxide enrichment, resulting in high assimilate availability. This meant better distribution of the available assimilates and reduced competition between sinks. The high yield is also supported by what was reported from previous research by works by Elattir (2003) that the highest plant density in processing tomatoes increased the yield by 40% without significant difference between the varieties. This is supported by correlation analysis results between plant growth characteristics and yield (Appendix VII) that showed that 89% of the yield per plant was positively correlated to the number of fruits per plant and 70.7% of the achievement in the number of fruits per plant was also positively correlated to leaf area per plant. This agrees with what was reported by Heuvelink et al. (2004) that dry matter partitioning is simulated based on the relative sink strengths of the plant organs. Within the plant, individual fruit trusses and vegetative units are distinguished. High leaf area results into increased light interception which in turn leads to increase in accumulation of radiant energy. As a result of this there is an increase in assimilate levels within the sinks. With the increase in assimilate levels, there is reduced competition among the available sinks, which brings about high plant yields. This shows that one of the possible ways of increasing yield in a plant are through increase in leaf area and photosynthetic rate and hence an increase in the number and capacity of the sinks.

The low fruit weight in Roma VF might be due to what Elattir (2003) found out that the mean fruit weight decreased when the plant density increased. The small fruit size in Roma VF might have come about as a result of high fruit number per plant that increased the number of sinks for the assimilates that were available for fruit development, but still managed to give a higher yield per plant. Yield, in this case, was therefore more of a function of number rather than average weight of fruits.

### 5.1.3 Storage characteristics

**Percentage change in fruit weight and physical texture over time**

Results of storage characteristics of fresh tomato fruits showed that on day 6 of storage, M82-1-8-VF recorded a significantly lower ($P \leq 0.05$) average fruit weight loss compared to Roma VF but was not significantly different ($P > 0.05$) from Cal J. On days 11, 21, 26 and 31, M82-1-8-VF also recorded significantly lower ($P \leq 0.05$) average fruit weight losses compared to both Roma VF and Cal J over the same period and under similar storage conditions. However, on day 16, there were no significant ($P > 0.05$) differences in % fruit weight loss among all the varieties. Results showed that by the sixth day fruits of all varieties had passed the permissible weight loss that was reported by Grierson and Kader (1986) that for tomato, the maximum permissible loss is 7% of original weight before becoming unsalable.

The fast rate of deterioration of the fruits might be attributed to the fact that the fruits were exposed to open air conditions. This might have exposed the fruits to high transpiration, leading to moisture loss. This agrees with what Barrett and Kader (2002) and van der Vossen et.al (2004) reported that the act of harvesting the fruit from the plant causes many changes to occur and mature-green tomatoes should be stored at 13 to 18$^{o}$C with 85 to 90% relative humidity. They also reported that deterioration is mainly caused by water loss and respiration and the amount of water lost by a vegetable crop before becoming unsalable varies with species and also varieties within a species. That is the reason why the rate of deterioration was different among the three varieties despite the fruits being exposed to similar conditions. The desiccation from moisture loss adversely affected the appearance, texture and weight of the fresh fruits, which agrees with what was reported by Ben-Yehoshua (1987), Seymour et al. (1993) and KAYS (1997) that transpiration, induces wilting, shrinkage as well as loss of firmness and succulence, all of which are components of freshness.

The results also showed that among the three varieties, fruits of Roma VF achieved a higher % weight loss throughout the storage period and showed rapid deterioration as observed using a rating scale for overall visual quality of the tomato fruits. This agrees with what was reported by Skrupskis et al. (2010) that natural losses are characterized by losses of moisture which unfavorably influence the storage ability of fresh produce. Roma VF which had the greatest loss in fruit weight also had the shortest period to ripening and deterioration, the opposite of which was the case with M82-1-8-VF.

## 5.2 Determination of processing and product quality characteristics of tomatoes

### 5.2.1 Processing characteristics

#### Proportion of pulp to fruit weight and product to pulp volume

Results of processing characteristics showed that there were no significant differences ($P>0.05$) among the varieties with regard to proportion of pulp to fruit weight and proportion of product to pulp volume (%) in the processing of all products of tomato sauce, tomato ketchup and tomato paste. The results fell short of the achievable yield reported by Boriss (2005) that in the humid state, one can value a yield of 97%, in respect to the tomato, with the remaining 3% being waste (peels and seeds). This might be attributed to a number of factors that include processing method used, volume of pulp used, differences in ripeness and even variety differences from those that were used to come up with the recommendation above. These factors are in line with what Boriss (2005) reported that the yield of juice extracted from the tomato depends on variety, form and dimensions of the berry, condition of ripeness and preparation technique.

**Degrees Brix ($^{O}$Brix) for all the products**

Analysis of the brix level in all the products showed that there were no significant differences (P>0.05) among the three varieties. The highest brix values were $13^0$, $21^0$ and $29^0$ in tomato sauce, ketchup and paste respectively. These results were lower than what was reported by Gourd (1983) that gives ideal brix values for tomato sauce, ketchup and paste to be $18^0$ to $20^0$, $25^0$ to $29^0$ and $29^0$ to $31^0$respectively.

One of the reasons why the ideal Brix levels were not achieved could be due to the fact that the fruits were harvested at breaker stage, before they were fully ripe and thereby leading to reduced accumulation of sugars that determine the brix level. This agrees with what was reported by Gourd (1983) that harvesting tomatoes before full ripeness has an effect not only on peak sugar content but also on full flavour spectrum, which affects consumer acceptability. Garcia and Barrett and Kader (2002) reported that accumulation of soluble solids largely depends on the rate of starch accumulation during rapid growth phase of development. Tomatoes harvested at the pink or red stage produced thicker pastes with greater serum viscosity and titratable acidity than tomatoes harvested at the more red stage and that soluble solids levels also increased with maturity.

This might also explain why the products did not achieve the desirable brix levels as they could have been not fully mature at the harvesting time.

### 5.2.2 Product quality characteristics

**Product pH**

Analysis of the products for pH showed that there were no significant differences ($P>0.05$) among the varieties in all products. The pH levels in all the products ranged between 4.0 and 4.3. The pH levels obtained are in line what was reported by Gould (1983) that pH 4.6 is the dividing line between acid and non-acid foods in that when a product has pH 4.6 or less, germination of bacterial spores from organisms is inhibited after proper sterilization. According to Gould (1983), important factors that affect product pH include cultivar, maturity, seasonal variations due to growing conditions, geographical areas, handling prior to processing, processing variables and salt. The results showed that all the products from all varieties were in the category of acid foods as they recorded a mean product pH of less than 4.6 and therefore able to inhibit bacterial spore germination. This means they all had the capacity to be stored for a long period before spoilage. This is also in line with what Garcia and Barrett (2006) reported that pH is very important because acidity influences the thermal processing conditions required for producing safe products. The report indicated that although the pH of mature tomatoes may exceed 4.6, tomato products are generally classified as acid foods (pH 4.6), which require moderate conditions of processing to control microbial spoilage and enzyme inactivation. In addition, Hobson and Grierson (1993) reported that tomato product flavour depends on the accumulation and balance between sugar and organic acid content. It was suggested by Garcia and Barrett (2006) that pH 4.4 is the maximum desirable to avoid potential spoilage caused by thermophilic organisms and pH 4.25 as the optimum value for processing tomatoes within which all the products fell.

The slight differences in product pH among the three varieties, though not significant, might be due to variation in variety and maturity. The other factors such as seasonal variations, geographical area, handling prior to processing, processing variables and salt, as reported in literature, could not contribute to these differences since they were similar in all the treatments.

**Vitamin C content**

Results from Vitamin C analysis of all the three products showed no significant differences among the three varieties. In tomato sauce and tomato ketchup the highest vitamin C content was 9.40 mg/100 g in each product while in tomato paste the highest content of 5.92 mg/100 g was recorded. These ascorbic acid levels were lower than what was reported by Gourd (1983) which shows that tomato sauce, ketchup and paste should have 16 mg/100 g, 49 mg/100 g and 15 mg/100 g, respectively.

The differences between the current results and what was reported in literature might be attributed to a number of factors. One of the factors could be related to what Gourd (1983) reported that yield and quality of tomato products depend in great measure upon the composition of the raw material. This means that the low ascorbic content levels might have come about due to low content in the raw tomatoes that were used to process the products. Another factor could be related to the rate at which the nutrient was lost from the raw tomatoes due to processing as reported by Gaby and Singh, 1991 that Vitamin C is easily destroyed by cooking and by exposure to air and light. It was reported that vitamin C chemically decomposes under certain conditions, many of which may occur during the cooking of food. The other reason for low levels in the products could be loss of the vitamin due to leaching, where the water-soluble vitamin dissolves into the cooking water and is later poured away and not consumed Gaby and Singh (1991). This is highly possible because during processing of the tomato products there was a step when sieving was done after blanching and the water was discarded before blending. Some of the vitamin C might have been lost with the water. However, differences in tomato varieties used in the two studies might also have contributed to the outcome of the results.

**Protein content**

An analysis of the protein content in the products showed that, in tomato sauce, Ca J had a significantly higher ($P \leq 0.05$) protein content compared to Roma VF and M82-1-8-VF. In tomato ketchup, it was again Cal J that had a significantly higher ($P \leq 0.05$) mean protein content compared to the other two varieties. However, in tomato ketchup, results showed that there were no significant differences ($P>0.05$) among all the three varieties. The protein content in all products ranged from 0.4 g/100 g to 1.1 g/100 g.

According to Roberts (2002) the Recommended Dietary Allowance (RDA) for protein in adults is 0.79 g per kg of body weight each day. For children and infants, the RDA, described as the amount of a nutrient in the diet that should decrease the risk of chronic diseases for most healthy individuals, is doubled and tripled, respectively, due to their rapid growth. The protein contents in the products were therefore in line with this requirement as they were within the recommended allowance. In addition to this, Hu et al., 2000 reported that there is evidence that suggests that people who eat high-protein diets typically excrete excess calcium in their urine. This means that the body releases stores of calcium into the bloodstream to counteract an increase in acids caused by protein consumption. Considering the risks of consuming high protein foods as reported by Hu et al., 2000, the protein levels obtained in all products were normal and not nutritionally hazardous to the consumer. This means they were within the acceptable levels recommended for human consumption.

# CHAPTER SIX: CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS

## 6.1 Conclusions

Roma VF was a significantly better variety in plant growth having recorded the highest means in number of main branches, number of leaves and leaf area compared to the other two varieties. In fresh fruit yield, despite recording a significantly lower mean fruit weight, Roma VF was a significantly better variety with highest means in number of fruits per plant and fresh fruit yield per plant. However, in storage characteristics, fresh fruits of M82-1-8-VF had significantly better storage characteristics at $25^{0}$C and relative humidity of 85 to 90 %.

In all processing characteristics, no variety was significantly better than the other in the proportion of pulp to fruit weight, proportion of product to pulp as well as degrees brix in all the three products of tomato sauce, ketchup and paste. However, in product quality characteristics, Cal J was a significantly better variety in mean protein content in two products of tomato sauce and paste than the other two varieties while Roma VF was a significantly better variety with regard to protein content in tomato ketchup. No variety was better than the other in product pH and Vitamin C content.

## 6.2 Recommendations

Based on the results of the study, Roma VF is recommended as the best processing variety for farmers to cultivate due to its good growth characteristics as well as high fresh fruit yield. However, due to its poor fruit storage characteristics it is recommended that the fruits to be processed as soon as they are ripe and not be kept for long periods. On the other hand, M82-1-8-VF is recommended as a dual purpose variety both for processing and for fresh market. This is because of its good storage characteristics that could allow farmers to keep it for a longer period before marketing as well as where processing capacity is very low.

## 6.3 Suggestions for further research

During the study only three varieties and one processing method were used. Therefore there is need for more processing varieties that have to be evaluated using other available processing methods. Similar work should also be done but at a higher scale since the current one involved use of small units that might have compromised the outcome of the results. More work also needs to be done to evaluate the processing characteristics at various heating periods and quantities of pulp including an economic evaluation in order to determine the economic viability of processing the various tomato varieties.

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# APPENDICES

## Appendix I: M.S. values for plant growth parameters

| Source of variation | d.f | Plant height | No. of main branches | No. of leaves | Leaf area |
|---|---|---|---|---|---|
| **Variety** | 2 | 18.276* | 4..333* | 4020.2* | 164860.* |
| **Residual** | 9 | 4.737 | 1.139 | 817.3 | 27994. |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

## Appendix II: M.S. values for tomato yield parameters

| Source of variation | d.f | No. of fruits per plant | Average fruit weight | Plant yield | Area yield |
|---|---|---|---|---|---|
| **Variety** | 2 | 263.226* | 26.676* | 67206.* | 18.667* |
| **Residual** | 9 | 7.883 | 4.030 | 12972. | 3.603 |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

## Appendix III: M.S. values for percentage loss in tomato fruit weight in storage

| Source of variation | d.f | %age weight loss Day 6 | %age weight loss Day 11 | %age weight loss Day 16 | %age weight loss Day 21 | %age weight loss Day 26 | %age weight loss Day 31 |
|---|---|---|---|---|---|---|---|
| **Variety** | 2 | 30.384* | 49.490* | 6.17ns | 124.780* | 177.920* | 278.14* |
| **Residual** | 9 | 6.113 | 5.660 | 20.82 | 8.312 | 7.778 | 18.42 |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

## Appendix IV: M.S. values for tomato processing characteristics

### Tomato sauce processing

| Source of variation | d.f | Pulp to fruit weight ratio | Proportion of product to pulp volume (%) | $^{o}$Brix |
|---|---|---|---|---|
| **Variety** | 2 | 0.01750ns | 121.4ns | 5.25ns |
| **Residual** | 9 | 0.02750 | 102.2 | 11.50 |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

### Tomato ketchup and tomato paste processing

| Source of variation | d.f | Proportion of product to pulp volume (%) | $^{0}$Brix | Proportion of product to pulp volume (%) | $^{0}$Brix |
|---|---|---|---|---|---|
| **Variety** | 2 | 23.44 | 3.250 | 23.80 | 35.58 |
| **Residual** | 9 | 44.28 | 6.417 | 56.09 | 30.61 |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

## Appendix V: M.S. values for tomato product quality characteristics

| | | **Tomato sauce** | | | **Tomato ketchup** | | | **Tomato paste** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Source of variation** | **d.f** | **Product pH** | **Vitamin C content** | **Protein content** | **Product pH** | **Vitamin C content** | **Protein content** | **Product pH** | **Vitamin C content** | **Protein content** |
| **Variety** | 2 | 0.0608ns | 22.45ns | 0.08547* | 0.01333ns | 17.926ns | 0.15953ns | 0.01583ns | 5.006ns | 0.13380* |
| **Residual** | 9 | 0.1231 | 13.03 | .01866 | 0.01806 | 6.352 | 0.088429 | 0.02722 | 3.338 | 0.01142 |

Ns, *, non-significant and significant at p≤ 0.05 level respectively

**Appendix VI: Correlation analysis results for tomato plant growth characteristics**

| | | | |
|---|---|---|---|
| **No_of_leaves/plant** | 0.937 | | |
| **Plant Height (cm)** | -0.034 | -0.071 | |
| **No of main branches/plant** | 0.195 | 0.119 | 0.236 |
| | **Leaf area/plant ($cm^2$)** | **No of leaves/plant** | **Plant Height (cm)** |

**Appendix VII: Correlation analysis results for tomato plant growth and yield characteristics**

| | | | |
|---|---|---|---|
| **No of fruits/plant** | 0.707 | 1.000 | |
| **Average fruit weight (g)** | -0.416 | -0.647 | 1.000 |
| **Plant yield (g/plant)** | 0.670 | 0.890 | -0.231 |
| | **Leaf area/plant ($cm^2$)** | **No of fruits/plant** | **Average fruit wt (g)** |