UNIVERSITY of RWANDA

COLLEGE OF AGRICULTURE, ANIMAL SCIENCES AND VETERINARY MEDICINE

EVALUATION OF PERFORMANCE OF FIVE DETERMINATE TOMATO (*Lycopersicon esculentum* L) VARIETIES CULTIVATED IN THE GLASSHOUSE AND OPEN FIELD UNDER ENVIRONMENTAL CONDITIONS OF BUSOGO, MUSANZE DISTRICT, RWANDA

A Thesis Presented

By

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Submitted to the School of Agriculture and Food Sciences

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the Award of the Degree of

MASTER OF SCIENCE in Crop Sciences

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CERTIFICATION

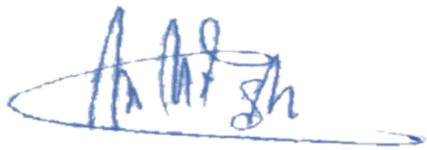
I, Dr. Ir. UMUHOZA Karemera Noëlla Josiane certify that I have read and hereby recommend for acceptance by the University of Rwanda the dissertation entitled "Evaluation of performance of five determinate tomato (*Lycopersicon esculentum* L) varieties cultivated in the glasshouse and open field under environmental conditions of Busogo, Musanze district, Rwanda" in partial fulfilment of the requirements for Master's Degree in Crop Sciences.

Dr. Ir. UMUHOZA KAREMERA Josiane Noëlla

27/04/2021

DECLARATION

I, SIBOMANA Philippe, declare that this dissertation is my original work and has not been presented to any other institution. No part of this work should be reproduced without the author's consent or that of the University of Rwanda.



SIBOMANA Philippe

27th April, 2021

DEDICATION

To the God Almighty for blessing my entire life, my spouse and siblings.

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ABSTRACT

The tomato (*Solanum lycopersicum* L) remains an important horticultural crop in Rwanda and its domestic demand is increasing with the population growth. However, climate change is having a significant impact on agricultural production worldwide as it causes remarkable yield losses. The knowledge of Rwandan farmers on the variety that can increase yield in different production circumstances remains also unidentified. Therefore, five determinate tomato varieties (Assila F1, Sifa F1, Roma VF, Rionex, and Cal-J) were cultivated in both glasshouse and open field at University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine from September 2019 to March 2020, in order to investigate their performance in both conditions. In open field, the randomized complete block design (RCBD) with three replicates was applied. The tomato varieties were grown under low temperature (11-12.5^{o}C minimum and 20-23^{o}C maximum). In glasshouse, the completely randomized design (CRD) with three replicates was used and tomatoes were subjected to the day and night mean temperatures of 36^{o}C and 18^{o}C respectively. They were evaluated on growth and yield parameters as well as their nutritional quality. For tomatoes grown under low temperatures, the highest yield was obtained on Assila F1 (35.8t/ha) with marketable yield of about 89% and Roma VF (27.4t/ha) with marketable yield of 88%. These varieties should be recommended to open field farmers in low temperature areas. However, the plant varieties grown under glasshouse conditions, scarcely produced the tomato fruits to the level that the highest yield obtained was 538.5g/plant on Sifa F1 with the average fruit weight of 30.23g. The highest yield among homozygous genotypes was Cal-J (320.4g) with the average fruit weight of 28. 27g. Nevertheless, this variety has probably acquired certain heat stress transcription factors for thermo tolerance to be considered for further scientific investigations.

Keywords: Tomato, determinate varieties, temperature, growth, fruit yield, nutritional quality.

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LIST OF ABBREVIATIONS

A: Absorbance

ABA: Abscissic acid

ANOVA: Analysis of variance

CABI: Centre for Agriculture and Bioscience International

CETS: Centroradialis, terminal self-pruning

$CH_3CO_2Na.3H_2O$: Sodium acetate tri-hydrate

Co: Company

CV: Coefficient of variation

DAT: Days after transplantation

DCPIP: 2,6-Dichlorophenolindophenol

DF: Dilution factor

DHAA: Dehydroascorbic acid

DM: Dry matter

DMRT: Duncan's multiple range test

DT: Day temperature

e.g: Example given

E: East

EC: Emulsifiable concentrate

Ɛ: Extinction coefficient

FAO: Food and Agriculture Organization of the United Nations

FAOSTAT: Food and Agriculture Organization Corporate Statistical Database

FT: Flowering locus T

FW: Fresh weight

g/l: Gram per litter

g/m^2: Gram per square metre

g: Gram

GA: Gibberellin

GM: Grand/general mean

H_2SO_4: Sulphuric acid

HSFA1: Heat shock factor A1

HSFs: Heat shock factors

i.e: id est

IFU: International Fruits and Vegetable Juice Association

K_2O: Potassium oxide

Kg/ha: Kilogram per hectare

l: Litter(s)

L-AA: L-ascorbic acid

LSD: Least significant difference

Ltd: Limited

m: Metre

m^2: Square meter

m^3: Cubic meter

MINAGRI: Ministry of Agriculture and Animal Resources

ml: Millilitre

mm: Millimetre

MMOHR: Molarity of Mohr’s salt solution

MW: Molecular weight

MWASC: Molar weight of ascorbic acid

NaOH: Sodium hydroxide

No: Number

NPK: Nitrogen, phosphorus and potassium complex fertilizer

NT: Night temperature

(NH4)Fe(SO4)2*6(H2O)6: ferrous ammonium sulfate hexahydrate or Mohr's salt

^oC: Degrees Celsius

OECD: Organization for Economic Co-operation and Development

%: Percent

pH: Hydrogen ion concentration

R^2: Coefficient of determination

R: Replication

RAB: Rwanda Agriculture and Animal Resources Development Board

RH: Relative humidity

rpm: Revolutions per minute

S: South

SC: Suspension concentrate

SPAD: Soil Plant Analysis Development chlorophyll meter

SV: SPAD value

t/ha: Ton(s) per hectare

TA: Titratable acidity

TFL1: Terminal flowers

TSS: Total soluble solids

UK: United Kingdom

UR: University of Rwanda

USA: United States of America

$\mu g/cm^2$: Microgram per square centimetre

V: Volume of mixed solvents

VDCPIP: Volume of DCPIP

VF: Verticillium and fusarium wilts

VR: Volume ratio

W: Weight

WP: Wettable powder

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

Tomato (*Solanum lycopersicum* L.) is reported as the most vegetable crop grown in home garden and the second greatly consumed after potato (*Solanum tuberosum L*.) worldwide (Benton, 2007). It is recognized as important commercial and dietary vegetable crops (Singh *et al*., 2014). According to the Food and Agriculture Organization (2017), tomato crop is grown in open field, greenhouses and screenhouses. The open-field production may be for the fresh market or the processing industry, while the greenhouse production is only for the fresh market. Tomato's popularity has been recognized recently, for its health benefits particularly vitamins and lycopene content. In 2017, the worldwide production of tomatoes totalled 182 million tons. The leading producers worldwide are China, India, Turkey, USA, Egypt, Iran, Italy, Spain, Brazil and Nigeria respectively (FAOSTAT, 2017).

In Rwanda, tomato crop is an important horticultural crop. It is produced on a total area of 6,800ha and comprises 24% of the total area on which the vegetables are grown. This crop is primarily grown in the open field. The production is bound by seasonality (Van Dijk *et al*., 2017). The yield of tomato crop in Rwanda is 8.6 tons per ha while the world yield is 37.6 tons per ha (FAOSTAT, 2017). Its cultivation in Rwanda covers (28.4%) as compared to other vegetables such as onions (14.2%) and cabbages (12.8%), by volume of total horticulture production (Clay & Turatsinze, 2014). However, the climate change is expected to cause extreme heat increase in Rwanda and other countries in East Africa. The region could also experience as much as one meter of sea level rise by the end of 21st century under a $4^{o}C$ warming scenario. The rain-fed agricultural systems will encounter significant problems and consequently livelihoods of a large proportion of the region's population will be distressed (Serdeczny *et al*., 2015). Nevertheless, a number of quantitative trait loci's, heat shock proteins, and genes were recognized in terms of heat resistance in tomato and a few stress-resistant tomato varieties are developed through traditional breeding techniques (Golam *et al*., 2012).

1.2 Problem statement

Tomato is among the most popular vegetables produced in Rwanda and it is sold on the domestic market both in fresh and in processed form. The domestic demand is increasing because of tomato processors and consumers. For this reason, Rwanda is a net importer of tomatoes from the neighbouring countries (Feed the Future, 2018).

The projected area under cultivation from 2016 was 28,262ha and will continue to be the same until 2050 and the consumption requirement will continue to increase with the population growth (MINAGRI, 2018). This indicates how efforts should be put to increase the production per unit area. The government's intention remains to increase the vegetables production by increasing the use of greenhouse technology in combination with other agricultural technologies. However, the knowledge on varieties that can increase yield in different tomato production areas remains unidentified to the farmers since Rwanda Agriculture and Animal Resources Development Board (RAB) has no seed accreditation system for tomatoes, nor seed multiplication programs specifically for tomato crop (Feed the Future, 2018).

Tomato production has been interfered by different biotic and abiotic constraints. The abiotic stresses are virtually interrelated; either individually or in combination. They cause morphological, physiological, biochemical and molecular changes that negatively affect plant growth and productivity and ultimately yield (Wakuma, 2018). Heat, drought, cold and salinity are the major abiotic stresses that cause severe cellular damage in plant species, including crop plants. The increasing threat of climate change is already having a substantial impact on agricultural production worldwide as heat waves cause remarkable yield losses and risks for future global food security are obvious (Christensen & Christensen, 2007).Therefore, the main purpose of the current study is to assess the performance of five determinate tomato (*Lycopersicon esculentum* L) varieties in glasshouse when exposed to the increase of temperature and their responsiveness in open field under environmental conditions of Busogo, in Musanze district of Rwanda.

1.3 Justification of the study

The study concerns the establishment of growth and the yield attributes associated with production and environmental conditions for the selected tomato varieties. The expected results will be a useful information to assist farmers in the experimental area particularly and other tomato farmers in general to make an appropriate choice of suitable varieties that can adapt to their respective agricultural environment. The study will encourage the future researchers to see how they can use the best introduced varieties in breeding program to make the Rwandan tomato varieties that can cope with our agricultural conditions.

1.4 Objectives of the study

1.4.1 General objective

This study aimed at evaluating the performance of five determinate tomatoes (*Lycopersicon esculentum* L*)* varieties under high temperature in glasshouse and in open field under the environmental conditions of Busogo, Musanze district, Rwanda.

1.4.2 Specific objectives

- To determine the vegetative growth for tomato plants grown in glasshouse and in open field conditions.
- To evaluate the yield parameters for tomato plants grown in glasshouse and in open field conditions.

1.5 Null hypothesis

- There are no differences in growth and yield characteristics of five tomato varieties under similar plant growth conditions: Roma VF, Cal-J, Rionex, Assila F1 and Sifa F1.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The tomato (*Lycopersicon esculentum* Mill. syn *Lycopersicon lycopersicum* L. or *Solanum lycopersicum* L.) is believed to be originated from the Andean region (Posada, 2017). The archaeological and linguistic evidence propose that tomato was domesticated in Mexico, outside its Centre of origin and finally contributed to its distribution throughout the world (Saavedra *et al.*, 2017).

However, the plant breeders choose to develop F1 hybrids, not only for heterosis, but also for their uniformity and security against illegal reproduction (Bai & Lindout, 2007). In fact, growing the tomato crop in open field seems to be difficult because of the adverse environmental conditions like a very low temperature (frost), high amount of rainfall throughout the growing season as well as the rate of pests and diseases that are known to cause loss in solanaceous production (Saavedra *et al.*, 2017).

2.2 Growth characteristics of tomato varieties

In most Solanaceae crops, there is a change between vegetative and reproductive phases, which present themselves as sectional units called sympodia. In tomato, the vegetative apical meristem transforms into floral after a series of 6–12 internodes with leaves (Samach & Lotan, 2007).

The vegetative growth continues within the top of axillary meristem, and increases vigorously shifting the inflorescence to the side and give rise to a new sympodium with three leaves and an inflorescence. This process is repeated indefinitely in plants of indeterminate growth habit (Lifschitz & Eshed, 2007).

The determinate growth in tomato is therefore a result of a recessive mutation in the self-pruning, which belongs to the CETS (centroradialis/terminal flower 1/self-pruning) gene family. Therefore, the ratio between flowering locus T (FT) and terminal flower (TFL1) indicates determinate or indeterminate growth in local tissues (McGarry & Ayre, 2012). The determinate growth in tomatoes results in roughly simultaneous fruit ripening, which, consequently allows large-scale mechanical harvesting and they are also recognized by their compact growth habit (Ozores-Hampton *et al*., 2013). Thus the term “determinate” refers to the plant growth habit, there are tomato plants that grow like a bush to a certain size (about 1-1.5m), set fruit, and then weaken.

Most of the early ripening tomato varieties are of this category. Those tomato varieties are highly preferred by commercial farmers that want to harvest most of the fruits from one picking. Some tomato varieties are resistant to nematodes and certain diseases, like verticillium and fusarium wilts. This resistance to verticillium wilt and fusarium wilt diseases is usually indicated by letters following the varieties' name like Roma VF (Akaeze & Aduramigba, 2017).

2.3 Effect of temperature on growth and production of tomatoes

Ideally, tomato requires a relatively cool and dry climate for high yield and premium quality but it is also adapted to a varied range of climatic conditions. Tomatoes have been grown as far north as the Arctic Circle (under protection) and down to the hot and humid equatorial regions. The optimum temperature range for growth and development is 21-24°C. Long exposure of tomato plants to the temperatures below 12°C can produce the chilling injury (CABI, 2019). The temperature has a large effect on all aspects of crop development. Leaf and truss initiation rates reduce linearly with reducing temperature. Though, these rates may vary for different cultivars, their response to temperature is the same.

The production of short leaves for tomato plants grown at sub-optimal temperatures affect the photosynthetic parameters. At that type of temperature, fruit set is reduced as a result of insufficient pollination and pollen quality (Sherzod *et al.*, 2019; Ohnishi *et al*., 2010)

High temperatures interfere with tomato growth and development and its negative effect on crop production is noticeable (Hatfield & Prueger, 2015). The mean temperatures above 27°C severely impair growth and fruit set. In addition, when the maximum day temperatures increase to 38^{o}C or above for 5-10 days, this causes the destruction of pollen and egg cells (CABI, 2019). When the physiological and biochemical responses in plants are affected by high temperatures, this may result in reduction of crop quality and yield (Min *et al.*, 2014).

2.4 Tomato quality characteristics

The content of dry matter (DM) and organic acids in tomatoes (*Lycopersicon esculentum* Mill) can have a valuable impact on both taste abilities as well as the productive potential of this crop (Stoyanova *et al.,* 2018). Tomatoes are great source of phytonutrients including vitamins, carotenoids and polyphenols. They are normally consumed fresh, cooked or through processed products (Thole *et al*., 2020). Tomatoes contain high levels of vitamin C (ascorbic acid) and this vitamin is a powerful antioxidant beneficial for human health (Fitzpatrick *et al.*, 2012). Vitamin C is therefore the generic name of L-ascorbic acid (L-AA) and this has many other chemical names as ascorbate and antiscorbutic vitamin. The L-AA molecule is made of asymmetrical six carbon atoms ($C_6H_8O_6$) which is structurally associated with the glucose. Ascorbic acid can reversibly oxidize into dehydroascorbic acid (DHAA) when exposed to copper, low alkaline media and heat. However, DHAA is a very short half-time product which can either reversibly or irreversibly oxidize in the tissues (Nermin, 2018).

Tomatoes have been predominantly preferred by consumers for their quality including colour, shape, sweetness and flavour among others. The latter is associated with the pH, titratable acidity (TA) as well as the soluble solids of tomatoes. When the fruits are more acidic this may influence greatly its flavour. The TA denotes the total concentration of free protons and undissociated acids in a solution that can react with a strong base and be neutralized. Anthon and Barret (2012) reported that citric acid, malic and glutamic acid are the most abundant inorganic acids in tomatoes that reacts with base and therefore influence the titratable acidity and pH in tomato juice.

Reducing sugars are the most dominant soluble solids that influence flavours of tomatoes and sweetness may depend on fructose (Tieman *et al.*, 2012). Lycopene belongs also to a group of naturally-occurring pigments known as carotenoids. Tomatoes and tomato-based products are the major sources of lycopene in the human diets. Lycopene has antioxidant characteristics and reveals the red pigment in some fruits and vegetables like tomatoes. Spectrophotometry method is used to determine the lycopene in fruits and vegetables (Wihong *et al*., 2017). However, the levels of lycopene in tomatoes and tomato products vary and that variation may be due to fruit shapes size, colour, degree of ripeness at harvest, method of production, growing conditions as well as the extent of processing. Tomato wastes were considered as promissing source of lycopene that can be exploited into useful foods (Górecka *et al.*, 2020).

CHAPTER THREE: MATERIALS AND METHODS

3.1 The experimental site

The experiment was conducted at University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine in glasshouse and open field, located in Busogo sector, from the agricultural season of September 2019 to March, 2020. Busogo has 2300m of altitude with the highest point at 2800m of above the sea level. The rainfall comprises between 1400mm and 1800mm while the mean temperature is 16.7^{o}C. Busogo is also located at the latitude of 1^{o}33'26'S and the longitude of 29^{o}32'39'E. The soils are classified into the andisol or andosol type and reflect to Virunga mountains. Busogo sector has 4 seasons divided as follow: light dry season from end-December to mid-February, heavy rainy season from mid-February to June, heavy dry season extending from June to end-August, and light rainy season from end-August to end-December. Volcanic soils of Busogo are very permeable with low depth on mountains and moderate depth in lower altitude characterized by sandy loam texture. The soil pH lies between 5.7 and 5.8 (Uwiringiyimana *et al*, 2019).

3.2 Test plant

Five determinate tomato varieties: Roma VF, Cal-J, Rionex, Sifa F1 and Assila F1 were used in the experiment.

Table 1:List of tomato varieties and their origin

Name of variety	Type	Country of production	Company
ASSILA F1	Determinate	USA	Seminis, Bayer group
CAL-J	Determinate	Kenya	East African Seed Co. ltd
RIONEX	Determinate	Kenya	Continental seeds

ROMA VF	Determinate	Netherlands	Pop vriend vegetable seeds BV
SIFA F1	Determinate	Kenya	Continental seeds

3.3 Experimental design

The experimental design was randomized completely block design (RCBD) with five treatments in open field and Completely Randomized Design (CRD) in glasshouse. The treatments are composed with two hybrid varieties namely Assila F1 and Sifa F1 and three pure varieties which are Cal-J, Rionex and Roma VF. The spacing of plots within block was 0.5m and 1.0m spacing between blocks. The experiment was composed of 15 plots each had the size of $9m^2$ or (3m×3m) while each plot contained nine plants.

3.4 Preparation of seedlings

Seeds were sown in seed trays and covered with plastic cover to increase the temperature in soil to favour germination (Motsa *et al*., 2015). Re-potting was performed after 30 days from the sowing date in order to improve the seedling's vigour. 80-100 seedlings were re-potted in a pot of 35cm of diameter. Easy gro, a foliar fertilizer composed by 27% N, 10% P_2O_5, 16% K_2O with trace elements 0.03% Boron, 0.05% Copper, 0.1% Iron, 0.05% Manganese, 0.001% Molybdenum, 0.06% Zinc and 0.007% of amino acid was applied onto the seedlings in order to boost their growth. The rate of application was 20g of fertilizer per 20l of water. In order to prevent the attack of early blight (*Alternalia solani*) and late blight (Mildew) in young tomato seedlings, chlorothalonil 500g/l was applied at a rate of 30ml of fungicide per 15l of water. Tomato seedlings to be transplanted in an open field were acclimated for two weeks before.

3.5 Field preparation and planting

In greenhouse, the plastic seed beds were used and sand, soil and organic manure were added at the ratio of 1:2:1. The well grown seedlings were transplanted in $0.005m^3$ pots after 45 days.

Glasshouse openings were closed and temperature of room was monitored daily using thermo-hygrometer testo 608-H1 (UK). The average day temperature was 36ºC with 39%RH while night temperature was 18ºC with 84% RH (see appendix no.3). In an open field, the plots were well ploughed and levelled. The seedlings of about 4-5 fully opened leaves were transplanted at 1.0m spacing between plants in the same row and 1.0m between rows. Farmyard manure (8t/ha) was applied and inorganic fertilizer was applied to all varieties in both experiments using NPK 17-17-17 and Urea (46% N) at the rate of 120kg/ha of Nitrogen, 90Kg/ha of Phosphate and 90Kg of potash (Alhrout *et al.,* 2018). Mulching and staking were also practiced in order to reduce the likelihood of plants with contact on humid soil. Pruning was performed after 60 days from transplantation date. The daily temperatures and precipitations were collected from Rwanda Meteorology Agency (see appendix no. 2). The fungi were controlled by using metalaxyl 8% combined with mancozeb 64% WP alternated with chlorothalonil 500g/l SC in both glasshouse and open field. The whiteflies and aphids were controlled by interchanging abamectin 18g/l EC with cypermethrin 4% combined with profenofos 40% in open field while those insecticides were used to control leaf miner in glasshouse.

3.6 Determination of the vegetative growth

Two plants per plot were randomly selected, for data collection in open field while all tomato plants in glasshouse were measured. Plant height, stem diameter, number of leaves, number of branches and chlorophyll content are the main parameters that were measured for each variety. All parameters were measured in all replications at 30, 45 and 60 days after transplantation (DAT); plant height was measured from the ground surface to the tip of plant. The number of leaves and branches per plant were counted on the same days' interval. The stem diameter (mm) was measured using the vernier caliper, SPAD 502 instrument was used to measure the SPAD value (SV) of tomato leaves and the chlorophyll contents (μg/cm^2) were estimated from the SPAD Value using Uddling *et al.* (2007) equation at R^2= 0.84. The weight of fruits was measured using laboratory scale for grams manufactured by Denver instrument, USA.

$$Y=0.0691e^{0.0459x}$$

Where Y is estimated chlorophyll content (g/m^2 of projected area) and x equals to the SPAD502 value (Uddling *et al.* 2007).

3.7 Evaluation of the yield parameters

The number of clusters per plant and number of flowers per cluster were measured at 60th day after transplantation while number of fruits per plant, mean weight of individual fruit and the total yield per variety were measured at harvesting time. The mean of fresh weight of individual fruit was calculated for all treatments and the yield per hectare was assessed. Sorting was done in order to obtain the marketable fruits and the marketable yield was calculated. Marketable fruits are those with average size and above and free from visible damage due to diseases, pests and physiological disorder (Getahun, 2019).

3.8 Determination of dry matter (DM) in tomato fruits

Fresh tomato fruits were sliced in order to get the uniform size. 100g of fresh tomatoes were distributed on trays in an oven and exposed to 80^{o}C for 8hours (Mawardii *et al.,* 2017). The containers were weighed empty before placing tomato slices, 100g for each fresh tomato variety were recorded after putting the analytical balance to zero. Labelled samples were put in layers of hot air oven. After eight hours under heat, the dried tomato slices were left into the oven for about an hour for cooling and prevent the accumulation of humidity and the percentages of DM were finally calculated using Buckmaster's formula (2020).

$$\text{DM } \% = \frac{W4 - W1}{W3} \times 100$$

W1: Container weight
W2: Container and wet sample weight before drying
W3:Wet sample weight
W4: Container and sample weight after drying

3.9 Determination of total soluble solids (TSS)

Tomato fruits were harvested and the well ripened ones were selected and cleaned using distilled water. The tomato juice was prepared using a blender HGB55E (Model HGBSSSS6) from Waring, USA. Eclipse Professional Optical Refractometer 45-02 (UK) was also cleaned using distilled water and dried thoroughly. A couple of juice drops were deposited onto the prism of the refractometer. By aid of outdoor light, the soluble solid was recorded through the eyepiece and the activity was repeated three times to get the accurate results for each treatment (Dobrin, et al., 2019).

3.10 Determination of pH and titratable acidity (TA)

pH and titratable acidity were measured following the method of Garner *et al.* (2003). To obtain a clear juice, tomato fruits were cleaned, sliced, blended and centrifuged using standard equipment. pH was measured using a pH meter at room temperature and records were taken. 6ml of juice for each sample were put into a 100ml beaker and 50ml of distilled water was added for making a dilution. Titration was performed using 0.1N NaOH to an end point of 8.2. The quantity of NaOH used in millilitres was finally recorded.

$$\text{TA (\%)}=\frac{(\text{ml of NaOH used})\times(0.1\text{NaOH})\times(\text{Milliequivalent factor})\times(100)}{\text{ml of juice}}$$

Where: Milliequivalent factor= 0.064

Source: Garner *et al.* (2003)

3.11 Determination of L-ascorbic acid in tomato using titrimetric method

For determining the quantity of ascorbic acid in tomato fruits, the method used has been proposed by the International Fruits and Vegetable Juice Association (IFU, Method No.17, 2019). 2,6-dichlorophenol-indophenol sodium salt dehydrate (DCPIP) solution was prepared by weighing 220mg of DCPIP and dissolve it in hot distilled water to make 1litter of solution. The solution was kept for one day for stabilization as required by IFU (2019) protocol. Sodium acetate solution 10% (CH_3CO_2Na * 3 H_2O) was prepared by dissolving 100g with distilled water to make 1liter of solution. Oxalic acid 2% solution also was prepared by dissolving 20g of oxalic acid with distilled water to make 1liter of solution. In order to make a standard solution of L-ascorbic acid, 50mg of $C_6H_8O_6$ powder was dissolved by 2% oxalic acid to a total of 100ml in a volumetric flask for direct use. A solution of Mohr's salt solution was prepared by weighing 4g of the salt and added in 1l of volumetric flask and 20ml of sulphuric acid (H_2SO_4) were added. Finally distilled water was added to make 1000ml of solution.Standardization of DCPIP was performed with the Ammonium

Iron(II) sulfate commonly known as Mohr's salt [$(NH_4)_2Fe(SO_4)_2*6(H_2O)_6$]. To make a solution, 3g of di-ammonium oxalate monohydrate were added in a 100ml Erlenmeyer flask. Distilled water was added (20ml) and 20ml of DCPIP was added. And that mixture was titrated by Mohr's salts solution to colourless. The blank value of DCPIP is therefore equivalent to the volume (ml) of DCPIP used during this titration. The average of blank value was calculated after three times of the procedure's repetition. Well ripened tomato fruits were selected, cleaned properly and unwanted parts were removed using a sharp knife.

(1) **L-ascorbic acid in mg/l= (C_{DCPIP} –B) ×F×DF**

Where: C_{DCPIP}= Consumption of DCPIP solution at end point in ml

B (Blank value of DCPIP) =1.5ml

F=Factor of the DCPIP solution

DF (Dilution Factor) =500

100g of sliced samples were then mixed by a blender. The tomato juice was homogenized and filtered using Whatman filter paper grade 42 to have a slight clear solution. By aid of pipette, 2ml of tomato sample were added in a beaker and 5ml of 10% sodium acetate were added and then diluted by 2% oxalic acid to 100ml while stirring at 3000rpm. 50ml of DCPIP solution were poured into a graduated burette and controlled droplets were let to titre the sample. Finally, L-ascorbic acid in tomato samples were calculated:

$$(2)\mathrm{FDCPIP} = \frac{\mathrm{CMOHR} \times \mathrm{MMOHR} \times \mathrm{MWAsc}}{2 \times \mathrm{VDCPIP}}$$

$$= \frac{CMOHR \times 0.01 \times 176.13}{2 \times 20}$$

$$= CMOHR \times 0.044$$

$$= 2.5 \times 0.044$$

F_{DCPIP}=0.11

Where:

FDCPIP=Factor of DCPIP solution

CMOHR=Consumption of Mohr's salt solution at endpoint in ml (2.5)

MMOHR=Molarity of Mohr's salt solution in mol/l (0.01)

MWASC-Molar Weight L-ascorbic acid in g/mol (176.13)

VDCPIP=Volume DCPIP solution in standardization in ml (20)

Source: IFU, Method No.17 (2019)

3.12 Determination of lycopene content in fresh tomato samples

Lycopene content of tomato samples were obtained following the method of Anthon and Barrett (2007) with slight modifications. Tomato samples for each variety were prepared. Red tomatoes were harvested, cleaned and blended in order to get a juice. From that juice, 100mg were dissolved in 1ml of distilled water and kept out of blight light. Lycopene extraction was performed by adding 8ml of solution prepared by mixing 4ml of hexane, 2ml of ethanol and 2ml of acetone. Distilled water (1ml) was added to the solution after 10minutes and vortexed with a magnetic stirrer at 3000rpm for one minute.

The samples were allowed to stabilize for 10minutes in order to allow phases to separate and all air bubbles to disappear. The upper layer (hexane) was collected in cuvette. Distilled water was used as blank sample to zero spectrophotometer at 503nm. The hexane extracts were put in spectrophotometer adjusted at 503nm wavelength. This wavelength was chosen in order to minimize any interference that may be caused by the amount of β-carotene in tomato samples as determined by Davis *et al.* (2002). Calculation of lycopene content in tomato samples were finally performed using the following formula.

$$\text{Lycopene (mg/Kg)} = \frac{A503 \times 0.55V \times MW \times 10^{6}}{W\varepsilon}$$

$$= \frac{1717 \times A503 \times 8ml}{100mg}$$

Simply: Lycopene (mg/100g) = A503×137.4/10

Where:

A=Absorbance of each sample at 503nm

MW (Molecular weight of lycopene) = 507g/mole

V: Volume of mixed solvents=8ml

VR (Volume ratio of upper layer/mixed solvents) =0.55

W: Weight of tomato added for lycopene extraction=100mg

Ɛ: (Extinction coefficient for lycopene in hexane) =172000

Ten is multiplied to the extinction coefficient and weight of tomato sample mixed with solvents, to bring the results to the quantity of lycopene obtained in 100g of fresh tomatoes.

CHAPTER FOUR: RESULTS

4.1 Growth characteristics of tomatoes varieties at 30DAT

The vegetative growth parameters evaluated at 30DAT in both glasshouse and open field were plant height, number of leaves, number of branches and SPAD 502 value (SV) used when calculating chlorophyll content in square centimetre of randomly selected leaves (see appendix no.4).

The results from analysis of variance (ANOVA) in open field showed significant differences between all varieties for number of branches and chlorophyll content whereas all treatments showed no significant difference on plant height, number of leaves and stem diameter at $P \leq 0.05$. The results in open field showed that the plant height of all tomato varieties ranged between 17.2 to 22.3cm. The number of leaves ranged from 6.7 to 7.7. The number of branches also was counted for each variety and the highest number was observed in Assila F1 while the lowest number was counted on Sifa F1 and Rionex. Stem diameter was measured and their average ranged between 6.9 and 7.9mm. Roma VF showed the highest chlorophyll content (47.8µg/cm^2) while Cal-J showed the lowest quantity (38.9µg/cm^2).

In glasshouse, the results from ANOVA showed no significant differences between all treatments for all parameters at $P \leq 0.05$. The plant height ranged from 28.2cm (Sifa F1) to 39.6cm (Assila F1). The highest number of leaves (9) were counted on Assila F1 while Roma VF, Rionex and Cal-J had the lowest number (8). The highest number of branches were found on Assila F1 and Sifa F1 while the lowest number of were found on Cal-J, Rionex and Roma VF. The largest stem (6.6mm) were found on Sifa F1 while the smallest size (5.5mm) were found on Assila F1. The highest chlorophyll content (39.1µg/cm^2) was estimated in Rionex while Sifa F1 had the lowest (36µg/cm^2).

Table 2:Vegetative characteristics of tomatoes at 30 DAT

	OPEN FIELD					GLASSHOUSE				
	Plant height (cm)	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorophyll (µg/cm^2)**	**Plant height (cm)**	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorop hyll (µg/cm^2)**
SIFA F1	18.2^a	6.7^a	2.7^c	7.1^a	39.3^b	28.2^a	8.3^a	0.7^a	6.6^a	36.0^a
ASSILA F1	22.3^a	7.3^a	6.3^a	7.6^a	44.1^{ab}	39.6^a	9.0^a	0.7^a	5.5^a	38.4^a
ROMA VF	17.9^a	7.7^a	4.0^{bc}	6.9^a	47.8^a	32.3^a	8.0^a	0.3^a	5.9^a	37.3^a
RIONEX	17.2^a	6.7^a	5.3^{ab}	7.8^a	41.7^{ab}	33.7a	8.0^a	0.3^a	5.7^a	39.1^a
CAL-J	19.1^a	7.3^a	5.3^{ab}	7.8^a	38.9^b	34.9^a	8.0^a	0.3^a	6.0^a	38.2^a
GM	18.9	7.1	4.7	7.4	42.4	33.8	8.3	0.5	5.9	37.8
C.V	6.8	5.8	2.4	3.5	5.3	50.8	2.8	24.7	11.4	5.1
LSD	5.6	1.3	1.4	1.1	5.9	10.8	1.0	1.2	1.7	6.2

The means for factors that are followed by the same letters in a column are not significantly different, according to Duncan's multiple range test (DMRT) at P≤0.05.

4.2 Growth characteristics of tomatoes varieties at 45DAT

In open field, the results from ANOVA after 45 days from the day of transplantation, showed that all treatments were not significantly different for number of branches and chlorophyll content while plant height, number of leaves and stem diameters were significantly different at $P \leq 0.05$. The results in table 3 indicated that the plant height at 45DAT ranged between 31.7cm and 45cm. The tallest tomato variety was Assila F1 while the smallest was Rionex. The tomato variety with highest number of leaves was Assila F1(37) while both Rionex and Sifa F1 revealed the lowest number (24.7). The number of branches for all varieties ranged from 5.7(Sifa F1) to 6.7(Cal-J and Assila F1). Results from measurement of stem diameter revealed that Sifa F1 was the largest (10.7mm) while the smallest was Assila F1(9.4mm). Tomato variety with highest chlorophyll content in leaves was Roma VF (56.4µg/cm^2) while Assila F1 showed the lowest quantity (44.4µg/cm^2).

In glasshouse, the results from ANOVA showed no significant differences between all treatments for all parameters except number of branches at $P \leq 0.05$. All tomato varieties were evaluated for their growth characteristics after 45 days from transplanting date. The tallest variety (60.1cm) was Sifa F1 whereas Rionex was the shortest (53.4cm). The number of leaves ranged from 9.3 to 12.3. The lowest number of leaves was counted on Sifa F1 and Cal-J varieties while the highest number was found on Assila F1. The highest number of branches (3) were counted on Cal-J while the lowest (1) were found on both Sifa F1 and Assila F1. The largest stem (7.5mm) were measured on both Assila F1 and Roma VF while the smallest (6.4) were measured on Cal-J and Sifa F1. The highest chlorophyll content (42.4µg/cm^2) were estimated in Sifa F1 while Cal-J had the lowest quantity (37.5µg/cm^2).

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Table 3: Vegetative growth characteristics of tomatoes at 45DAT

	OPEN FIELD					GLASSHOUSE				
	Plant height (cm)	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorophyll ($\mu g/cm^2$)**	**Plant height(cm)**	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorophyll ($\mu g/cm^2$)**
SIFA F1	36.7^{b}	24.7^{b}	5.7^{a}	10.7^{a}	49.3^{a}	60.1^{a}	9.3^{a}	1.0^{b}	6.4^{a}	42.4^{a}
ASSILA F1	45.0^{a}	37.0^{a}	6.7^{a}	9.4^{b}	44.4^{a}	57.1^{a}	12.3^{a}	1.0^{b}	7.5^{a}	40.7^{a}
ROMA VF	34.9^{b}	30.3^{ab}	6.0^{a}	9.6^{ab}	56.4^{a}	55.9^{a}	12.0^{a}	1.3^{b}	7.5^{a}	41.7^{a}
RIONEX	31.7^{b}	24.7^{b}	6.0^{a}	10.3^{ab}	51.3^{a}	53.4^{a}	11.3^{a}	2.3^{ab}	7.0^{a}	40.4^{a}
CAL-J	38.9^{ab}	35.0^{ab}	6.7^{a}	10.1^{ab}	44.7^{a}	57.6^{a}	9.3^{a}	3.0^{a}	6.4^{a}	37.5^{a}
GM	37.4	30.3	6.2	10.0	49.2	56.8	10.9	1.7	7.2	40.5
C.V	1.2	6.9	8.5	3.8	7.1	6.8	4.3	17.6	4.8	4.9
LSD	7.9	10.5	1.6	1.1	14.5	12.6	4.3	1.4	2.1	6.0

The means for factors that are followed by the same letters in a column are not significantly different, according to Duncan's multiple range test (DMRT) at P≤0.05.

4.3 Growth characteristics of tomatoes varieties at 60DAT

In open field, the results from ANOVA after 60 days from the day of transplantation, showed that there is a significant difference for the number of plant height, number of leaves and stem diameter whereas number of branches and chlorophyll content are not significantly different at $P \leq 0.05$. Assila F1 was the tallest (64.4cm); followed by Cal-J (55.9cm) while Sifa F1 was the smallest (49.3cm). When number of leaves were counted, Cal-J had the highest number (62) followed by Rionex (61.3) and the lowest number was counted in the plots where grown Sifa F1(32.3). The highest number of branches was found on both Roma VF and Rionex (7.3) though the lowest number of branches was counted in Sifa F1 plantation (6). The latter showed the largest stem diameter (13.7mm) followed by Rionex (13mm) while Assila F1 had the smallest width (11mm). The chlorophyll content in tomato leaves were also estimated and the results showed that Roma VF accumulated the highest amount of chlorophyll in leaves (61.3μg/cm^2) followed by Sifa F1(60.4μg/cm^2) whereas Assila F1 accumulated less (45.7μg/cm^2).

The results from ANOVA, in glasshouse, showed no significant differences between all treatments for all parameters except number of branches at $P \leq 0.05$. The plant height was measured for all treatments and Assila F1 with Roma VF were the tallest (92cm) while Cal-J was the shortest (68.5cm). The highest number of leaves (21.7) were counted on Roma VF while the lowest number (17.7) was found on Sifa F1. The highest number of branches was counted on Sifa F1 and Cal-J while the lowest number was counted on Assila F1. The largest diameter (10mm) was measured on Assila F1 while the smallest (7.1) was found on Cal-J. The highest chlorophyll content was estimated on Sifa F1 (48.7μg/cm^2) whereas Cal-J had the lowest chlorophyll content in leaves (37.4μg/cm^2).

Table 4: Vegetative growth characteristics of tomatoes at 60DAT

	OPEN FIELD					GLASSHOUSE				
	Plant height (cm)	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorophyll ($\mu g/cm^2$)**	**Plant height(cm)**	**No. of leaves**	**No. of Branches**	**Stem diameter (mm)**	**Chlorophyll ($\mu g/cm^2$)**
SIFA F1	49.3^{b}	32.3^{b}	6.0^{a}	13.7^{a}	60.4^{a}	75.8^{a}	17.7^{a}	3.0^{a}	8.0^{a}	48.7^{a}
ASSILA F1	64.4^{a}	58.7^{a}	6.7^{a}	11.0^{b}	45.7^{a}	92.0^{a}	18.7^{a}	1.0^{b}	10.0^{a}	40.0^{a}
ROMA VF	51.8^{b}	44.0^{ab}	7.3^{a}	12.3^{ab}	61.3^{a}	92.0^{a}	21.7^{a}	2.0^{ab}	9.7^{a}	43.8^{a}
RIONEX	53.0^{b}	61.3^{a}	7.3^{a}	13.0^{a}	60.2^{a}	79.6^{a}	18.3^{a}	2.7^{a}	8.3^{a}	41.8^{a}
CAL-J	55.9^{ab}	62.0^{a}	7.0^{a}	12.2^{ab}	49.8^{a}	68.5^{a}	19.0^{a}	3.0^{a}	7.1^{a}	37.4^{a}
GM	54.9	51.7	6.9	12.5	55.5	81.6	19.1	2.3	8.6	42.3
C.V	5.0	9.2	6.1	5.3	8.7	4.5	22.3	4.9	7.2	7.5
LSD	8.6	21.9	2.5	1.8	32.9	34.2	11.5	1.5	3.6	14.9

The means for factors that are followed by the same letters in a column are not significantly different, according to Duncan's multiple range test (DMRT) at $P \leq 0.05$.

4.4 Evaluation of yield characteristics of tomato varieties

The number of clusters per plant and number of flowers per cluster, in all treatment were counted at 60DAT while the other parameters were taken at harvesting time. The results from ANOVA for tomatoes grown in open field showed significant differences between all treatments for number of clusters per plant, average weight of a single fruit as well as total and marketable yield. Nevertheless, all treatments showed no significant difference on number of flowers per cluster and number of fruits per plant at $P \leq 0.05$. All tomato varieties were harvested six times with one-week interval. The results showed that Cal-J had the highest number of clusters (30.3) followed by Assila F1 (24.3) while SIFA F1 had the lowest (14.3). The average number of flowers for each cluster showed that Assila F1 was the first to hold a large number (8.7), followed by Cal-J (7.7) whereas Rionex had the lowest number of flowers (6). The average number of fruits per plant ranged from 42.8 to 60.4. The highest number was counted on Assila F1 while the lowest number was counted on Sifa F1. The average weight for a single tomato showed that Assila F1 was the first to weigh highest grams followed by Sifa F1, Roma VF, Rionex and Cal-J respectively. The extrapolated yield per hectare showed that tomato hybrid (Assila F1) had the highest yield (35.8t/ha before sorting and 31.7t/ha after sorting), while Roma VF was the first pure variety to give high yield (27.4t/ha before sorting and 24t/ha after sorting).

The results from ANOVA showed no significant differences between all treatments for all parameters except the mean weight of individual fruit at $P \leq 0.05$ for tomatoes grown in glasshouse. The yield parameter evaluated were number of clusters per plant, number of flowers per cluster, number of fruits per plant, mean weight of individual fruit and weight of fruits per plant. Therefore, the results showed that Roma VF had the highest number of cluster (6.3) followed by Cal-J (6) while Rionex had the lowest number of clusters (4.7). When the number of flowers per cluster was counted, Sifa F1 had the highest (5.7) while Cal-J had the lowest number. The highest number of fruits (17.3) were counted on Sifa F1 while the lowest number was found on Rionex (5.7). This last variety showed the highest weight of individual fruit while the lowest weight was weighed on Assila F1. The production of individual plant showed that Sifa F1 had the highest (538.5g) followed by Assila F1 (335.4g), Cal-J (320g), Roma VF (311.2) and finally Rionex (203.1g).

Table 5: Yield characteristics of tomato varieties

	OPEN FIELD							GLASSHOUSE				
	No. of clusters per plant	No. of flowers per cluster	No. of fruits per plant	Average fruit weight (g)	Total yield (t/ha)	Marketable yield (t/ha)	Marketable yield (%)	No. of clusters per plant	No. of flowers per cluster	No. of fruits per plant	Mean weight of individual fruit (g)	Weight of fruits per plant (g)
SIFA F1	14.3^{b}	6.7^{a}	42.8^{a}	84.4^{b}	24.3^{b}	20.4^{b}	84	5.7^{a}	5.7^{a}	17.3^{a}	30.2^{ab}	538.5^{a}
ASSILA F1	24.3^{ab}	8.7^{a}	60.4^{a}	109.5^{a}	35.8^{a}	31.7^{a}	89	5.7^{a}	4.7^{a}	13.7^{a}	23.8^{b}	335.4^{a}
ROMA VF	19.3^{ab}	7.3^{a}	53.4^{a}	80.3^{b}	27.4^{b}	24.0^{b}	88	6.3^{a}	4.7^{a}	13.0^{a}	24.2^{b}	311.2^{a}
RIONEX	18.0^{b}	6.0^{a}	57.0^{a}	78.3^{b}	25.4^{b}	22.5^{b}	89	4.7^{a}	4.7^{a}	5.7^{a}	35.9^{a}	203.1^{a}
CAL-J	30.3^{a}	7.7^{a}	60.2^{a}	45.0^{c}	25.1^{b}	20.4^{b}	81	6.0^{a}	4.0^{a}	11.3^{a}	28.3^{b}	320.4^{a}
GM	21.3	7.3	54.8	79.5	27.6	23.8		5.7	4.7	12.2	28.5	342
C.V	11.7	9.7	16.1	3.7	10.1	11.9		27.4	6.5	16.1	5.2	14.8
LSD	10.6	3.0	16.8	21.2	7.4	6.8		4.2	2.1	16.4	7.0	485.6

The means for factors that are followed by the same letters in a column are not significantly different, according to Duncan's multiple range test (DMRT) at P≤0.05.

4.5 Laboratory analysis of nutritional content of tomato varieties

Tomatoes harvested in open field were transported to the laboratory of food science of the college to be analysed. Six important elements were analysed mainly pH, Titratable Acidity (TA), Total Soluble Solids (TSS), L-Ascorbic Acid (L-AA), Lycopene and Dry Matter (DM). The results from ANOVA showed significant differences between all treatments except pH at $P \leq 0.05$. The pH of tomato juice for all treatments ranged from 4 to 4.3, TA 0.52-0.67%, TSS ranged from 3.6-4.8mg/100g of fresh weight (FW), lycopene 8.4-11mg/100gFW and finally 5.7-7.1% of DM. The highest proportions were found as follow: for pH the highest findings were found on Assila F1 and Rionex, highest titratable acidity and total soluble solids was found in Roma VF, for TSS, Rionex had the highest percentage. Assila F1 had the highest L-AA, lycopene content as well as DM.

The results from ANOVA showed significant differences between all tomato varieties grown in glasshouse except pH at $P \leq 0.05$. The pH ranged from 4 to 4.3 for all treatments. The highest TA (0.66) was found in Assila F1 followed by Roma VF (0.61) while the lowest proportion was found in Rionex (0.52). The highest TSS (4.8%) was found in Cal-J though the lowest proportion (3.1%) were found in Roma VF. The highest L-AA (15.2mg/100gFW) was found in Rionex and the lowest (11.6mg/100gFW) was found in Sifa F1. The highest lycopene content (11.7mg/100gFW) were found in Rionex while the lowest amount (8.3mg/100gFW) was found in Roma VF. The highest proportion of DM (9g/100gFW) was found in Rionex while then lowest proportion were found (7.3g/100gFW) in Sifa F1.

Table 6: Nutritional content of tomato varieties

	OPEN FIELD						GLASSHOUSE					
	pH	**TA (%)**	**TSS (%)**	**L.AA (mg/100g FW)**	**Lycopene (mg/100g FW)**	**DM (%)**	**pH**	**TA (%)**	**TSS (%)**	**L.AA (mg/100g FW)**	**Lycopene (mg/100gFW)**	**DM (%)**
SIFA F1	4.0^{a}	0.54^{c}	3.6^{d}	11.4^{b}	8.7^{c}	6.1^{c}	4.0^{a}	0.54^{c}	4.4^{b}	11.6^{d}	9.2^{b}	7.3^{d}
ASSILA F1	4.3^{a}	0.52^{d}	3.7^{d}	14.3^{a}	11.0^{a}	7.1^{a}	4.1^{a}	0.66^{a}	4.3^{c}	13.6^{c}	9.4^{b}	7.4^{cd}
ROMA VF	4.1^{a}	0.66^{a}	3.9^{c}	12.0^{b}	9.1^{b}	5.7^{d}	4.3^{a}	0.61^{b}	3.1^{e}	12.1^{d}	8.3^{c}	8.1^{b}
RIONEX	4.3^{a}	0.61^{b}	4.8^{a}	11.4^{b}	8.1^{e}	6.2^{c}	4.3^{a}	0.52^{d}	3.8^{d}	15.2^{a}	11.7^{a}	9.0^{a}
CAL-J	4.1^{a}	0.61^{b}	4.7^{b}	14.1^{a}	8.4^{d}	6.4^{b}	4.1^{a}	0.61^{b}	4.9^{a}	14.5^{b}	8.9^{b}	8.0^{bc}
GM	4.2	0.59	4.1	12.7	9.1	6.3	4.2	0.59	4.1	13.4	9.5	8.0
C.V	0.0	1.9	0.1	6.4	0.1	0.6	0.00	1.9	0.9	2.2	1.8	3.0
LSD	0 N/A	0.015	0.04	2.0	0.18	0.18	N/A	0.015	0.14	0.67	0.54	0.7

The means for factors that are followed by the same letters in a column are not significantly different, according to Duncan's multiple range test (DMRT) at $P \leq 0.05$

CHAPTER FIVE: DISCUSSIONS

5.1 The performance of tomato varieties in the open field

5.1.1 Vegetative growth and yield characteristics of tomato varieties grown in the open field

The temperature has a large influence on growth and development in tomato (Deribe *et al*., 2016). In the current study, determinate tomato varieties were grown in open field with temperatures that ranged from 11-12.5ºC (minimum) and 20-23ºC (maximum) below the optimum temperature for growth and development of tomato crop (21-24ºC) as suggested by CABI (2019) report.

The varieties that supported a high number of leaves limited the light distribution along the whole plant and therefore resulted in low chlorophyll content. This is in line with the findings of Feng *et al*. (2016) who reported that the light interception and the efficacy of light energy utilization are affected directly by canopy structure.

The highest total yield was estimated in Assila F1 followed by Roma VF, Rionex, Cal-J and Sifa F1 respectively. Assila F1 produced the highest average weight of individual weight followed by Sifa F1, Roma VF, Rionex and Cal-J. These findings are close to the statistics of food and agriculture organization which reported that tomato yielded 37.6t/ha in 2017. Hussain *et al* (2001) reported that Tanja cultivar produced highest yield of 41.45t/ha while Nadir produced the heaviest fruits (88.3g/fruit). Heuvelink and Dorais (2005) reported that tomato grown outdoors has the potential to produce between 40 and 100t/ha.

The positive relationship between the number of clusters per plant and tomato yield was observed with exception to Cal-J that required a heavy pruning due to it's canopy architecture that bear a high number of branches and leaves and therefore limit the light entrace throughout the plant. This may also explain how Cal-J variety was affected by low temperatures. Chen *et al.* (2014) reported that tomato cultivated at low temperature produced higher canopy density and more clumped caused by higher leaf area and shorter internodes.

The number of flowers per cluster had an effect on total yield of tomato varieties. Nevertheless, there was a slight deviation to Sifa F1 and Cal-J and may be due to flowers abortion. This may also explain their responsiveness to lower temperatures that caused those varieties to shed their flowers as they were exposed to the minimum temperatures ranged between 11 to 12.5^{o}C. Acoording to Ozores-Hampton *et al.* (2012) the low night time temperatures (below 13^{o}C) cause the tomato crops to drop their flowers and focus on survival. Mohan and Senthilkumar (2019) also reported that tomatoes blossom and flower drop were seriously affected of disproportitional temperatures.

The results of the current study showed that higher yield may depend on both number of fuits per plant and the average weight of individual fruit. The lower the weight of a fruit, the lower the total yield will be. It is in agreement with Souza *et al*. (2012)who found that there was a positive and high phenotypic correlations between fruit yield per plant, average fruit weight and fruit wall thichness and their association as they contributed to yield of fresh market tomatoes.

In general, the tomato varieties were not significantly affected by low temperatures. This may be due to the acclimation of seedlings before their transplantation to the open field. Previous acclimation of some woody plants determine their resistance to low temperatures but also genetics pays an important role in determining the degree of tolerance to low temperatures. A diffusible factor that promotes acclimation, probably abscissic acid (ABA) moves in the phloem from leaves to overwintering stems and may be responsible for the changes (Taiz & Zeiger, 2002). However, the current results are in agreements with OECD (2017) who reported that tomato requires minimum temperature above 18^{o}C for vegetative growth and can also survive the lower temperatures (12^{o}C).

5.1.2 Nutritional content of tomato varieties grown in open field

5.1.2.1 Dry matter (DM) content of tomato fruits grown in the open field

The DM content of tomato fruits is of main importance as it controls which fresh fruit mass results from the dry mass partitioned into the fruit. In addition, it is expressed as soluble solids and sucrose accumulation and may be seen as major determinant of tastiness and processing characteristics in food industry (Heuvelink & Dorais, 2005). In this study, the highest DM was obtained in Assila F1, followed by Cal-J, Rionex, Sifa F1 and Roma VF respectively. Generally, the DM content ranges between 5-7.5% in tomatoes and may reach 17% in wild tomato species as reported by Dorais *et al*, (2001a). Stoyanova *et al.* (2018) obtained 4.5-5.6% when they were assessing DM content and organic acids in tomatoes grown under different manuring and irrigation methods.

Though temperature has an impact on composition of tomato, in the current study where tomatoes were grown at low temperatures that ranged from 11^{o}C to 12.5^{o}C and high temperatures of 20-23^{o}C did not affect the production of DM for all varieties grown. This should be correlated to the findings of Van Der Ploeg and Heuvelink (2005) who stated that lowering the night temperature (NT) set-point from 15^{o}C to 11^{o}C from anthesis until picking of the first fruits, resulted in a 6% increase in yield after 18 weeks of fruit picking and caused in an increase mean fruit weight.

5.1.2.2 Total soluble solids (TSS) of tomato fruits grown in the open field

Sugars influence the palatability of tomato and may be the part of quality needed when selecting tomato cultivars for breeding program. TSS is a refractometric index indicating the amount (%) of dissolved sum of sugars (sucrose and hexoses; 65%), acids (citrate and malate; 13%) and other slight components (phenols, amino acids, soluble pectins, ascorbic acid and minerals) in a solution of tomato fruits juice (Beckles, 2012).

The highest TSS (%) was recorded in Rionex, followed by Call-J, Roma VF, Assila F1 and Sifa F1. There was significant difference among all varieties according to ANOVA at $P \leq 0.05$. These findings are in the range of those obtained by Cantwell (2010) who reported that soluble solids of red tomato range between 3.8 and 7.6% depending on their type.

Aoun *et al.* (2013) also analysed the quality traits of traditional tomato fruits of Tunisia and found that the TSS ranged between 2.02 and 4.5%. Though TSS is regarded as an important quality characteristic in tomato, according to the current findings, the varieties with higher TSS content may result in lower yield. This was in the same agreement with OECD (2017) who reported that the wild tomato species with high TSS have low yield. In the current studies, the low temperatures did not affect considerably the TSS obtained. This may be in relation with the findings reported by Van Der Ploeg and Heuvelink (2005) that reducing the night temperature from 16^{o}C to 11^{o}C do not change the quality of tomatoes.

5.1.2.3 pH and titratable acidity (TA) of the tomato fruits grown the in open field

The fruit's pH and TA are among the important quality characteristics of processing tomatoes. These with other tomato quality characteristics can be affected by the fruit maturity and over maturity (Anthon *et al*., 2011). The ANOVA showed a significant difference in TA between all varieties. The highest TA (%) was recorded in Roma VF with the pH of 4.1, followed by Cal-J with pH of 4.1, Rionex with the pH of 4.3, Sifa F1 with the pH of 4.00 and Assila F1 with the pH of 4.3.

In general, the results showed that the difference in pH between all treatment ranged between 0.2-0.3 and the higher the pH was increased, the lower TA was recorded. This may be due to the loss of citric acid in juice with high pH as explained by Anthon *et al*. (2011). The current results are also in line with the work of Fikreyohannes and Bhalekar (2016) who reported the similar percent of TA in various tomato cultivars. They also stated that the citric acid contributed to approximately 40-90% of the total acidity in the ripe tomatoes depending on the variety. In the current study the cultivation of tomato varieties in low temperatures below the optimal did not affect the variation of TA and pH. Van Der Ploeg & Heuvelink (2005) reported that low temperature from 16^{o}C to 11^{o}C did not change the quality of tomatoes.

However, the knowledge on the effect of growing tomatoes under low temperatures on specific quality attributes remains insufficient. Etienne *et al*. (2013) reported that the organic acid content in fleshy fruits is affected by environmental factors and cultivation practices but how these factors alter metabolism to bring about changes in organic acid content is undefined.

5.1.2.4 L-ascorbic acid(L-AA) of tomato fruits grown the in open field

The L-AA content of tomato fruits were significantly different among different tomato varieties. The highest average quantity of L-AA was obtained in Assila F1, followed by Cal-J, Roma VF while the lowest quantity was estimated in both Sifa F1 and Rionex. Agamy (2016) reported that the L-AA was 12.79 mg/ 100g of fresh tomatoes while Cantwell (2000) reported 22.5mg/100g FW in red-ripe tomatoes. The justification of low ascorbic acid obtained in the current study may be associated with low temperature and light intensity to which tomatoes were exposed.

5.1.2.5 Lycopene content of tomato fruits grown in the open field

The most observable modifications are associated with the loss of chlorophyll and the accumulation of lycopene when fruits mature. These carotenoids increase in fruits as tomatoes progress from the mature-green to red-ripe stage (Saltveit, 2005). The results of the current study, showed a significant difference for lycopene content in all tomato varieties. Lycopene content varied from 8.067 to 11mg/100gFW. The highest amount was obtained in Assila F1 while the lowest were found in Rionex. The results are in fair agreements with Davis *et al*. (2002) who obtained the lycopene content that varied from 3.3 to 12.3mg/100gFW using spectrophotometry at 560nm wavelength.

Anthon and Barrett (2007) used the same method at 503nm wavelength and obtained the lycopene content in tomato juice that ranged between 6.55 and 8.99mg/100g FW while Suwanaruang (2016) obtained 10.4699mg/100gFW at 503nm wavelength.However, other authors like Fikreyohannes & Bhalekar (2016) obtained the low ranges (2.00-5.95mg/100g FW) while Cantwell (2000) obtained 4.83mg/100gFW. The results of the current study revealed that low temperatures did not change on the standard quantity of lycopene of fresh tomato fruits.In addition, this may indicate that the fluctuations of temperatures during growth cycle of tomato result in different growth behavour than keeping low temprature at a constant level. This may be in the range of Saltveit (2005) findings who reported that the optimum temperature for pigment synthesis is 16-21^{o}C while temperature above 30^{o}C significantly reduce lycopene and carotenoid synthesis.

5.2 Performance of tomato varieties cultivated in the glasshouse

5.2.1 Growth characteristics for tomato varieties cultivated in glasshouse

The current experiment was carried out under the average day temperature (DT) of 36^{o}C while the night temperature (NT) was 18^{o}C.The optimum temperature considered ranged between 21and 24^{o}C (CABI, 2019). The highest height of tomato was recorded in both Assila F1 and Roma VF, followed by Rionex, Sifa F1 and Cal-J. Benti *et al*. (2017) reported the tallest tomato plant in Melka (60.87cm) among other determinate tomatoes when they were grown under high temperature of about 35^{o}C**.** It is observable that high temperature affects the plant by producing tall plants than normal. Srivastava *et al*. (2016) also reported the same trends in tomato hybrids while Izumi *et al.* (2007) confirmed that the plant height of rice increased within the range of 30 to 35^{o}C.

The ANOVA showed no significant difference among tomato leaves for the varieties grown on the same range of increased temperature. Hussein *et al.(*2018) reported the number of leaves for tomatoes that varied from 22.30 to 32.27 depending on variety. The increased temperature in glasshouse caused the plants to produce the lower number of leaves than normal plants. That temperature also caused all varieties to produce the lower number of branches. The varieties recorded with the highest number of branches were Sifa F1 and Cal-J while the lowest number was recorded in Assila F1. Benti (2017) recorded the average number of branches that ranged from 6 to 7 which are higher than the current observations.

The largest stem was observed on Sifa F1 while the smallest was found on Cal-J. The results are in the range with those stated by Hussein *et al*. (2018) who obtained 8-12mm of tomato stem depending on the variety. The plants grown under high temperature showed the ability to produce lower biomass due to affected meristematic activity and leads to reduced growth of cell size and different organs like leaves (Kim *et al.,* 2007).

The highest chlorophyll content was obtained in Sifa F1 while Cal-J had the lowest. The results from the current experiment revealed that the chlorophyll content of tomatoes grown under high temperature is lower than normal. During high temperature conditions, the photosynthesis is adversely affected, chlorophyll content in plant also decreases. Nonetheless, a plant cultivar that produces a high chlorophyll content during these conditions is considered as a heat tolerant (Wani & Kumar, 2020).

5.2.2 Yield characteristics tomato varieties cultivated in the glasshouse

The highest number of clusters per plant was recorded on Roma VF followed by Cal-J, Sifa F1 and Assila F1 had the same average number, while the lowest number of clusters were counted on Rionex. When counting the number of flowers per cluster, Sifa F1 was the first to bear the highest number, followed by Assila F1, and Rionex while the lowest number of flowers was found on Cal-J. The findings are close to those of Zahedi and Ansari (2012) who cultivated tomatoes under higher temperatures (32-42^{o}C) and reported the highest average number of flowers per cluster of 6.62.

However, it can be observed that, with high temperature conditions, the plant with higher number of clusters results in lower number of flowers and fruits per cluster and subsequently the yield becomes low. This may be caused by flowers' abortion for the sake of survival of the plant. The high temperature for day and night (33/30^{o}C) caused rapid interruption of reproductive organs development followed by abscission in pea plantation (Guilioni *et al.*, 1997). The increase of the temperature also interfers with pollen viability and germinability of pollens (Young *et al.,* 2004).

Sifa F1 had the highest number of fruits per plant, followed by Assila F1, Roma VF, Cal-J and Rionex. This has correspondence with the yield per plant where Sifa F1 also was the first to produce the highest yield, followed by Assila F1, Cal-J, Roma VF and Rionex. Zahedi and Ansari (2012) obtained the highest average number of fruits per cluster (5.33) while the highest yield recorded per plant was 3.42kg/plant). Biratu (2018) cultivated tomato varieties under high day and night temperatures (38.88/25.98ºC) and harvested the highest number of fruits per plant (27) with plant yield of 571.8g. However, the results of the current study showed that the plant varieties with higher number of flowers per cluster produced higher number of fruits and turned into higher yield. This is in fair agreement with Wahid *et al*. (2012), who reported that there was a positive relationship between fruit set and yield in tomato grown under stress conditions.

The tomato varieties showed significant difference for the mean weight of individual fruit. The highest weight was recorded in Rionex, followed by Sifa F1, Cal-J, Roma VF and Assila F1 respectively. Biratu (2018) recorded the mean weight per fruit that ranged from 25.2-93.6g depending on the type of variety. However, Abdelmageed and Gruda (2007) treated tomatoes under high temperature (37 day/27ºC night) and obtained 1.8-2.5 fruits per plant with the yield that ranged between 10.7 and 17.8g per plant. Wani and Kumar (2020) also reported that high temperatures caused about 65 to 70% of fruiting points to shed down.

The plant cutivars that perform better than others while exposed to high temperature may be result of great molecular response. When plant or plant part is exposed to high temperatures, there is a complex relationship between many genes, epigenetic and environmental factors that may occur in form of gene expression (Wani & Kumar, 2020). During that scenario, the produced heat shock proteins (HSPs) through heat shock factors (HSFs) network results in response to high temperatures (Wahid *et al*., 2012). Mishra *et al.* (2002) reported that HsfA1 performed as master regulator of thermo tolerance to reduce the expression of heat shock genes that were induced by high temperatures in tomato.

5.2.3 Nutritional value of fresh tomato varieties

5.2.3.1 Dry matter (DM) content of tomato fruits cultivated in the glasshouse

The temperature may influence the DM partitioning between fruits and vegetative plant parts either directly or indirectly through its influence on development and fruits abortion (Heuvelink E. , 1995). The DM for the current experiment ranged between 7.301 and 8.957%. The highest DM was recorded in Rionex while the lowest amount was recorded in Sifa F1. De Koning (1993) reported that DM concentration of tomato fruits varied from 5.2 in spring to 6.0% in summer. There is a variation of DM in plant depending on type of genotype but also temperature may have slight influence on it. The accumulation of fresh weight in fruit is to a great extent determined by accumulation of dry weight (Heuvelink & Bertin, 1994). Therefore, the temperature may significantly affect the partitioning of assimilates between the vegetative and generative parts of the plant (Adams *et al.*, 2001). Though its effect should not have a direct effect on partitioning, indirectly can have an impact on the rate of development, fruit set and abortion (Heuvelink E. , 1995).

5.2.3.2 Total soluble solids (TSS) for tomato fruits cultivated in glasshouse

Sugars contribute a lot to the amount of total solids in tomato fruits (Selahle *et al*., 2014). However, solar radiation and temperature have a large influence on their accumulation in fruits (Beckles, 2012).The TSS ranged from 3.1-4.837% where Cal-J showed the ability to synthesize the highest amount, followed by Sifa F1, Assila F1, Rionex and finally Roma VF. Lokesha *et al.* (2019) reported that they obtained 3.5-5.1% when the tomatoes were exposed to high temperature of 40±2^{o}C and it increased significantly in all genotypes. However, the results of the current study showed no increment caused by high temperature (36/18^{o}C) during day and night respectively.

Nevetheles, Gautier *et al*. (2005) reported that the increase of temperature had a beneficial effect on sugars content in cherry tomatoes cultivated under low competition while those cultivated in high competition were negatively affected.

Thus, it is questionable to find the sugar produced by fruits during winter season in glasshouse equal that produced in the field in summer as the high temperature affects pollen grains before anthesis results in decreased fruit set and therefore lower accumulation of total sugar(Deribe *et al.*, 2016; Mazzeo *et al.*, 2018).

5.2.3.3 pH and titratable acidity (TA) for tomato fruits cultivated in the glasshouse

The TA obseved ranged from 0.52 to 0.66% while the pH ranged between 4.0 and 4.3. Assila F1 had the higher TA than other varieties while Rionex had the lowest. The varieties showed a significant difference in TA while the mean difference for the pH of tomato juice was not significantly different and the increase of temperature did not show a significant effect on the variation TA of tomato. The results of the current findings are supported by Fikreyohannes and Bhalekar (2016) who cultivated tomato cultivars in normal conditions and obtained the TA that ranged between 0.44 and 0.59% for F5 tomato treatments and 0.45-0.68 for F6 treatments. They also found the pH that ranged between 4.07 and 4.36. When Lokesha *et al.* (2019) exposed tomatoes under high temperature (40±2ºC), they recorded the TA that ranged between 0.50 and 0.68%. The TA has a negative impact on the quality of tomato as the variety with high TA will result in low sweetness considering the sugar-acid ratio (Gunawardena & De Silva, 2016).

5.2.3.4 L-ascorbic acid (L-AA) for tomato fruits cultivated in the glasshouse

There was a significant difference among tomato genotypes where the highest amount was obtained in Rionex while the lowest quantity was found in Sifa F1. The quantity is lower than that reported by Fikreyohannes and Bhalekar (2016) (21.53-36.27mg/100g FW) while Cantwell (2000) reported L-AA that ranged between 12.5 and 22.5mg/100g FW depending on the stage of ripeness. The high temperature was reported to reduce the amount of synthesized L-AA by tomato fruits. At the seedling and early vegetative stage, it may trigger the adaptation of plant metabolism and results in high concentration of L-AA. However, at the late vegetative stage and fruit formation, the high temperature may impair the plant functions and cause a reduction of L-AA (Hernández, *et al*., 2018).

5.2.3.5 Lycopene content for tomato fruits cultivated in the glasshouse

Lycopene is only present in a limited number of plants mainly tomato, watermelon, pink grapefruit, guava, red papaya and rosehips. This important carotenoid influences the red colour of tomato fruits (Hedges & Lister, 2005). The results of the current experiment showed that the lycopene of the analysed genotypes were significantly different.

The highest lycopene content was analysed in Rionex while the lowest quantity was found in Roma VF. The obtained quantity was in fair range for the normal lycopene quantity (3-18mg/100g FW) of tomato as reported by Hedges and Lister (2005). The obtained quantity was higher than those reported by Sivakumar and Srividhya (2016) who obtained the range of 2.30-4.69mg/100g FW. The lycopene contents of fresh tomatoes range from 0-18mg/g FW, but in most cases they fall under the range of 5 to 8mg/100g FW (Dumas *et al*, 2003). Interestingly, when the fruit's skin is blended with the pulp, this may also increase overall measurement of lycopene as Sharma and Le Maguer (1996) reported that the skin contains five times lycopene than in the pulp (54mg/100gFW compared to 11mg/100g FW). In the current study, the high temperature (36^{o}C day/18^{o}C night) did not reduce significantly the amount of lycopene when compared to the standards. Dumas *et al*. (2003) reported that temperatures above 30^{o}C stop the lycopene biosynthesis while Sivakumar and Srividhya (2016) reported that lycopene content in diverse genotypes of tomato were increased under drought.

CHAPTER SIX: CONCLUSION

The main objective of the current study was to assess the performance of five determinate tomato (*Lycopersicon esculentum* L*)* varieties cultivated in greenhouse specifically glasshouse and in open field. The hypothesis that there is no difference in growth and yield characteristics of the evaluated tomato varieties grown under similar conditions was not accepted. Assila F1 should be chosen as the best hybrid that can be grown by farmers under low temperature areas as it has shown the ability to reward a higher yield, fruit's dry matter, L-ascorbic acid, lycopene content and acceptable palatability. Roma VF could be selected as the best performer among the evaluated homozygous genotypes for their acceptable characters. In addition, Roma VF should be an important plant material in future when selecting the cold tolerant tomato varieties and mapping their trait loci associated with these genes for further breeding program.

The tomato grown in the glasshouse under high temperature during day and relatively average night temperatures showed difference performance capacities. In general, none of the varieties performed to the best of optimal yield though they were affected differently. Nevertheless, the highest yield was recorded in Sifa F1 but had the low weight of individual fruit to the right of consumers, this shows the failure of hybrid tomatoes to cope with high temperature while producing suitable yield. Though Cal-J has not reached the acceptable yield, it has probably acquired certain heat stress transcription factors for thermo tolerance to be considered for further scientific investigations.

During this study, it was observed that there is a positive relationship between fruit set and yield for tomatoes grown under high temperatures. This should be a key to selecting best genotypes that hold their flowers and fruits when exposed to high temperature conditions. However, the current study should be repeatedly done for next seasons in order to increase the truthfulness. In addition, a continuous hunting of the genetic diversity in tomato for high temperature tolerance will be a paramount weapon for adapting to the climate change that the world is experiencing.

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APPENDICES

Appendix 1: Similarity index report

THESIS

ORIGINALITY REPORT

8%	10%	5%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.fao.org Internet Source	3%
2	edepot.wur.nl Internet Source	1%
3	ir.jkuat.ac.ke Internet Source	1%
4	canadianpreppersnetwork.com Internet Source	1%
5	www.j3.jstage.jst.go.jp Internet Source	1%
6	www.regional.org.au Internet Source	1%
7	www.researchgate.net Internet Source	1%

Exclude quotes	Off	Exclude matches	< 1%
Exclude bibliography	On		

Appendix 2: Daily meteorological data during experimental studies

SEPTEMBER 2019

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION (mm)
1	11.8	22.2	1.1
2	11.1	22.7	11.5
3	10	20.5	5.4
4	10.2	21.4	0
5	10.4	24.1	0
6	11.8	22.6	4.6
7	13.6	23.1	0
8	12.4	20.2	0
9	11.6	22.6	0
10	10.8	21.3	0
11	11	22.1	1.1
12	11.2	23.2	7.2
13	11.4	22.9	3.2
14	11	23.2	5
15	9.8	23.8	1.5
16	10.4	22.7	14.4
17	11.8	21.6	0
18	10.6	22.6	0
19	9.2	24.1	12.7
20	11	22.9	0
21	11.5	22.8	0
22	9.3	24.3	3.5
23	11.7	24.2	1.5
24	12.9	24.6	0
25	12.2	23.9	2.4
26	8.8	20.4	1
27	14	18.3	4.9
28	11.8	21.2	1
29	10.2	24.1	21.5
30	12.4	17.4	22.2

Rwanda Meteorology Agency (2021)

OCTOBER 2019

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION(mm)
1	9.8	21.9	4
2	9	21.8	4.2
3	9.9	20.2	12.4
4	11.5	20.7	0
5	9.3	21.1	11.6
6	11.1	19.3	8.3
7	13.1	19.5	0.7
8	9.8	22	0
9	10.2	22.5	4.3
10	11.4	20.9	1.2
11	12.4	19.6	7.6
12	11.8	16.6	38.3
13	10.8	20.9	16.1
14	11	16.5	15.5
15	8.6	22.2	0
16	12.9	20.6	10.2
17	11.1	22	2
18	11.5	21	0
19	11.2	21.2	2.5
20	9.9	22.2	1.3
21	10.4	18.8	1.5
22	10.9	21.8	0
23	11.2	21.5	8.5
24	11.6	18.6	23.5
25	10.2	18.8	21.9
26	10.8	19.4	32.6
27	11.2	21.2	1.4
28	11	21.9	4.5
29	11.8	22.3	1
30	10.3	20.6	16.3
31	10.5	18.1	12.4

Rwanda Meteorology Agency (2021)

NOVEMBER 2019

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION (mm)
1	8.3	22	7.3
2	10.1	20.2	0
3	9.6	21	0
4	10.4	23.1	0
5	10.8	23.8	0
6	11.8	21.7	12.1
7	10.2	21.5	0
8	10.4	21.3	5.1
9	9.6	21.8	6.8
10	8.8	20.8	37.2
11	10.2	19.9	4.1
12	11.4	21.8	3.5
13	11	21.8	12.4
14	12.8	20.8	5
15	9.1	22.8	0
16	11.2	23.3	0
17	11.3	24.2	0
18	11.5	21.5	3.1
19	11.4	22.1	0
20	12.2	20.3	2.2
21	11.4	22.4	0
22	11.2	23.7	1.8
23	13	16	29.6
24	12	19.2	5.3
25	11.8	20.8	0
26	10.6	23.1	28
27	13.8	22.2	0
28	12.1	21.8	7.9
29	13.8	20.7	0
30	12.2	22.2	0.5

Rwanda Meteorology Agency (2021)

DECEMBER 2019

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION (mm)
1	11.2	21.2	4.3
2	13.5	23.2	0
3	12.1	22.2	8
4	12.5	19.6	47.9
5	12.8	22.1	29.6
6	14	22.5	5.2
7	12.8	21.8	12.6
8	13.2	20.4	2.4
9	13	22	1
10	12.2	22.2	1.1
11	15.1	19.1	4.8
12	13.2	22.1	0
13	9.9	20.3	0
14	12.4	21.9	0
15	12	22.7	4.8
16	11.2	21.9	0.5
17	10.7	22.9	0
18	9.7	23.1	3.7
19	12.6	23.7	2.8
20	13.2	23.1	5.3
21	12.4	21.6	0
22	12.4	20.9	2.2
23	13.7	22.1	0
24	13.5	22.9	0
25	12.4	24	23
26	13.9	22.8	0.3
27	15.1	22.9	0
28	13.6	21.3	2.6
29	13.2	22.9	0
30	10.7	24.5	1.4
31	10.8	24.7	0

Rwanda Meteorology Agency (2021)

JANUARY 2020

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION
1	11.3	24.3	0
2	11.5	24.1	0
3	10.8	23.8	0
4	12.9	22.2	0.7
5	12.1	21.5	0
6	10.4	21.8	0
7	9.7	22.2	5
8	11.8	20.1	12.3
9	11.1	22.9	5.1
10	10.4	21.9	0
11	10	21.5	0
12	10.2	22.5	56.1
13	12.2	23.4	16.2
14	10.2	24.1	1.3
15	10.7	24.6	0
16	10.2	24.4	1
17	13.8	24.7	0.2
18	15.9	22	2.9
19	15	21.6	0.1
20	11.5	24.8	0
21	10	24.4	0
22	12.1	24.8	25.2
23	12.8	22.8	3.8
24	13.8	20.1	0
25	11.8	24.4	26.1
26	12	20.4	0.6
27	12.2	21.8	1.4
28	14.2	18.3	4.2
29	13.8	18.9	0
30	11.6	20.5	3.1
31	12.1	21	11.4

Rwanda Meteorology Agency (2021)

FEBRUARY 2020

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION (mm)
1	13.2	20.9	0.4
2	12.9	21.9	6
3	12.5	23.5	0.3
4	11.7	23.7	0.6
5	13	20.6	17.4
6	12	21.8	0
7	11.6	24.2	11.3
8	10.2	24.6	0
9	9.4	25.3	0
10	8.4	25.2	0
11	9.2	25	0
12	10.5	24.1	0
13	12.1	24.2	0
14	11.2	23.1	0
15	11	21.7	3.8
16	8.9	22.1	0.3
17	8.8	24.5	0
18	11.4	24.6	1
19	12.2	23.1	3.7
20	11.6	20.5	12.7
21	8.2	22.2	0
22	9.5	23.2	0
23	11.2	24.3	0
24	12.2	21.8	5.9
25	13.6	23.4	0.3
26	11.5	24.3	0
27	12.1	23.2	0
28	12.4	18.5	2.7
29	10.5	23.7	0

Rwanda Meteorology Agency (2021)

MARCH, 2020

DAY	MIN TEMPERATURE (ºC)	MAX TEMPERATURE (ºC)	DAILY PRECIPITATION (mm)
1	11.9	25.6	24.3
2	13.4	23.3	0
3	11.6	26.1	1.3
4	10.8	23.3	0
5	12.4	23.9	1.2
6	14.2	23	0
7	13.2	24.1	0
8	12.2	24.8	0
9	13.2	22.2	6.9
10	13.6	23.8	7
11	14.8	23.5	3
12	13.3	21.6	8.4
13	13.3	22.6	3.5
14	14	24.8	0
15	12	25.3	18
16	11.9	24.5	0
17	11.5	25.1	13.7
18	13.8	20.3	0.5
19	13.8	22.1	0.2
20	11.9	23.1	1.1
21	9.8	20.3	3.3
22	9.6	22.5	2.1
23	10.2	23.5	10.5
24	13.2	22.1	0
25	12.7	20.2	11.9
26	10.8	23.5	6.8
27	11.6	22.1	5.3
28	9.7	21.8	0
29	11.4	22.1	0
30	10.8	23.9	0
31	11	22.3	9.4

Rwanda Meteorology Agency (2021)

Appendix 3:Temperature and relative humidity of glasshouse during experiment

Month	Before noon		After noon		Night	
	Temperature (ºC)	RH(%)	Temperature (ºC)	RH(%)	Temperature (ºC)	RH(%)
November, 2020	34.5	35.0	34.8	41.1	19.0	83.0
December, 2020	35.6	41.0	35.1	38.4	18.6	84.0
January, 2021	36.1	40.1	35.7	35.5	18.3	85.1
February, 2021	37.0	37.9	35.2	36.4	18.5	84.4
March, 2021	37.85	37.0	37.0	36.0	18.1	85.0

Data taken using thermo hygrometer testo 608-H1 (UK)

Appendix 4: Raw data

OPEN FIELD GROWTH PARAMETERS: 30DAT

	RIONEX			**ASSILA F1**			**SIFA F1**			**ROMA VF**			**CAL-J**		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
No-leaves	7	6	7	7	7	8	6	6	8	7	8	8	8	7	7
Stem diameter(mm)	7.9	7.8	7.7	8.4	7.4	6.9	7.0	6.9	7.4	6.4	6.8	7.4	8.9	7.2	7.4
No-branches	6	5	5	7	6	6	3	2	3	3	4	5	5	6	5
Plant height	19.0	15.7	16.9	28.3	19.2	19.4	19.7	17.2	17.7	14.8	17.2	21.6	19.7	19.4	18.3
SPAD Value	53.5	44.7	47.2	53.9	46.4	53.4	46.7	40.4	49.8	59.7	54.9	51.8	42.2	44.8	48.4
Chlorophyll ($\mu g/cm^2$)	46.1	38.5	40.7	46.5	40.0	46.0	40.3	34.8	42.9	51.5	47.3	44.7	36.4	38.6	41.7

OPEN FIELD GROWTH PARAMETERS: 45DAT R: Replication

No-leaves	32	23	19	43	30	38	25	23	26	29	38	24	33	38	34
Stem diameter(mm)	11	10	9.9	10	8.9	9.0	11	10	11	9.0	9.8	9.8	11	10	9.2
No-branches	7	6	5	7	6	7	6	5	6	6	7	5	8	6	6
Plant height	37.7	32.0	25.3	47.8	42.4	44.8	36.7	35.0	38.0	29.9	39.0	36.3	36.6	40.0	40.2
SPAD Value	62.5	51.0	65.1	52.9	51.7	50.0	69.7	47.0	55.0	60.0	55.3	80.9	48.0	57.6	50.1
Chlorophyll ($\mu g/cm^2$)	53.9	44.0	56.1	45.6	44.6	43.1	60.1	40.5	47.4	51.7	47.7	69.7	41.4	49.7	43.2

OPEN FIELD GROWTH PARAMETERS: 60DAT

	RIONEX			ASSILA F1			SIFA F1			ROMA VF			CAL-J		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
No-leaves	65	47	72	55	51	70	34	22	41	42	56	34	77	55	54
Stem diameter(mm)	13.7	13.0	12.3	12.0	10.0	11.0	15.3	12.0	13.7	12.0	13.0	12.0	13.0	12.7	11.0
No-branches	8	6	8	7	5	8	6	5	6	7	9	6	8	7	6
Plant height(cm)	48.9	52.8	57.2	59.2	68.2	65.8	52.5	48.4	47.0	50.6	57.0	47.9	54.0	63.9	49.7
SPAD Value	70.9	55.5	83.3	53.6	56.9	48.6	96.6	54.3	59.2	49.9	56.9	106.6	53.1	69.1	51.1
Chlorophyll ($\mu g/cm^2$)	61.1	47.8	71.8	46.2	49.1	41.9	83.3	46.8	51.0	43.0	49.1	91.9	45.8	59.6	44.1

OPEN FIELD: YIELD PARAMETERS R: Replication

No Clusters per plant	22	11	21	31	20	22	17	10	16	15	26	17	29	25	37
No flowers per cluster	6	7	5	11	9	6	6	6	8	8	6	8	9	8	6
No fruits per plant	54	69	48	60	62	59	51	43	35	56	64	40	80	59	42
Average individual fruit weight	82.8	63.5	88.5	109.5	110	109	84	83	86.2	79	78.9	83	56.8	55.6	22.6
Total yield (t/ha)	26.0	25.7	24.4	33.7	38.6	35.0	29.9	20.9	22.2	26.4	34.4	21.4	26.9	29.2	19.2
Marketable yield (t/ha)	23.7	22.5	21.4	29.8	34.1	31.1	25.7	18.0	17.5	22.9	30.0	19.0	22.7	24.7	13.8

OPEN FIELD: LABORATORY ANALYSIS

	RIONEX			ASSILA F1			SIFA F1			ROMA VF			CAL-J		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
pH	4.3	4.3	4.3	4.3	4.3	4.3	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.1	4.1
Titratable acidity(%)	0.61	0.59	0.62	0.53	0.50	0.54	0.55	0.53	0.54	0.66	0.65	0.67	0.61	0.61	0.62
Total soluble solids (%)	4.83	4.82	4.80	3.63	3.60	3.59	3.59	3.61	3.60	3.91	3.95	3.93	4.63	4.65	4.67
L-Ascorbic acids (mg/100g FW)	10.0	12.1	12.1	13.8	14.3	14.9	9.4	12.7	12.1	11.6	13.8	10.5	14.3	14.3	13.8
Lycopene (mg/100g FW)	8.0	8.0	8.2	11.0	11.0	11.0	8.7	8.7	8.7	9.1	9.2	8.9	8.4	8.4	8.4
Dry matter (%)	6.22	6.22	6.13	7.17	7.12	6.92	6.19	5.97	6.21	5.63	5.70	5.67	6.47	6.45	6.37

R: Replication

GLASSHOUSE GROWTH PARAMETERS:30DAT

	RIONEX			ASSILA F1			SIFA F1			ROMA VF			CAL-J		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
No-leaves	8	8	8	9	10	8	9	8	8	8	8	8	8	8	8
Stem diameter(mm)	5.3	5.7	6.0	4.0	6.7	5.7	5.7	7.0	7.0	4.7	6.0	7.0	6.3	4.7	7.0
No-branches	0	1	0	1	1	0	0	0	0	0	0	1	1	0	0
Plant height	23.7	20.3	28.0	25.3	27.6	25.3	14.1	23.6	25.0	29.8	19.3	27.7	29.7	25.3	25
SPAD Value	45.9	48.1	42	47.3	42.3	45.2	44.8	45.4	35.1	45.3	47.2	37.4	42.9	43.3	46.6
Chlorophyll ($\mu g/cm^2$)	39.6	41.5	36.2	40.8	35.5	39.0	38.6	39.1	30.3	39.1	40.7	32.2	37.0	37.3	40.2

GLASSHOUSE GROWTH PARAMETERS:45DAT

No-leaves	11	10	13	15	14	8	9	9	10	14	10	12	8	10	10
Stem diameter(mm)	7.3	6.9	6.8	8.3	7.9	6.4	6.5	7.7	8.3	6.1	7.4	9.1	6.5	5.3	7.3
No-branches	2	3	2	1	1	1	1	0	2	2	0	2	3	3	3
Plant height	59.4	48.6	52.1	60.6	64.3	46.3	69.5	55.8	55.1	61.0	47.6	59.0	55.1	61.9	55.9
SPAD Value	47.3	50.1	43.3	49.0	46.2	46.4	49.0	46.7	52.0	55.7	47.3	42.1	47.3	40.1	43.0
Chlorophyll ($\mu g/cm^2$)	40.8	43.2	37.3	42.2	39.8	40.0	42.2	40.3	44.8	48.0	40.8	36.3	40.8	34.6	37.1

R: Replication

GLASSHOUSE GROWTH PARAMETERS:60DAT

	RIONEX			ASSILA F1			SIFA F1			ROMA VF			CAL-J		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
No-leaves	28	16	11	19	22	15	19	11	23	23	20	22	8	9	18
Stem diameter(mm)	9	8	9	14	9	7	7	8	9	9	9	11	7.2	6	8
No-branches	2	4	2	1	1	1	3	3	3	2	1	3	3	3	3
Plant height(cm)	80.0	90.4	68.3	94.0	89.0	93.0	85.5	67.0	74.8	99.8	99.2	77.0	61.4	41.0	103.2
SPAD Value	47.8	52.8	44.5	48.2	50.1	40.8	52.9	47.4	69.1	65.9	46.3	45.0	51.7	37.4	41.0
Chlorophyll (µg/cm^2)	41.2	45.5	38.6	41.6	43.2	35.2	45.6	40.9	59.6	56.8	40.0	34.5	44.6	32.2	35.3

GLASSHOUSE: YIELD PARAMETERS

No Clusters per plant	**6**	**5**	**3**	**6**	**7**	**4**	**7**	**3**	**7**	**7**	**5**	**7**	**11**	**2**	**5**
No flowers per cluster	5	4	5	3	6	5	5	6	6	4	6	4	5	3	4
No fruits per plant	10	5	2	5	8	28	26	21	5	16	13	10	15	6	13
Average individual fruit weight(g)	35.9	35.9	35.9	25.7	20.0	25.6	29.6	33.8	27.3	24.0	21.5	27.1	23.1	26.7	35.0
Plant yield (g)	358.5	179.25	71.7	128.5	160.1	717.75	769.76	709.08	136.68	383	279.618	271	346.3	160.2	454.73

R: Replication

GLASSHOUSE: LABORATORY ANALYSIS

	RIONEX			ASSILA F1			SIFA F1			ROMA VF			CAL-J		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
pH	4.3	4.3	4.3	4.1	4.1	4.1	4.0	4.0	4.0	4.3	4.3	4.3	4.1	4.1	4.1
Titratable acidity(%)	0.53	0.50	0.54	0.66	0.65	0.67	0.55	0.53	0.54	0.61	0.59	0.62	0.61	0.61	0.62
Total soluble solids (%)	3.91	3.89	3.70	4.19	4.31	4.30	4.51	4.39	4.40	3.17	3.18	3.07	4.8	4.89	4.82
L-Ascorbic acids (mg/100g FW)	15.4	14.9	15.4	13.8	13.8	13.2	11.6	12.1	11.0	12.7	12.1	11.6	14.9	14.3	14.3
Lycopene (mg/100g FW)	11.3	11.4	12.4	9.5	9.3	9.5	9.0	9.1	9.5	8.4	8.2	8.2	8.9	9	8.9
Dry matter (%)	8.95	8.47	9.452	7.61	6.94	7.641	7.91	6.86	7.133	7.94	8.12	8.375	7.81	8.057	8.109

R: Replication