

**EVALUATION OF GROWTH AND YIELD CHARACTERISTICS OF HYBRID
INDETERMINATE TOMATO (*Solanum Lycopersicum l.*) VARIETIES UNDER
TUNNEL GREENHOUSE PRODUCTION IN ZIMBABWE**

**A dissertation submitted in partial fulfilment of the requirements for the Master of
Science degree in food security and sustainable agriculture
(Production option)**

Bindura University of Science Education



**Faculty of Agriculture and Environmental Science
Department of Agricultural Economics, Education and Extension**

Kumbirai Mapfiza

B1749238

MARCH 2022

RELEASE FORM

Name of Candidate: Kumbirai Mapfiza

Reg Number: B1749238

Degree: Master of Science Degree in Food Security and Sustainable Agriculture

Project title: Evaluation of growth and yield characteristics of hybrid indeterminate tomato (*Solanum Lycopersicum L.*) varieties under tunnel greenhouse production in Zimbabwe

Permission is hereby granted to **Bindura University of Science Education Library** to produce a single copy of this dissertation and lend such copy for private, scholarly or scientific research only.

Signed.....

Permanent address: House # 4994 Mainway Meadowlands, Harare

APPROVAL FORM

The undersigned certified that they have supervised and recommended to Bindura University of Science Education for acceptance of dissertation entitled '**Evaluation of growth and yield characteristics of hybrid indeterminate tomato (*Solanum Lycopersicum L.*) varieties under tunnel greenhouse production in Zimbabwe**' submitted in partial fulfilment of a Master of Science Degree in Food Security and Sustainable Agriculture.

Name of Supervisor:

Signature :

Date :

DECLARATION

I hereby declare that the research project entitled '**Evaluation of growth and yield characteristics of hybrid indeterminate tomato (*Solanum Lycopersicum L.*) varieties under tunnel greenhouse production in Zimbabwe**' submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of the original work done by me under the guidance and supervision of **Dr R. GADZIRAYI** and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science Degree in Food Security and Sustainable Agriculture. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree or diploma

Author : Kumbirai Mapfiza

Reg Number : B1749238

Signature :

Date :

DEDICATION

This research effort was inspired by my son Msa and daughter Nandi.

ACKNOWLEDGEMENTS.

I am greatly indebted to my project supervisor Professor Christopher T. GADZIRAYI whose guidance enabled me to undertake and complete this research effort. I also extend my gratitude to fellow students who provided material and moral support that was invaluable for the completion of this project.

My humble appreciation goes to Pedstock Investments Pvt Ltd staff and its management team for supporting my study by providing material and field space on which the research was conducted. Special mention goes to Patience and Elphigio who both worked tirelessly on the experiment site.

I also would like to acknowledge my family for their support towards the successful completion of this dream. To many more that I may have not mentioned, please may the almighty God kindly bless you all for your kindness and love for my work.

ABSTRACT

Tunnel greenhouses provide opportunities for year round crop production as they passively control environments by trapping heat and therefore either extend the growing season or ensure an early start to the season. Hybrid indeterminate tomato varieties are a suitable option for Zimbabwe which has recorded low yields of up to 7tha⁻¹ in comparison to world averages of up 37tha⁻¹ due to the use of recycled seed as well as field production conditions that are not conducive. The objective of the study was to assess growth and yield attributes of new hybrid indeterminate tomato (*Solanum lycopersicum* L.) varieties bred by Haaretz as well as characterise the physical traits of the varieties under Zimbabwe conditions. The experiment was laid in a Randomized Complete Block Design with six treatments replicated three times. Treatments consisted of varieties (3295, 29412, 29202, 3297 and 3298) and Daniella as a control. Data were analysed using GenStat 14th edition and means were separated using Least Significant Difference (LSD) at 5% level of significance. Variety 29202 had the highest plant height (521.70cm) and was significantly different from other varieties whilst variety 3298 had the lowest plant height (418.20cm). Leaf area was highest in variety 29202 (204.55cm²) while 3298(141.10 cm²) recorded minimum leaf area. Significant difference for days to flowering were noticed where 29412 was the earliest hybrid to flower in 17.25days while 3298 was last to flower in 24.667 days. Daniella recorded the highest average fruit weight of 218.30 g whereas lowest average fruit weight was observed in 3298 (120.70 g). Highest yield per hectare was recorded for variety 29202 (142.80tonsha⁻¹) while 3298 achieved the lowest yield of (80.23 tonsha⁻¹). Highest shelf life was observed in 3297 (33.75 days) followed while variety 29412 had the shortest shelf life (18.67 days). Results of this study show that Haaretz tomato variety 29202 is better than Daniella variety in terms of yield and shelf life. Presence of green shoulder was observed in variety 3295 only and this is an undesirable fruit quality. Therefore, farmers are recommended to use tunnel greenhouses to grow 29202 which produced higher yields of up to 142.80tonsha⁻¹ and also exhibited shelf life of 28 days. Growers that do not cooling facilities in very hot regions are recommended to grow variety 3297 which had a long shelf life of 33.75days however yielding120tha⁻¹ though further research is recommended in terms of diseases tolerance and other quality parameters for the two varieties.

Key words: Tomato, varieties, growth and yield

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
%	Percentage
cm	Centimetre
cm ²	Centimetre squared
Et al.	And co-worker/ and others
Comp D	Compound D fertiliser (7:14:7)
Fig	Figure
KG	Kilogram
Ha	Hactare
Ha ⁻¹	Per hactare
i.e	That is
LA	Leaf Area
G	Gram
m ⁻²	Per square metre
Max	Maximum
Ha	Hectare
Kg	Kilogram
kg/ha	Kilogram per hectare
Lsd	Least significant difference
M	Metre
m ²	Square metre
Ms	Mean squares
N:P: K	Nitrogen: Phosphorous: Potassium ratios
P	Phosphorous
SS	Sum of squares
SSA	Sub Saharan Africa
t	Tonnes
USD	United States Dollar

TABLE OF CONTENTS

Contents	Page
RELEASE FORM	i
APPROVAL FORM	ii
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
LIST OF ACRONYMS AND ABBREVIATIONS	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDICES	xi
CHAPTER 1	
1.1 Background	1
1.2 Statement to The Problem	4
1.3 Objectives of The Study	5
1.3.1 Main objective	5
1.3.2 Specific Objectives	5
1.4 Research Questions	5
1.5 Hypothesis	5
1.6 Justification	6
1.9 References	7
CHAPTER 2 :LITERATURE REVIEW	
2.0 History of Tomato	7
2.1. Anatomy and physiology of the tomato plant	8
2.2. Chemical composition of the tomato plant	8

2.3. Tomato classification	8
2.3.1 Heirloom tomatoes	9
2.3.2 Hybrid tomatoes	11
2.3.3 Characteristics of hybrids	12
2.4. Determinate and Indeterminate varieties	13
2.5. Environmental conditions suitable for tomato growth	14
2.6. Soil conditions suitable for tomato growth	14
2.7. Tomato growth	15
2.8. Factors determining tomato plant yield	15
2.8.1. Challenges faced by farmers in tomato fruit production	16
2.9. Growth parameters	19
2.10. Yield factors	20
2.10.1. Days to 50% flowering	20
2.10.2. Number of fruits per plant	20
2.10.3. Average fruit weight (g)	21
2.10.4. Diameter of fruits (cm)	21
2.10.5 Yield per plant (kg)	22
2.10.6. Yield per plant (ha)	22
2.11. Tunnel greenhouse production	23
2.12. Requirements for growing tomatoes under protected structures	28
2.12.1. Growing media	28
2.12.2. Fertigation	28
2.12.3. Relative humidity	29
2.12.4. Light	29
2.12.5. Irrigation	29
2.12.6. Labour	32
2.12.7. Pest management	32
2.13. Trellising	33
2.14. Pruning and Training	33
2.15. Postharvest qualities of tomato	34
2.15.1. Tomato fruit colour	35
2.15.2. Tomato firmness	36

2.16. Summary	37
2.2. References	38

CHAPTER 3: METHODOLOGY

3.1. Experimental site	49
3.2. Experimental design	49
3.3. Details of tunnel greenhouse used for experiment	50
3.3.1. Seedbed management	50
3.3.2. Transplanting of seedlings	50
3.2.3 Crop maintenance	51
3.2.4. Pest and disease control	51
3.2.5. Irrigation management	52
3.2.6. Trellising	52
3.3 Termination of crop	54
3.4 Data Collection Methods	54
3.4.1 Sampling Procedures	55
3.4.2. Morphological and phenological parameters	55
3.4.3. Plant height (cm)	55
3.4.4. Leaf area (cm²)	55
3.4.5. Distance between clusters (cm)	55
3.4.6. Number of flowers per cluster	56
3.4.7. Number of days to 50% flowering	56
3.4.8. Node to 50% inflorescence	56
3.4.9. Days to fruit set	56
3.4.10 Fruit diameter (cm)	56
3.5.11 Days to first fruit picking	57
3.5.12. Fruit weight	57
3.5.13. Yeild per plany (kg)	57
3.6. Statistical Ananalysis	57
3.5. Data Analysis	57

4. CHAPTER 4: RESULTS AND DISCUSSION OF RESULTS

4.1. Introduction	59
4.2. Materials and Methods	59
4.2.1. Description of Study Area	60
4.2.2. Research Design	60
4.2.3. Sampling Procedure	60
4.2.4. Data Collection Procedure	60
4.2.5. Data Analysis Procedure	60
4.2.6. Challenges Encountered During Data Collection	61
4.3 Results and discussion	61
4.3.1. Plant height	62
4.3.2. Tomato leaf area	62
4.3.3. Days to flowering	63
4.3.4. Number of fruits per cluster	64
4.3.5. Distance between fruit clusters per plant	64
4.3.6. Average fruit weight	65
4.3.7. Polar diameter of fruit	65
4.3.8. Yield per hectare	66
4.4. Recommendations	69
4.5. Conclusion	69
4.6. References	70

5.0 CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1. Introduction	74
5.2. Materials and methods	74
5.2.1. Description of study area	75
5.2.2. Research design	75
5.2.3 Sampling procedure	75
5.2.4. Data collection	75
5.2.5. Challenges encountered during data collection	76

5.3. Results	77
5.3.1. Shelf life	77
5.3.2. Fruit pericarp thickness (cm)	78
5.3.4. Presence of green shoulder on fruit	78
5.3.5. Exterior colour of immature fruit	79
5.3.6. Exterior colour of ripened fruit	79
5.3.7. Predominant fruit shape	80
5.3.8. Fruit size homogeneity	81
5.5. Recommendations	81
5.6. Discussion	82
5.7. References	82

CHAPTER 6

6.1. Introduction	84
6.2. Summary	84
6.3. Conclusion	85
6.4. Policy implication and recommendations	86
6.5. Suggestions for future research work	87
6.6. Appendices	88

LIST OF TABLES

Table		Page
1	RCBD as with treatments replicated in Blocks	50
2	List of Chemicals used to control pest and diseases	52
3	Exterior colour of tomatoes at full ripe stage	78
4	Homogeneity of fruits	79

LIST OF FIGURES

Figure		Page
1	Global Tomato production	7
2	Market share of tomato by country	8
3	Illustration of differences between determinate and Indeterminate tomato	13 39
4	Tomato colour chart corresponding to stage of ripening	67
5	Newly transplanted tomatoes in tunnel greenhouse	53
6	Picture of trellised hybrid tomato in tunnel greenhouse	61
7	Plant height of different tomato varieties	62
8	Leaf area of different tomato varieties in tunnel greenhouse	63
9	Days to flowering in relation to the 6 tomato varieties	63
10	Number of fruit clusters in relation to tomato variety	65
11	Distance between fruit clusters	65
12	Days to first fruit picking	66
13	Fruit weight of tomato varieties	67
14	Fruit diameter of different varieties	68
15	Yield/ha in tonnes	69
16	Shelf life of the different varieties	69
17	Presence and absence of green shoulder in ripened fruits	78
18	Exterior colour of immature fruit	79
19	Exterior colour of ripe fruit and grading	80

LIST OF APPENDICES

Number	Appendix	Page
1	ANOVA for Plant height at 120 days after transplanting	88
2	ANOVA for Leaf area for different varieties	88
3	ANOVA for Days to first flowering	88
4	ANOVA for Number of fruit clusters	89
5	ANOVA for Difference between fruit clusters	89
6	ANOVA for Days to first fruit picking	89
7	ANOVA for Different fruit diameter	90
8	ANOVA for Fruit weight	90
9	ANOVA for Yield per ha in tons	90
10	ANOVA for Shelf life of ripe fruit in days	91
11	ANOVA for fruit pericarp thickness	91

CHAPTER 1

1.1. Background

Tomato (*Solanum Lycopersicum L*) is one of the most important vegetables in the world which currently ranks third in global vegetable production in the world (www.hortbiz.com). It ranks third, largest vegetable crop in the world after potato and sweet potato, but it is on top of the list of canned vegetables (Hussein et al, 2002). In 2017, tomato global production was approximately 177, 8 million tons, planted on 5million hectares with an average yield of 37 t/ha (www.worldatlas.com). The tomato fruit is used as a fresh salad vegetable, popular ingredient in soup, stews, and sauces, various other dishes and has become a major source of several plant nutrients providing important nutritional value to the human diet (Singh et al., 2017). Tomatoes are widely cultivated in tropical, sub-tropical and temperate climates where the leading tomato producing countries are China, the United States of America, India, Egypt, Mexico, Brazil and Indonesia (Faostat, 2014).

Nutritionally, tomato is composed mainly of water (approximately 90%), soluble and insoluble solids (5-7%), citric acid and other organic acids and vitamins and minerals (Pedro and Ferreira, 2007). Tomatoes are a good source of several essential vitamins and minerals namely, vitamin C, potassium, vitamin K₁ and vitamin B₁.The fruit is commonly called the “poor man’s orange” because it is an excellent source of vitamin C (Giovannucce, 1999). Tomatoes add variety of colours and flavour to food and are also known for their medicinal properties (Freeman and Reimers, 2010). Ripe tomatoes have a high content of antioxidant lycopene, beta-carotene, naringenin as well as chlorogenic acid which play a possible role in the prevention of certain forms of cancer and also, noted for their heart disease prevention properties (Agarwal and Rao, 2000; Radzevicius et al. 2009).

A tomato is a herbaceous annual with a creeping stem covered with single hairs whose plants are characterized either as indeterminate or determinate types based on plant habit and vigour (Perez et al., 2017). The determinate types eventually form a flower cluster at the terminal growing point, causing the plant to stop growing in height (Papadopoulos, 1991). Determinate tomatoes are bushy and usually stop growing at about 1.5 m (Biswas et al., 2015). The leaves are compound and alternate and the flowers are borne in inflorescences of 4 – 6 yellow flowers. The fruits are in a variety of shapes; round, elongated, cylindrical and oval or pear shaped and in varying sizes (Singh et al., 2014). Plants that do not set

terminal flower clusters, but only lateral ones and continue indefinitely to grow taller are called indeterminate (Upadhyay et al., 2005) The notable characteristics observed for these two classes are; growth period, planting to harvest period, plant height, fruit bearing period and yields (Mabengwa, 2013).

Tomato is a typical day neutral plant and it is mainly self-pollinated, but a certain percentage of cross pollination also occurs (Jackson et al, 1997). It is a warm season crop reasonably tolerant to heat and drought and grows under wide range of soil and climatic conditions (Anastacia, 2011) Despite the availability of several varieties, growers in sub-Saharan Africa find it difficult to cultivate tomatoes. The reasons being, their suitability for a particular region, requirement for more attentive management, ripening at once which leads to the problem of storage and processing facilities, lack of high and quality yield under open conditions and unstable inheritance of specific traits through their seeds, pest and disease problems (SNV, 2016). Zimbabwe has been no exception to these challenges which have resulted in very low yields below 7t/ha as a result of using recycled seed as well as fluctuating supply due to the use of determinate open pollinated varieties which thus affecting product availability during the winter season resulting in high pricing that is beyond the reach of many households (Chibi et al., 2015). Growing of indeterminate varieties that spread their yield over a period of six to eight months can ensure consistent supply to the market (Perez et al., 2017). Greenhouse production ensures environmental manipulation to ensure season extension for tomatoes (Black et al., 2008)

In Zimbabwe, tomatoes are among the most important and prominent horticultural crops grown for both home consumption and the domestic market (SNV, 2014). Whilst a lot of work has been done through research to bring about food security particularly in the area of maize through improved varieties in Zimbabwe; little research has been done to develop new varieties for tomatoes with the bulk of varieties having to be imported from other countries (Chibi et al., 2015). However, production of tomatoes in rural areas of the country has potential to increase employment and improve farmers' livelihoods especially after the summer season (Jackson et al, 1997).

Owing to the limited availability of improved cultivars that are suitable for different purposes, the yield of tomatoes in Zimbabwe is an average of 7,57t/ha which is far below the world's average of 37t/ha (FAO, 2015). Improved tomato varieties in particular indeterminate

varieties, that are being grown in Europe, Israel, Brazil and Morocco have a potential yield of 90t/ha to 150t/ha (www.haaretz.com). Therefore, identification of improved tomato varieties that are adaptable, high yielding and disease tolerant is crucial if the country is to become food secure (SNV, 2014). In general, with ever increasing demand for tomatoes, it has become imperative to develop high yielding, tolerant and suitable hybrids for cultivation in different agro-climatic conditions to boost up the tomato production per unit area and per unit time according to the consumers and growers preference (Bielinski et al., 2014).

The unavailability of varieties and recommended information packages, poor quality seeds, poor irrigation systems, lack of information on soil fertility, disease and insect pest, high post-harvest loss, lack of awareness on improved technologies and poor marketing systems are the major constraints in Zimbabwean tomato production (Chibi, 2015). Protected agriculture offers a measure to help offset the predicted decrease in crop yields and productivity due to climate change, by increasing the grower's control over environmental factors (Arin and Ankara, 2001). Some of the associated benefits may include: protection from cold temperatures, reduction of wind damage, a decrease in foliar disease pressure, expansion of suitable production areas, extension of the growing seasons, increased crop yields, improved fruit crop quality, and achieving a more stable market (Hunter, 2010). Furthermore, Veershetty (2004) confirms that good productivity requires availability of water throughout the cycle, as the tomato plant is very sensitive to water stress.

Extending the growing season by protecting plants from cold temperatures can drastically improve productivity in the early and late season and high tunnel greenhouses are one way that has been shown to effectively and profitably extend the growing season for warm and cool season crops in certain climates (Foord, 2004). High tunnels look and operate like greenhouses, but the temperature is maintained only by passive heating and cooling unlike standard greenhouses (Booth et al., 2007). High tunnel trap heat created by incoming solar radiation and optimal temperatures are maintained by manually opening and closing the doors and sides to provide cross ventilation (Abdel-Ghany, 2011).

Tunnel greenhouses thus reduce the need for fungicide and pesticide application contributing to a more sustainable production system as they deter entry of insect pest because of the presence of walls (Eldin, 2009). The decision to utilize high tunnels to extend the growing

season is based on a number of factors that present advantages and disadvantages. The primary advantage to high tunnel production is profitability as high tunnels have been shown to increase net returns per acre by protecting quality, increasing yields, and providing the opportunity to obtain off season price premiums (Black et al., 2008).

1.2. Statement of Problem

In Zimbabwe the use of recycled seed is peculiar with small scale farmers due to the poor distribution of hybrid seed which is mainly available in major towns and is also expensive as well as the use of inappropriate growing structures (SNV, 2016). This has resulted in use of poor yielding seed that has low tolerance to pest and diseases. Indeterminate hybrid varieties spread their yield over a period of six to eight months when grown under tunnel greenhouse structures, whereas the locally grown determinate varieties are harvested within three to four weeks (Singh, 2017). The low seasonal production, yielding an average of 7t/ha resulted in Zimbabwe being a net importer of tomatoes between 2009 and 2014 until a change in legislation banned the importation of tomatoes. However, the shortage has remained with prices going as high as \$3/kg due to a combination of low supply, poor yields and high input cost (Chibi et al., 2015).

At present, cultivation of tomato in open fields is a wide spread practice in Zimbabwe however, open field tomato production in Zimbabwe is mainly seasonal resulting in shortages (SNV, 2016). Research has shown that, the tomato crop grown in open fields is exposed to various abiotic and biotic stresses and therefore, it is not possible to produce high quality tomato in terms of size, shape, and colour and free from diseases and pests as compared to tomato produced under tunnel greenhouse environment (Singh et al, 2014). Lack of information on selecting well-performing varieties may lead to lower yield or unacceptable fruit quality. Most tomato cultivars used for commercial food production in Zimbabwe are imported from South Africa and Tanzania (SNV, 2016). Information on the performance of these tomato varieties under Zimbabwean conditions, utilizing tunnels greenhouse structures is still very limited. Unfavourable weather conditions, such as hail and high temperatures during the summer season or low temperature during winter, have resulted in farmers trying to optimise yield and quality of tomatoes by using protected structures (Maboko et al., 2011).

There is therefore need for continuous research on the suitability of new hybrid indeterminate tomato varieties for production in Zimbabwe in relation to growth and yield with reference to the production under tunnel greenhouse environments if the country is to be able to meet its local demand for nutritious food. With the ever increasing demand for tomatoes, it has become imperative to determine locally adapted high yielding, resistant and suitable hybrids for cultivation in different agro-climatic conditions to boost the tomato production per unit area and per unit time according to the consumers and growers' preference (Bertelli and Macours, 2014). The country also has potential to export quality produce to Europe and other African countries if there is sufficient production.

1.3. Objectives of the study

1.3.1. Main objective

The goal of this project was to evaluate the growth and yield characteristics of indeterminate hybrid tomato varieties under tunnel greenhouse conditions in Zimbabwe

1.3.2. Specific Objectives:

The specific objectives were to

- To determine the growth and yield characteristics of indeterminate tomato hybrid varieties under greenhouse production.
- To characterise the physical traits and shelf life of the indeterminate tomato varieties under tunnel greenhouse production.

1.4. Research Hypothesis

- There is no significant relationship between tomato variety and growth and yield characteristics of indeterminate hybrid tomato varieties under tunnel greenhouse production.
- There are no significant differences on the physical traits and shelf life of the different tomato varieties

1.5. Justification

Indeterminate tomato varieties are more desirable than determinate varieties. They take longer period in production of fruits, thus make the farmer have fruits for selling for a longer period and ensure that there is always a crop on the market throughout the year (Maboko and Du Ploy, 2008). Promotion of indeterminate tomato varieties growing by smallholder farmers reduces the costs incurred on frequent seed procurement when using determinate varieties. Tunnel greenhouse structures minimises exposure of the tomato plant to pathogens and undesirable environmental factors. Results generated by this research are to be used as a push factor on the government and private sector to intensively invest capital on the procurement of tunnel greenhouse materials to be used by tomato producing farmers as well as generate information on suitable hybrid indeterminate varieties for Zimbabwe. In turn the whole economy will benefit from extended periods of tomato production. Average yields are estimated at 7,5t/ha in Zimbabwe against world averages of up to 37t/ha (SNV, 2016).

This research is a pilot project for hybrid indeterminate tomato varieties that were bred by Haaretz seeds in Israel for possible adoption in the country. For the past 5years, Daniella variety also bred by Haaretz as a hybrid indeterminate has been grown in Zimbabwe mainly for the urban market as well as the export market (Chibi et al., 2015). This research needed to promote production of hybrid indeterminate tomato varieties in the tunnel greenhouses resulting in high yield per unit area compared to determinate varieties and farmers own recycled seed. Results obtained adds more information to the body of knowledge on the use of controlled environments like tunnel greenhouses as a method of producing horticultural crops and the performance of the crop under Zimbabwean conditions. The results contribute to the improvement of the horticultural supply system i.e. improve the range and accessibility of safe processed tomatoes and fruit crop products to urban consumers, thereby increasing incomes and employment for producers and intermediaries.

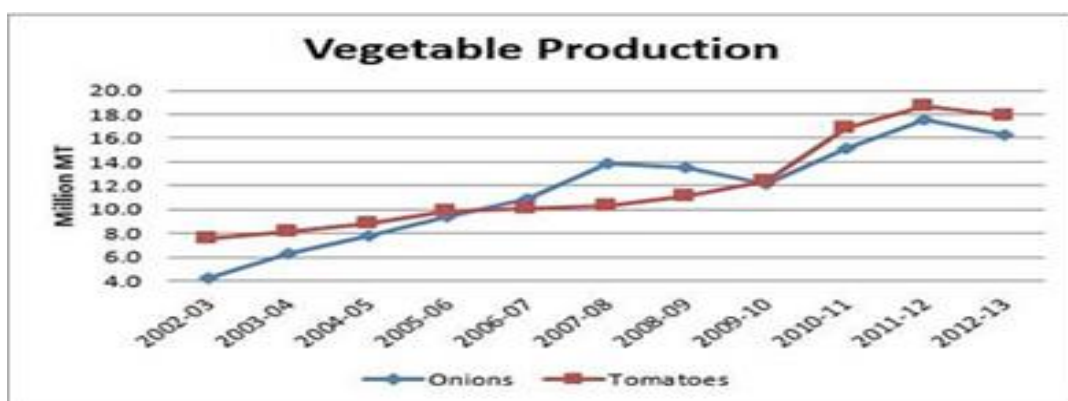
CHAPTER TWO

LITERATURE REVIEW

2.0. History of Tomato

The Spanish found in the American hemisphere an herbaceous plant whose fruit was edible, called “tomatl”, which translated to Spanish became tomato (Cox and Tilth, 2009). The tomato (*Lycopersicon esculentum*), is the most widespread contribution of Mexico throughout the world, with a great variety of culinary uses (Edlin, 2009). The tomato species *Lycopersicon esculentum* formerly *Solanum Lycopersicon* belongs to the Solanaceae family. The tomato was originally taken from Central America and the first selections were done in Mexico (Hussein & Filli, 2016). It was brought to Europe by the Spaniards shortly after 1535 and then by the Portuguese to the East before 1604 (Kumar et al., 2007). The Portuguese also took it to their territories around Southern Africa at an early date: explorers found it there around 1850 (Medina et al., 2017). From a very humble start the tomato grew to be one of the most popular vegetable crops in the world today; bringing Joseph B. Feldt’s prophecy of 1845 to fulfilment: “Like the potato slow in its rise, it is likely to be slow in its fall”(Knapp, 2015). Below are graphs depicting world tomato production

Fig 1: Global tomato production. (www.faostat.org).



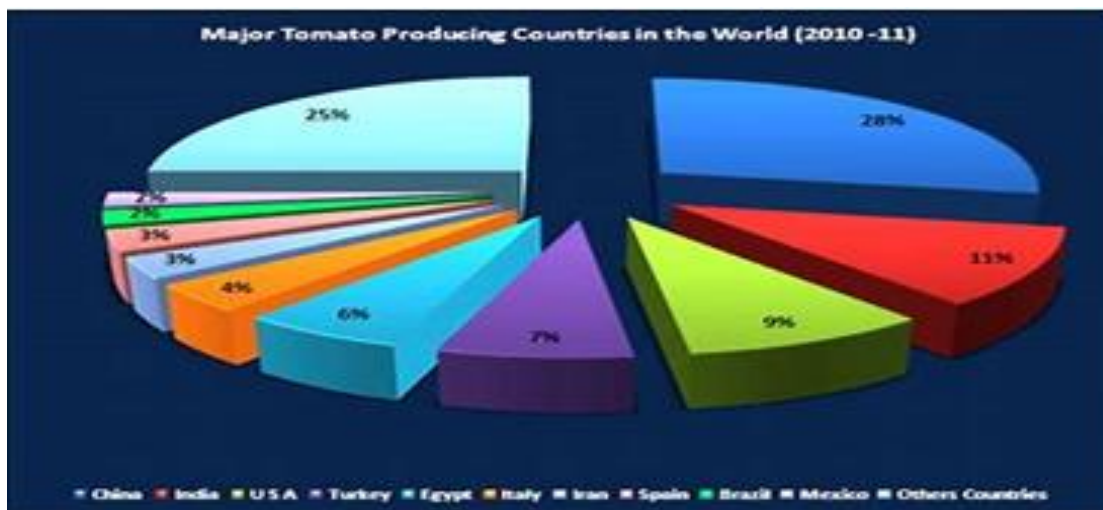


Fig 2: Market share of tomato production by country

2.1. Anatomy and Physiology of the tomato plant

The tomato is an herbaceous, usually sprawling plant of the nightshade family that is typically cultivated for its edible fruit (Hochmuth and Hochmuth, 2012). The scientific species *Lycopersicon* means "wolf peach", and comes from German were wolf myths (Dorais et al., 2001). These myths say that the deadly nightshade was used to summon werewolves, so the tomato's similar but much larger fruit was called the "wolf peach" when it arrived in Europe from the New World (Medina et al., 2017). The tomato presents itself in different shapes, sizes and colours with different brix or sugar levels (Singh, 2017). Tomato (*Lycopersicon esculentum*), is a tender warm season crop. It is characterized by glandular hairs (trichomes) that emit strong aroma when broken (Shrestha and Sah, 2015). Tomato plants are typically vinyl, prostrate, and are either determinate, semi determinate or indeterminate based on whether the apical stem terminates in an inflorescence (Singh et al, 2014). Most shoots form in the axils of leaves and it has got a deep tap root which may extend to three meters with extensive secondary roots (Pedro and Ferreira, 2007). The fruits are mostly red but there are some other colours such as yellow and purple. There is a lot of variation between cultivars in the size and shape of the fruits, in the thickness of the fleshy mesocarp as well as the development of the placenta (Veershetty,2004).

2.2. Chemical Composition of the tomato plant

Tomatoes have very high lycopene content, which has several health benefits (Chibi et al., 2015). Tomato tops the list of processed vegetables and is a very good source of lycopene, ascorbic acid and β -carotene, which are rich in antioxidants (Giovanicci, 1999). Tomato seeds contain 24 per cent oil, which is used as salad oil and in manufacture of margarine. Tomato is also rich in medicinal value. The pulp and juice are digestible, mild aperients, promoters of gastric secretion and blood purifiers the tomato has antiseptic properties against intestinal infections and it is useful against cancer of the mouth and sour mouth (Goud, 1992). Some tomato plants have a self-pruning gene responsible for determining the determinate growth habit. Ripening inhibitor and non-ripening genes are responsible for determining shelf life, but is not a genetically modified (GMO) trait (Perez et al., 2017). Nowadays long shelf life tomatoes are available without these genes.

Although the tomato is known in Europe in the sixteenth century, its widespread consumption occurred two hundred years later due to the distrust of consumers and botanists, since it was considered only an ornamental plant of the mandrake family (Edlin, 2009). Mandrake family are small perennial plants of the Mediterranean area, capable of killing those who consume alkaloids (Hussain et al., 2002); although, the tomato was already consumed in Italy, seasoned with oil, salt and pepper.

2.3. Tomato Classification

There are at least three different ways to classify tomato varieties. Tomatoes can be classified by their genetics, the time of length that they produce, and even their shape (Birhanu and Tilahun, 2010). There are approximately 7,500 tomato varieties grown for various purposes (Das et al., 1998). Tomato varieties can be divided into several categories, mostly based on shape and size. Slicing or globes, also known as round tomatoes, are used in processing or fresh consumption (Eldin, 2009). Beef steaks are large tomatoes often used for sandwiches and plum tomatoes are bred for higher solids for use in tomato sauce and paste (Perez et al, 2017). Cherry tomatoes are small, round, often sweet, and used whole in salads (www.haaretz.com). Grape tomatoes, a more recent variety, are a smaller variation of a plum

tomato primarily used in salads and some are associated with a purple colour (www.niritseeds.com).

2.3.1 Heirloom

This classification centres on a tomato's genetic line (Abdelmageed et al, 2007). Heirloom tomatoes are strains that have been reproduced for generations without cross-breeding (Edlin, 2009). Some heirlooms have production histories spanning hundreds of years and they are true to their type from their own seed (Benton, 2008). They are renowned for their consistency and like hybrids; they can be eaten raw or cooked. A tomato variety is considered an heirloom if it has been cultivated for at least 3 generations without cross-pollination between varieties (Prema et al., 2011). Heirloom varieties are considered to be open-pollinated (OP) however all OP's are not heirlooms (Perez et al., 2017). The difference has little to do with seed purity and more to do with documentation. Heirloom tomatoes are open pollinated varieties with a history tomato with a verified history. It has been documented and verified for purity when passed down within a family or community through generations (Yue and Tong 2009).

Open pollination promotes continual small changes in the plant's production and immunities, which explain the local adaptation witnessed in most heirloom cultivars (Medina, 2017). The only interference needed from humans to continue these lines is a place to grow and, isolation from other cultivars for strains that are particularly prone to out crossing and because of this trait heirloom tomatoes are also known as 'Open Pollinated' (Singh et al.,2002).

A defining characteristic of heirlooms as a whole is the sheer variety available in different shape size and colour. Colours of heirlooms range from yellow, red, orange, purple, white, green, and bicolour combinations (Biswas et al., 2015). There is also wide variety in their shapes and sizes. One can find tiny cherries and huge two-pounders in the same garden, along with globe, flattened, oblong, pumpkin, egg, pear, and pepper shaped fruits. This wide variety in colour and shape is reflected as well in a wide variety of flavours as heirlooms have fruit that can be very sweet to highly acidic, and therefore the tomato can be found to suit any palate or need (Jones,2008). Variety can also be seen within cultivars of the same name or origin, this variety is a result of the small changes due to different climates that lead to local adaptations. Because of local adaptation 'Cherokee Purple' that has been grown in one climate

for several generations may taste different than 'Cherokee Purple' grown in another climate (Shretha and Sah, 2015).

The wide variety available in heirlooms is one of many reasons why heirlooms have made a comeback in produce lately in countries in Europe and the Americas. Consumers have grown tired of the cookie-cutter tomatoes found in the super market and are willing to seek out these unique fruit. Heirlooms, or 'old standard varieties', are found in peoples home gardens more often than modern hybrids because of taste and personal preference (Jones, 2008). Another reason some people would grow heirlooms, however, is because it was developed in their area and is therefore locally adapted to their soils and climate (Annastacia et al., 2011).

Heirlooms produce large numbers of seeds and bear tomatoes identical to parents and are thus deemed stable. They are considered flavourful, and even superior to commercially-produced varieties. Many heirlooms have unique shapes and sport a variety of colours, including purple, yellow, white, orange, pink, red, green, black, and striped and thus exhibit individuality (Eldin, 2009). Research has shown that the individuality of heirlooms tends to produce unusual, misshapen, or inconsistent tomatoes whereas most consumers simply want red, juicy tomatoes. Heirlooms also take longer to mature and produce fewer tomatoes than hybrids and are therefore deemed less productive (Kumar, 2007).

2.3.2. Hybrid tomatoes

Hybrid tomatoes, on the other hand, are a cross between two different varieties and hybrids are cultivated both commercially and in the home garden (Chibi et al., 2015). Hybrid tomatoes are a cross between two genetically different tomato varieties. With a hybrid, you get the best qualities of both parents and commercial growers like hybrids because they are predictable (Kaiser and Ernest, 2017). Home gardeners prefer them because they present fewer problems. While these early cultivars offered a plethora of variety, breeders were still searching for yet more improvements to fruit size, plant productivity, and disease resistance and in 1946 the first hybrid cultivar, 'Single Cross', was released (Singh, 2017).

Hybrids combine the best characters from both parents and produce a phenomenon called 'hybrid vigour' (Hussain et al., 2002). 'Single Cross' was superior in production, fruit size and appearance than anything on the market up to that point (Mabengwa and Mutumpike, 2013). Hybrids are the result of breeding two stable, genetically homogenous lines (using one specifically as the mother and the other as the father) to get a superior offspring (Hunter, 2010). This offspring is called the F1 generation by breeders, geneticists and growers. Saving seed from an F1 and growing it out the next season would produce the F2 generation (Hanson and May, 2003). However the fruit would not be similar to the F1 generation.

The F2 generation is also referred to as the segregation generation because when grown out it will separate back into its original parts, which are the two parent cultivars used to make the original cross, and produce some interesting, but not usually good, crosses as well (Perez et al., 2017). Because of this segregation generation home growers and large producers alike are not able to save seed from F1 hybrids. Inability to save seed is advantageous to seed manufacturers and marketers since their clients must buy new seed each year to get consistent produce (Harold et al., 2007). Hybrid tomatoes quickly dominated the seed market due to their advantages and continuous improvement. Cross breeding with wild cultivars from Central America not only added greatly needed genetic diversity but also disease resistance, which up to this point had almost reached its limit in older varieties (Erdal et al., 2007).

2.3.3. Characteristics of hybrids

Hybrids are believed to be higher yielding thus more productive (Cox and Tilth, 2009). They also have a reputation for not being as susceptible to certain diseases and pests as their heirloom counterparts' thus more disease resistant (Benton, 2008). Hybrids produce even in bad weather and questionable growing conditions. Consistency is one of the favourable characteristics of hybrids as they are known for yielding tomatoes of similar size and with fewer blemishes (Singh, 2017). Longer shelf life even under adverse conditions as harvested hybrid tomatoes endure transportation across continents and still remain palatable better than heirlooms (Annastacia, 2011). Most consumers agree that hybrids' are not as flavourful as heirlooms. Hybrids also exhibit instability or genetic breakdown in the long term, as hybrids do not produce seeds as strong as what birthed them according to experts (Mabengwa, 2013).

2.4. Determinate and indeterminate varieties

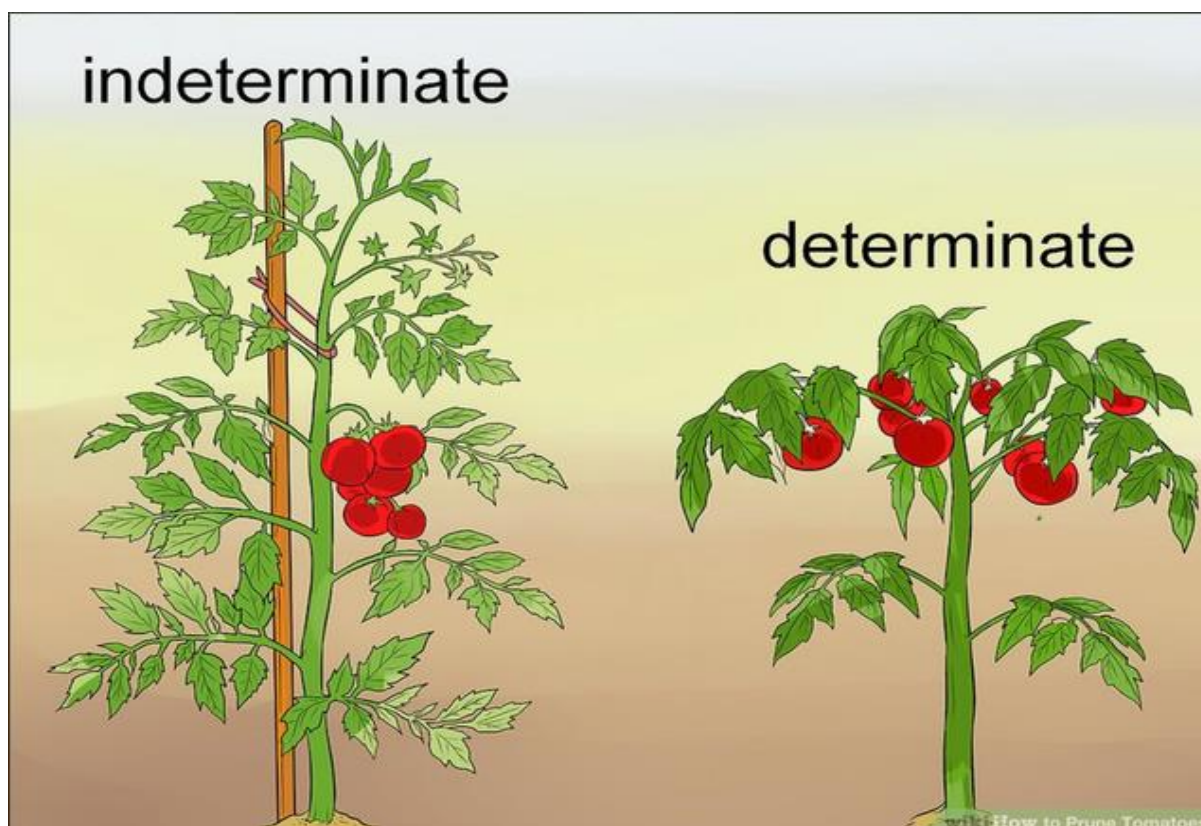


Fig 3: Illustration showing differences between determinate and indeterminate tomato varieties (Biswas et al., 2015)

Tomato varieties can be classified as determinate or indeterminate. Determinate or bush types bear a full crop all at once and top off at a specific height (Eldin, 2009). A determinate tomato plant produces fruit for three to four weeks and then production fades out because it eventually forms a flower cluster at the terminal growing point, which causes it to stop growing in height (Perez et al, 2017). They are preferably grown by commercial growers who wish to harvest a whole field at one time.

Indeterminate varieties develop into vines that, under favourable growing conditions, never top off and continue to produce fruit until cold weather sets in (Chibi et al., 2015). They are preferred by commercial fresh market growers and home growers who want ripe fruit throughout a growing season. Optimal growing conditions for specific cultivars need to be determined, as wrong cultivar choices can lead to great financial losses (Singh, 2017). Indeterminate tomatoes are vining, growth does not stop and sequential flowering starts at the

bottom at sides of plant whereas for determinate varieties there is finite growth and main stem ends with reproductive organ (Radzevicius et al 2009).

2.5. Environmental conditions suitable for tomato plant growth

Tomato is more successful where there are long sunny periods. The optimum growing temperatures are 21⁰C to 24⁰C (Aoun et al., 2013). At these temperatures good quality seeds will take about seven days to emerge. After emerging generally tomatoes require three weeks in the seedbed for growth and subsequent hardening (Reiss, 2004). Temperature affects flowering and pollination. The hot and dry weather leads to drying of the flowers and stops pollination. If temperatures are below 15⁰C or above 29⁰C, pollen release is restricted resulting in incomplete fertilization of ovules (Arora et al, 2006). This causes collapsed fruit walls and formation of deep indentation in the fruit, a phenomenon called cat face (Ros, 2013). Daily maximum air temperature between 25⁰C and 35⁰C is ideal for plant growth and with adequate soil moisture; tomato plants can tolerate temperatures well in excess of 37⁰C, although extremely hot temperatures can adversely affect the developing fruit (Erdal et al., 2007). Tomatoes grow well in a variety of soil textures, but commercial growers tend to prefer the sandy soils as sandy soils drain better and warm up more readily than denser soils (Perez et al, 2017).

2.6. Soil Conditions suitable for tomato growth

Tomatoes grow best in light, free draining, and fertile loam soil with pH of 5 – 7. However, tomatoes can be grown in a variety of soils (Naika et al., 2005). Regarding fertilizer requirements, tomatoes require an abundance of the three major elements namely, nitrogen, phosphorus, and potassium (Mabengwa, 2013). Adequate soil nitrogen application is important to enhance foliage growth which has a major bearing on crop maturity and protects the fruits from sunscald(Kumar et al., 2007) . Phosphorus influences fruit quality by stimulating vigorous root growth that enables more nutrients to enter the plant thereby promoting sturdy stem growth and healthy leaf formation. Tomatoes use large amount of potassium (Mishra et al., 2010). This element is important in stimulating early plant growth and regulating normal carbohydrate and protein metabolism (Medina, 2017) The nutrient content of the fresh tomato per 100g is as follows: Water 93ml,

calories 21, protein 1 g; fat 0.2g; carbohydrate 4g, fibre 0.6g; plus minerals and vitamins (Singh et al., 2004).

Denser soils like loam and clay loam may also be used as long as the fields are carefully irrigated and well drained (Mabengwa, 2013). Universally, all soil is prepared prior to planting using a variety of speciality equipment to improve the overall quality of the soil by breaking up clods and adding amendments. Following soil preparation, uniform and parallel raised beds are formed and, usually, a drip irrigation system is installed where raised beds are typically covered with a thick plastic (Singh et al., 2017) Young tomato plants, sprouted in greenhouses, are transplanted to the fields by hand or with the use of specialized mechanical equipment.

2.7. Tomato growth

Plant development can be considered as the process of plant changing from one growth stage to another into specialised parts. It involves cellular, structural and organisational changes, as well as changes in processes that occur within the plant (AVRDC, 1990). According to Hochmuth and Hochmuth (2012), development is the result of strictly regulated gene expression but influenced by exogenous factors and this regulation is in time and space. It is assumed that the genotype- sum of genes determines the phenotype-sum of traits. Plant development involves a number of distinct phases- embryogenesis, seed formation, seed germination, vegetative development, reproductive development, senescence and death. Some of the phases are subject to environmental regulation and others are strictly regulated, independent of environment -developmental homeostasis (Jawaharlal and Veeraragavathatham, 2003).

2.8. Factors determining tomato plant yield

Tomato yield is affected by internal (genetic factors) and external factors. Internal factors speak to the genetic makeup of the plants and these characters are less influenced by environmental factors since they are governed by genetic make-up of the crop and for tomatoes (Singh et al., 2002). The below internal factors are desirable: High yielding ability, early maturity, resistance to lodging, drought flood and salinity tolerance, tolerance to insect pests and diseases, chemical composition of grains (oil content and protein content), quality

of grains in terms of fineness or coarseness and quality of the straw in relation to sweetness and juiciness(Hunter, 2010).

External factors are the climatic, edaphic, biotic, physiographic and socio-economic factors. Nearly 50% of yield is attributed to the influence of climatic factors (Ros, 2013). The following are the atmospheric weather variables which influence crop production namely; precipitation, temperature, atmospheric humidity, solar radiation, wind velocity as well as atmospheric gasses (Hussain et al, 2002). Edaphic factors relate to the soil condition as plants grown on land completely depend on the soil on which they grow (Maboko et al, 2011). The soil factors that affect crop growth are soil moisture, soil air, soil temperature, soil mineral matter, soil organic matter, soil organisms, and soil reactions (Mishra et al., 2010). Biotic factors also affect crop growth and these are the presence of biological organisms like other plants (weeds) and animals including insect pest which may also have both harmful and beneficial effects on the tomato crop (Tumwine, 1999). The tomato is susceptible to both weeds and insect pest.

Physiographic factors like increase in altitude can cause a decrease in temperature and increase in precipitation and wind velocity (Naika et al, 2005). Steep slopes can result in run off of rain water resulting in loss of nutrient rich top soils. Exposure to low light intensity and strong dry winds as observed in mountain slopes can result in poor crop yields (Harold et al, 2007). Socio-economic factors also affect crop production as the economic condition of the farmers greatly determines the resource mobilizing ability and the breeding of varieties for increased yield and pest and disease resistance (SNV, 2016). Socio-economic factors affect choice of crops with recycled seed domination crop production in poor rural areas because of the high cost of hybrid seed. Each society has a preferred livelihood source and the societal inclination to farming and the availability of members for cultivation affects crop production (Jackson et al., 1997).

2.8.1 Challenges faced by farmers in tomato fruit production

The most cultivated varieties in Sub Saharan Africa are ‘Floradel’, ‘Marglobe’, ‘Heinz 1370’, ‘Rio Grande’, ‘Roma VF’, ‘Moneymaker’, ‘Anna F1’, ‘Marmande’, Star as examples. Factors influencing selection of tomato varieties include market demands, resistance to disease pathogens, suitability to production systems, and regional

adaptability (Diver, 2002). Tomatoes are adapted to a wide range of environmental conditions, but in temperate areas low temperatures and short growing seasons can limit growth. Tomatoes prefer slightly acidic soils with a pH of 6.0 to 6.8 (Cox and Tilth, 2009). The tomato plant requires significant quantities of water, but not in excess, since tomato roots will not function under water-logged (anaerobic) conditions.

Biotic stresses create additional losses, with newly emerging plant diseases and pests causing decreased yields and serious reductions in produce quality (Perez et al., 2017). In the developed world, these challenges can often be managed by technologies such as drip irrigation or pesticides. Farmers in sub-Saharan Africa, however, often lack the financial means or physical access to technical solutions that can mitigate their risks. Furthermore, improved seed is minimally available on a commercial basis in Zimbabwe and this is particularly true for vegetables (SNV, 2014). Zimbabwe has a wide range of diverse agro-climatic conditions ranging from Natural region 1 to Natural region V, but vegetable cultivation practices have generally been restricted to regional and seasonal needs.

High-yielding, adapted vegetable varieties with resistance to pathogens are even more important for smallholder farmers, especially given the high incidence of nutritional deficiency and malnutrition in the region (Mabengwa, 2013). Technology adoption is dependent on available assets; therefore, technologies that require fewer assets will be more readily adopted (Hussein & Filli, 2016). Infrastructure constraints also play a major role in limiting the success of smallholders in West Africa post-harvest (SNV, 2016). In Zimbabwe, lack of climate-controlled shipping, roads in poor condition and few operational processing facilities limit farmers' capacity to successfully move their products to market (Chibi et al., 2015). Zimbabwean farmers, particularly smallholders, need the means and opportunity to improve both their actual yields and the predictability of their yields to ensure a consistent supply of vegetables (Chibi et al., 2015).

Improved diagnostics and management of diseases and pests, as well as access to inputs and irrigation, will be necessary to provide consistent production of quality produce in unpredictable markets. Studies have shown that fresh tomato prices in sub-Saharan countries including Zimbabwe can fluctuate as much as 80%, making grower income extremely unpredictable (SNV, 2014). Tomato cultivation is continuous throughout the year, with planting occurring at the beginning of each wet season in most countries in sub-Saharan

Africa and Zimbabwe is no exception (Jackson, et al, 1997). Tomatoes are seeded, transplants established and set in fields, and fruits mature within a period of 90-120 days (Hunter, 2010). Tomatoes thrive best in moderate climates, but can adapt to a wide range of climatic conditions and require warm weather and abundant sunshine for best growth and development (Hussein & Filli, 2016). The plant grows best with uniform moisture and well drained soils (Jackson et al, 1997). Tomatoes can be grown in open field conditions or in a greenhouse under environmentally controlled conditions.

Investments in infrastructure, including roads, electrification, and cold chain and processing plants, must increase dramatically to ensure that farmers can access necessary inputs, transport their produce safely and efficiently, and process it into value-added products that can either be exported or stored (Mabengwa, 2013). Increased yield potential, stability and quality are in turn likely to attract additional investment, giving farmers access to inputs and improving infrastructure for transportation, processing and export (Anastacia et al., 2011).

In Zimbabwe, smallholder farmers producing tomatoes have small plots (e.g., 0.5 hectares) that are hand cultivated and watered by a variety of methods by furrow, food, gravity, drip irrigation, or sprinklers (SNV, 2016). Typically, these growers plant a range of determinate open-pollinated varieties (e.g., pear-shaped processing types to round fresh market types), purchased in small quantities or seed saved from year to year, and having few or no resistance genes. In some cases, seed of hybrid varieties may be utilized, but this may be more expensive or difficult to find, and are expensive, especially for smallholders in rural areas (Anastacia et al., 2011). Fields are established with transplants produced in seed beds, and varying levels of fertilizer is used depending on the availability.

The yields are poor, and the price depends on seasonal availability. There are also examples of commercial tomato production, often associated with large canneries like Koo in South Africa. Here hybrid seed is used as well as larger fields and more modern technologies, e.g., use of tractors for cultivation, application of fertilizer and pesticides and drip irrigation (Maboko et al., 2011). However, this type of tomato production in Zimbabwe remains relatively uncommon. Tomato growers in Zimbabwe are faced with a number of disease and

pest problems. Soil-borne diseases include bacterial wilt caused by *Ralstonia solanacearum* and Fusarium wilt caused by *Fusarium oxysporum* f. sp. *lycopersici*; foliar diseases include bacteria spot caused by *Xanthomonas* spp., late blight caused by *Phytophthora infestans* and *Septoria* blight caused by *Septoria lycopersici*; and mosaic viruses, such as Tomato mosaic Virus and Cucumber mosaic virus, can cause yields and produce damage (SNV, 2016). Pests include worms, such as the cotton bollworm (*Helicoverpa armigera*), nematodes, mining insects, thrips, various aphid species, and mites, e.g., spider mites (*Tetranychus urticae*) (Proctor, 2000).

Recently, outbreaks of the tomato leaf miner (*Tuta absoluta* (Meyrick) (*Lepidoptera: Gelechiidae*) have caused substantial damage to tomato crops in some Sub-Saharan African countries (Mabengwa, 2013). This paper describes a project spanning eight months that is aimed at piloting five indeterminate tomato varieties in Zimbabwe under tunnel greenhouse conditions to improve both the quantity and the quality of Zimbabwean tomatoes and tomato seed varieties available to local growers.

2.9. Growth Parameters

2.9.1 Plant height (cm)

In a research carried out by Thangam and Thamburaj (2008) on the comparative performance of six varieties and fourteen hybrids of tomato under agro shade net (50%) and in open field during consecutive summer seasons under Coimbatore conditions, the results showed highest plant height under shade over the open field conditions in all the cultivars and hybrids. Among the fourteen cultivars, Naveen was the tallest (307.58 cm) both under shade and open field condition (88.45 cm). Two tomato varieties Ratan and BARI Tomato-3 were screened by Parjev et al., (2010). Results observed showed better growth of tomato in terms of plant height under poly house conditions against open field conditions in Bangladesh of Ratan compared to BARI Tomato-3.

Sima et al., (2011) investigated the yield potential and quality of six tomato hybrids under greenhouse conditions of Romania, and reported maximum plant height with Monroe F1 (248.33 cm) followed by Tolstoi F1 (245 cm). Chapagain et al. (2011) observed that among the tomato varieties evaluated under plastic house conditions of Nepal for two

consecutive years from 2009 to 2010, Srijana was the tallest variety (268.70 cm) followed by Manisha (232.3 cm).

2.9.2 Number of branches per plant

Singh et al., (2004) in their field trials to evaluate promising tomato varieties during rainy season and they observed the maximum number of branches (7.3) per plant in BT-10 and lowest (3.8) in T-30. Patil (1997) observed the maximum number of branches (12.67) per plant in DWD-1 X 79B 1390-29-3-sp-2-2 and the minimum (7.33) in DWD-1 X DWD-2-20-2-cc and DWD-1 X 79B 1390-24-2 during rabi season. Jayprakashnarayan (2007) reported that the maximum numbers of branches were recorded in TP 45(12.89) and minimum was recorded in TP 19 (7.78).

2.10. Yield Factors

The correlation of these components to yield and among themselves is of considerable importance to crop improvement. Yield components have been used in analysing and identifying sources of variation in yield and in plant breeding these can be exploited for improving cultivars to give higher yields (Fenny et al.,1991). Knowledge of how these morpho – physiological components of yield associate with each other and yield is very useful in improving, the hard to improve traits in plant breeding such as yield, which its direct selection is not effective (Sam and Iglesias, 1993).

2.10.1. Days to 50 per cent flowering

Sumathi et al. (2013) evaluated the performance of 24 tomato genotypes under poly house and open condition for yield characters observed the earlier flowering in genotypes raised under open condition than in poly house condition. During the first season earliest flowering (28.35 days) was observed in the genotype NS-6666 and in second season, Meenakshi (23.80 days) was observed to be earlier under open condition. Arora et al. (1982) evaluated certain tomato varieties during offseason to identify varieties suitable for raising a summer crop of tomato and HS 102 was found to give early fruit set. Prasad Singh (1990) evaluated four varieties of tomatoes, viz., Pusa Ruby, HS 101, Marglobe and Punjab Chhuhara in three locations (Kalantola, Badlain, Bahir and Nazir) of Binda Diara area of Bihar during summer season and found that variety Pusa Ruby recorded the minimum days (31.31) to first fruit set. Differences in the time of initiation of the first inflorescence was due

to the amount of assimilates available at the apex during the sensitive phase, and they reached maximum before flower initiation takes place (Sam and Iglesias, 1993). Jayprakashnarayan (2007) reported that the genotype TP 57 took minimum (21.67) days to 50 per cent flowering and genotype TP 15 took maximum (38.35) number of days for 50 per cent flowering.

2.10.2. Number of fruits per plant

Prema et al. (2011) evaluated six genotypes (Tomy Toe, Stupice Harry, Red Pear, Podland Pink, Broad Ripper and EC-1) of cherry tomato for growth, yield and quality attributes. The per cent fruit set was maximum (88.54) in EC-1 followed by Stupice Harry (88.10). Whereas, Ishwarappa (2011) observed maximum per cent fruit set in STH-801 (93.17). Arora et al. (2006) recorded significant difference in fruit set percentage in indeterminate tomato hybrids in green house structure where maximum fruit set percentage was recorded in Avatar (88.0), while minimum was recorded in TH- 612 (62.0). Among the different semi-indeterminate tomato hybrids studied maximum percentage of fruit set (84.0) was recorded in NP-5003 and TH-977, while minimum (50.0) was recorded in ARTH-210 (Arora et al. 2007).

2.10.3. Average fruit weight (g)

Singh and Raj (2004) reported that Sel-120 produced fruits with maximum weight (144.40 g). Fenny et al., (1994) recorded an average fruit weight of 80 g in L-72 cultivar under hot and moist conditions. Hanna et al., (1992) observed an average fruit weight of 101-146 g in LHT-24 compared with 156-176 g in Floradade during summer season at Port Sulphur. aradwaj and Thakur (1994) recorded the maximum fruit weight (56.60 g) in Roma and the lowest (29.86 g) in Pant Bahar. Joshi et al. (1998) observed the highest fruit weight (87.50g) in Sutton Prolific and Sioux and lowest (38.70 g) in Sutton Roma. Shivakumar (2000) reported highest fruit weight (106.31 g) in H176 and lowest (69.59) in Pusa hybrid 2. Sheferaw Nesgea (2001) reported highest (106.57 g) fruit weight in Arka Alok and lowest fruit weight (36.27 g) in Pusa Ruby. S-28 recorded highest fruit weight (86.03 g) and Pusa Ruby lowest fruit weight (16.45g) in a study conducted by Mohanty and Prusti (2002) under Orissa conditions. Dudi and Sanwal (2004) observed maximum average fruit weight in Rupali (60.69 g) and minimum in HTH-88(38.2 g).

2.10.4. Diameter of fruits (cm)

Prema et al. (2011) reported that maximum fruit length (3.56 cm) in cherry tomato cultivar, Podland Pink followed by Red Pear (3.13cm). Chapagain et al. (2011) reported largest fruit size in US-04 with a diameter of 5.78 cm. Similarly Islam et al. (2012) found maximum fruit length (5.33 cm) in CLN1555A while, the line CH155 had the minimum fruit length (3.00 cm). Sima et al. (2011) evaluated six tomato hybrids in greenhouse for yield potential and quality reported significantly highest fruit length for Monroe F1 (53.50 mm) followed by Menhir F1 (52.64 mm).

2.10.5. Yield per plant (kg)

Singh et al., (2005) reported that maximum fruit yield per plant was observed from Karnataka hybrid (2.85 kg) followed by Naveen (2.61 kg) under multi span poly house covered with UV stabilized polyethylene film conditions. Kumar et al. (2007) evaluated 42 tomato genotypes under green house and open field conditions. The genotypes COTH1, CLN14665 and CLN1352A, were identified as the best under greenhouse conditions based on yield per plant over the open field conditions. Prema et al. (2011) observed that the highest mean fruit yield per plant (4.25 kg) in Pod land pink followed by Tomy toe (3.64 kg).

Islam et al. (2012) observed maximum fruit yield per plant (1.89 kg) in CLN1555A followed by CLN1555C (1.82 kg) among the 11 inbred lines of cherry tomatoes studied. Similarly Singh et al. (2013) studied the performance of different tomato hybrids under greenhouse conditions during the year 2008-09 and 2009-10 at Hissar. Results revealed that Avinash-23 recorded maximum yield per plant (2.90 kg) followed by Richa (2.88 kg).

2.10.6. Yield per Hectare (t)

Singh et al., (2001) observed that maximum marketable yield in tomato hybrid Narita (285 t ha⁻¹) followed by Naveen (148 t ha⁻¹) under Tarai conditions of Uttar Pradesh. The tomato variety Arka Alok gave highest yield (53.26 t ha⁻¹) and Arka Ahuti the lowest (19.72 t ha⁻¹) according to Sheferaw (2001) under Bangalore conditions in poly house conditions. Higher productivity of tomato (93.20 t ha⁻¹) and capsicum (76.40 t ha⁻¹) was observed inside

greenhouse by Reiss et al., (2004) mainly because of higher temperature (4-9 oC) inside the greenhouse compared to the outside temperatures observed during month of December to February and high rate of utilization of carbon-dioxide inside greenhouse. The microclimate inside the greenhouse during winter months was mainly responsible for better yield due to their beneficial effects on flowering and fruiting. Parjev et al. (2010) compared four tomato varieties under poly house conditions of Nepal, and results showed that NSITH-162 produced the highest marketable fruit yield (89.05 t ha⁻¹) and Avinash-2 produced the lowest yield (51.98 t ha⁻¹).

Chapagain et al. (2010) reported 47.9 t ha⁻¹ and 30.9 t ha⁻¹ fruit yield in plastic house and in open field condition respectively in the farmers' field of ARS Pakhribas. Parvej et al. (2010) reported that the tomato plants grown with polyhouse climate produced 29 per cent higher fruit yield than the tomato plants grown at the outside of polyhouse. Prema et al. (2011) observed the highest fruit yield (75.55 t ha⁻¹) in Podland Pink followed by Tomy Toe (59.91 t ha⁻¹). In another field investigation Chapagain et al. (2011) assessed the performance of tomato varieties under plastic house for two consecutive years from 2009 to 2010 in Nepal. The highest marketable yield was recorded from All Rounder (86.6 t ha⁻¹) followed by Srijana (80.8 t ha⁻¹).

2.11. Tunnel Green House production

Solar energy, is an abundant, clean and safe source, that is an attractive substitute for conventional fuels for passive and active heating applications(Hunter, 2010)(Hussein & Filli, 2016). During the day, excess solar heat is collected for short or long term storage, and it is recovered at night in order to satisfy the heating needs of closed enclosures(Hussein & Filli, 2016). A greenhouse is an enclosed structure, which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favourable microclimate for higher productivity(Fidaros et al., 2008).

The steady-state study of the heat transfer inside a greenhouse neglects the effect of heat storage from the structures and plants which can significantly shift the time of maximum temperature appearance and consequently alternate the thermal internal pattern of the greenhouse and the determination of thermal and energy needs(Singh, 2017). Because of heat storage, during a day there are two time dependent parameters determining the thermal

behaviour of the construction which have to be taken into account; the solar irradiance and the temperature of high specific heat materials inside. The total consideration of those parameters demands an unsteady approach on a solar day cycle. Because of the practical difficulties in accurately measuring the solar radiation input several analytical and numerical protected structures and vegetable production.

Protecting crops from harsh weather to enhance off season production and improve quality is an increasingly common strategy used by modern vegetable growers (Arin and Ankara, 2001). More growers are using protective structures as agricultural plastics become less expensive and more specialized. Protective structures for plants have been used for centuries all over the world in an attempt to improve production (Black, 2008). Early protective structures included wood frames covered in paper, paper domes, glass domes or “cloches,” and glass greenhouses (Both, 2007).

Improved plastics technology drastically advanced crop protection by providing a lightweight, durable, and relatively inexpensive material compared to glass (Reiss et al., 2004). Polyethylene, a common agricultural plastic, was first used as a greenhouse cover in the U.S. in 1948 by Professor Emery Myers Emmert at the University of Kentucky (Jensen, 2004). Now plastics are used for many agricultural products such as drip tape, plastic mulch, and row covers. Plasticulture is the name given to crop production that utilizes plastic products to enhance crop performance (Abdel-Ghany and Al-Helal, 2011). The benefits realized by increase in yield, increase in quality, and improved water savings are often greater than the cost of agricultural plastics (Black et al, 2008). For example, black plastic mulch helps raise the soil temperature, which promotes early yield of various crops and limits weed growth and water evaporation at the soil surface. This reduces herbicide and water costs, and also encourages the production of valuable out of season produce (Benton, 2008).

A significant problem facing world agriculture is the variation in crop yields from year to year due to variation in environmental stresses like drought, flooding, high wind velocities and high or low temperatures (Boulard and Wang, 2002). Damage caused by stresses can also result in physiological disorders in crop plants. Cat face in tomatoes is caused by poor pollination resulting from low temperatures and growing crops under protection can contribute to overcome these problems in order to get high yields of good quality (Hochmuth

and Hochmuth, 2014). Protected cultivation using tunnel greenhouses involves more sophisticated growing techniques than unprotected cultivation in the open field and allows the growing of crops out of season.

Tunnel greenhouse production implies greater financial cost for the grower in the construction and management of the protective structures however crops that are grown out of season command a price premium when sold in direct markets (Ford, 2004 and Black et al., 2008). Protective coverings vary from shade netting and simple film plastics known as passive protected cultivation, to structures with glass or rigid sheet plastic and equipped with sophisticated environmental controls (active protected cultivation) (Abdel-Ghany and Al Helal, 2011).

Tunnel greenhouses are structures where environmental control equipment is absent or simple in order to minimize the initial cost and running costs as with tunnel greenhouses (Fidaros et al., 2008). The environment is naturally controlled in a passive way by the physical properties of the structural covering materials (Foord, 2004). Structures are typically designed to make maximum use of climatic resources like solar energy and temperature, and minimizing the use of artificial energy like electricity (Hunter, 2010). Solar energy, an abundant, clean and safe source, is an attractive substitute for conventional fuels for passive and active heating applications (Fidaros et al., 2008). During the day, excess solar heat is collected for short or long term storage, and it is recovered at night in order to satisfy the heating needs of closed enclosures and high tunnel greenhouses are an example of passive protected cultivation that uses solar energy for heating (Chibi et al., 2015).

2.11.1. Row Covers

Row covers are thin plastic blankets designed to shelter crop plants from cold and wind, and raise day temperatures to promote growth (Emmet, 1956). Polyethylene, polypropylene, and polyvinyl chloride are common plastics used to make row covers. Thin polyethylene (1 to 4-mil thicknesses) is used for row covers or “low tunnels” placed low to the ground over a crop, and are supported by a wire hoop structure to resemble a tunnel. Thin polyethylene row cover alone was shown to protect tomato plants from freezing when outside temperatures were -3.8 °C (Chibi et al., 2015). The support hoop is typically made of heavy gauge wire or plastic

pipe. Polyethylene row cover requires daily ventilation because the cover traps substantial heat that can damage crops. Research has demonstrated plastic row covers to improve productivity of certain crops (Gerber et al., 1988).

Slitted plastic technology was developed in an attempt to mitigate heat build-up and eliminate the need for manual ventilation; however the slits in the plastic do not provide adequate ventilation to avoid flower and fruit abortion in tomato or bolting in lettuce (Erdal et al., 2007). Plastics can now be spun-bonded to produce a lightweight fabric-like cover that allows air to pass through, making it more appropriate for cool season crop protection (Gosselin and Trudal, 1985) Polypropylene is commonly used to make spun-bonded covers, and is sometimes referred to as floating row cover or row cover cloth. Polypropylene can also serve as an excellent method for pest exclusion (Hanson and May, 2003).

2.11.2. High Tunnel Greenhouses

High tunnels greenhouses are larger protective structures designed to shelter plants from cold temperatures and other adverse climate conditions (Kumar et al., 2007)). Tomatoes grown in high tunnels can yield up to 4 weeks ahead of field grown tomatoes due to the accelerated growth rate because of raised temperatures (Hunter, 2010). Growers able to provide the earliest locally grown tomatoes can often demand a premium price as customers are eager for those first truly vine-ripened tomatoes (Singh et al, 2014). Producers who capture the early market may gain loyal season-long customers. Similarly, the scarcity of locally grown late-season tomatoes can provide a profitable market for growers able to extend production well into winter (Naika et al, 2005).

Extending the season has the potential of spreading out cash flow, increasing overall farm profits, and gaining new customers. Other advantages to high tunnel production include: higher marketable yields, improved fruit quality, fewer culls, and a reduction in pesticide applications (Reiss et al, 2004). They are also designed to accommodate the full height of a crop as well as people and machinery for soil tillage and crop management. The structural frame of a high tunnel is typically made of galvanized steel pipe or PVC pipe that is arched in a tunnel shape (Abdel-Ghany, 2011). High tunnels are covered with polyethylene greenhouse plastic, but do not include the heating and cooling equipment common to standard

greenhouses. Thick polyethylene plastic (6 to 8 mil) is UV stabilized to slow deterioration(Fidaros et al., 2008).

High tunnels protect plants from the cold in several ways. When short wave radiation enters a high tunnel on a sunny day, the radiation is partly absorbed by the soil and plants inside(Chibi et al., 2015). Latent heat dissipates from the surface of the soil and plants by convection, transpiration, and emitted long wave radiation. The plastic covering on the high tunnel traps the warm air and reflects some long wave radiation back toward the soil and plants after the outside temperature drops(Singh et al., 2004). During the night the temperature inside a high tunnel may approach the outside temperature, but the plants stay warmer due to the plastic cover which retains heat by limiting long wave radiation emitted by the plants (Foord, 2004).

Still air inside the high tunnel will not cool as rapidly as the air outside because the air inside cannot mix with cooler air (Foord, 2004). This phenomenon is similar to the protection provided by a wind break, which provides a protective boundary layer around the plants (Reiss et al., 2004). The frost protection of a high tunnel is limited to 1 to 4 °C at night when outside temperatures are near freezing (Heindenreich et al., 2007). The combination of low tunnels within a high tunnel further enhances the temperature protection by trapping warm air and long wave radiation closer to the plants (Gerber et al., 1988). Soil temperatures are naturally warmer than the air in the winter and cooler than the air in the summer. The soil stays even warmer inside a high tunnel due to absorption of heat trapped by the high tunnel (Hussein et al., 2016). The type of plastic on a high tunnel will affect temperature, relative humidity, light, and CO₂ reaching the plants inside. Plants in high tunnels must adapt to daily temperature swings from as high as 35 °C during the day to 5 °C at night (Kaiser and Ernst, 2017). The altered environment of a high tunnel requires a different management perspective than managing plants in the open field.

Protected cultivation is a unique and specialized form of agriculture in which the microclimate surrounding the plant is controlled partially or fully, as per the requirement of the plant species grown during their growth period (Kaiser and Ernest, 2017). The intent is to grow crops where otherwise they could not survive by modifying the natural environment to

prolong the harvest period often with earlier maturity, to increase yield, improve quality, enhance the stability of production and make commodities available when there is no outdoor production (Chibi et al., 2015). In general, protected structures are used to overcome low temperature in temperate regions or high temperature in the countries having tropical climate. There is a lot of potential for increasing the area manifold under low cost greenhouses in peri-urban areas for production of high value vegetables during off-season to take benefit of the high price of the produce (Pedro and Fereirra, 2007) and to setup the vegetable production and improve its quality.

Protected cultivation has tremendous potential in increasing production, productivity and quality of vegetable crops like tomato, cherry tomato, coloured capsicum, cucumbers, muskmelon and summer squash, some rare vegetables, medicinal and ornamental plants even under adverse agro-climatic conditions (Black et al, 2008). Protected cultivation is a unique and specialized form of agriculture in which the microclimate surrounding the plant is controlled partially or fully, as per the requirement of the plant species grown during their growth period (Mishra et al., 2010). The intent is to grow crops where otherwise they could not survive by modifying the natural environment to prolong the harvest period often with earlier maturity, to increase yield, improve quality, enhance the stability of production and make commodities available when there is no outdoor production (Arin and Ankara, 2001).

A number of factors may affect the response of greenhouse crops to CO₂ enrichment. Thus, for example, optimum temperatures and high light intensities greatly increase the effectiveness of CO₂ enrichment although some yield increase may be obtained even under low light conditions (Abdel and Ahmed, 2011). Diffusion resistance at the plant canopy and individual leaf levels determines the plant's capability to utilize supplementary CO₂ (Benton, 2008). The field, CO₂ addition would produce maximal effects on photosynthetic rates in a canopy with upright leaves, where canopy diffusion resistance is low. In greenhouse, the rate of CO₂ supply has been demonstrated to be a more important determinant of crop photosynthesis rate (Singh et al, 2017).

2.12. Requirements for growing tomatoes under protected structures

2.12.1. Growing media

The other important component of growing crops under protected conditions is growing media. An ideal growing medium should have good water holding capacity, high porosity for better aeration, good drainage and high rate of diffusion of oxygen to roots. It should also be biologically and chemically stable (Michelle, 2014). A well decomposed growing medium provides organic matter and humus to the soil, which helps in improving physical conditions of soil. Several growing media such as rock wool, coco peat, foam, perlite, wood chips, vermi-compost and sawdust have been found suitable for tomato production (Mabengwa et al., 2013). Another important component of protected cultivation, which influences productivity and quality of tomato, is application of fertilizers with the irrigation water called fertigation. Fertigation incorporates desirable features, which can improve water as well as nutrient use efficiency (Diver, 2002). Fertigation permits application of various fertilizer formulations directly in low concentration at the site of active roots, thus improving the efficiency of nutrients and saving fertilizer application costs (Ros, 2013). This is a regular and widely accepted fertilizing practice in growing of crops under protected conditions.

2.12.2. Fertigation

Fertigation is becoming more popular because of availability of high-grade completely water-soluble fertilizer materials. Indeterminate varieties require more evenly spaced nitrogen applications as their vegetative growth will continue throughout the season (Maboko and Du Ploy, 2008). It is a well-established fact that macro nutrients such as nitrogen, phosphorus and potassium have profound effect on crop productivity and quality (Mishra et al., 2010). Among these three essential nutrients nitrogen is an integral part of chlorophyll (the only energy synthesizing apparatus of plants), protoplasm, proteins and nucleic acids. Consequently its deficiency checks the growth and reduces the yield significantly (Michelle et al., 2000).

Phosphorus on the other hand, participates in energy transfer, early and prolific flowering, stimulates root growth, seed and fruit development, whereas, potassium is essential for number of biological reactions. It also helps in translocation of food material to different parts of plant as well as it enhances disease and drought tolerance (Podadopoulos, 1991).

2.12.3. Relative Humidity

Relative humidity is an important consideration with regard to high tunnel production. Relative humidity describes the amount of water vapour in the air at any time. The closed conditions of a high tunnel create an environment with higher relative humidity and little air movement until ventilated (Reiss et al., 2004). These conditions can promote diseases that thrive in high humidity, creating a need to ventilate even when outside conditions are cooler than desired. However, high tunnels also protect plants from rainfall which decreases the likelihood that foliar diseases will develop (Both et al, 2007). The management of temperature and relative humidity in a high tunnel is primarily controlled through ventilation. Cross ventilation can be achieved by orienting the high tunnel parallel to prevailing winds, and limiting the size (Fidaros, 2008).

Heidenreich et al. (2007) suggested that high tunnels should not be longer than 29.3 m or wider than 9.1 m to achieve adequate ventilation. The daily manual ventilation required for high tunnel production would only be feasible for tunnels that do not require extensive travel to reach. Installing automatic roll up sidewalls increases the construction cost, but greatly reduces the need for daily labour.

2.12.4. Light

Covering a crop with plastic reduces the amount of photosynthetically active radiation (PAR) that a plant receives. In a high tunnel with a single layer of 6 mil greenhouse plastic, the accumulated light integral was decreased by 437 mol m⁻²(24%) on average compared to outside (Both et al., 2007). Row covers further decrease light transmission to plants. Clean polypropylene row cover cloth allows for 80% light transmission while plastic row cover has approximately 75% light transmission (Kumar et al et al., 2007). Light transmission through row cover cloth is greater than through plastic because it allows specks of direct sunlight to pass through. Light levels are also reduced as the sun angle changes in the winter in the northern hemisphere. The changing light angle will cause the southern exposure of a high tunnel to receive more direct light in the winter and early spring and fall (Both et al, 2007). During the summer months, the east and west exposures will receive direct sun exposure for part of the day. The high tunnel should be located where it is not shaded by surrounding structures when the sun angle is at its lowest point if winter production is desired (Black et al, 2008).

2.12.5. Irrigation

Irrigation has been a cornerstone of agriculture for thousands of years and has helped food production expand apace with population growth (Ros, 2013). Today, the 18% of global cropland that receives irrigation water accounts for about 40% of global food production (FAO, 2012). In Asia, where 37% of the cropland is currently irrigated governments and international agencies responded to major famines of the 1960 to 1970s with large-scale investments in irrigation, improved crop varieties, and fertilizer contributing immensely to the success of the green revolution (Harold et al, 2007). This development strategy, the Green Revolution was as much a story of water as it was of modern crop technology.

Tomato growing is considered a high risk activity due to the great variety of environments and systems in which it is grown, high susceptibility to pests and diseases, and high demand for inputs and services, which lead to high financial investment per unit area. Furthermore, Huchmoth and Hochmuth (1990) remark that good productivity requires availability of water throughout the cycle, as the tomato plant is very sensitive to water stress. The commercial value of the table tomato is defined by the characteristics and quality of the fruit (Das et al., 1998). In the Lowveld of Zimbabwe, tomato growing is more common in winter, as temperatures are milder (SNV, 2016). Nevertheless, low rainfall makes crop dependent on irrigation, as lack of water greatly affect the quality and quantity of production (FAO, 2010).

Among the different irrigation systems used in tomato growing, drip irrigation has become a viable option in the world (Mishra et al., 2010) for its many advantages, such as the possibility to grow in areas of low water availability, high levels of efficiency (Benton, 2008), and lower incidence of diseases of plant aerial parts, leading to high yield and fruit quality. Although drip irrigation requires a high initial capital investment, it is one of the best techniques to use in applying water to vegetables and orchards (Cox and Tilth, 2009).

When compared to sprinkler irrigation, drip irrigation can distribute water uniformly, increases plants yield, reduces evapotranspiration, and decreases the use of water and fertilizer (Dorais et al., 2001). Furthermore, its pumping requires less energy; it potentially minimizes negative irrigation impacts on soil, and facilitates the use of fertigation (Razzak et al., 2013). When water is a limiting factor for agricultural production, irrigation with water deficit index provides greater economic return than total irrigation (Benton, 2008). Deficit irrigation management is possible when crop production function is estimated. When

properly applied, the technique shows great potential to increase water use efficiency (Mishra et al., 2010), especially in areas of low water availability (Harold et al., 2007). The deficit irrigation could be used for tomato without reduction in yield and also with increase in fruit quality parameters, such as the content of sugar and antioxidants moieties (Birhanu and Tilahun, 2010).

The amount of water applied to crop, along with other production factors, allows changes in growth. Such quantitative analysis is based on the assessment of data from sequential collections, in order to describe changes in production of dry matter depending on time, by calculating growth rates (Hobson et al., 1983). In addition, it allows identifying plant traits linked to environmental conditions, as well as yield potential under optimal growth conditions.

Irrigation enables year-round crop production, higher yields, growth in rural incomes, and a dramatic reduction in acute and chronic hunger. In sub-Saharan Africa (SSA), by contrast, only 4% of agricultural land is irrigated (Mashego, 2001). Although an estimated 40 million ha are suitable for irrigation, only 7.3 million ha are actually irrigated, and the vast majority of this irrigated land is concentrated in just four countries: Madagascar, Nigeria, South Africa, and Sudan (Bertelli and Macours, 2014). Although achieving food security in SSA is a multifaceted effort, evidence from across scales from suggests that more reliable access to water, especially in the form of smallholder irrigation, has great potential to reduce hunger, raise incomes, and improve development prospects in the region (Perez et al., 2017).

Roughly 70% of Africa's extremely poor populations (per capita income of <\$1.25/d) live in rural areas and depend primarily on agricultural production for their livelihoods (FAOSTAT, 2014). Although up to 30–40% of their income typically comes from nonfarm activities, even these activities are often closely linked to agriculture (SNV, 2016). Most of these agriculture dependent communities have little chance of escaping poverty and becoming food secure without a significant change in development strategy, because the very nature of their farming systems keeps them mired in poverty (Mabengwa, 2013). In most of SSA, smallholder cropping systems are dominated by rain fed cereal like maize, sorghum, millet and starchy staple root crops mainly yams and sweet potatoes. These crops have limited nutritional benefits, and their low market value makes it difficult for smallholders to survive economically on their small land base, typically 1–2 ha (Maboko and Du Ploy, 2008). Yields

for smallholder farmers in SSA remain the lowest in the world, and rapid population growth is reducing the per-capita farmed area, making household food security for smallholder farmers an increasingly challenging goal (Chibi et al., 2015). In the coming decades, the anticipated rise in average temperatures, reductions in soil moisture, and increased rainfall variability are expected to compound the problems of low crop productivity (Bertli and Macours, 2014).

2.12.6. Labour

Indeterminate varieties require ongoing pruning, clipping and harvesting, while determinate varieties are trellised and harvested over shorter periods (Both et al., 2007). However, the upright open canopy of indeterminate varieties facilitates easier harvest. Continuous weed control, maintenance of drip liners, opening of row covers as well as fertigation all require labour (Erdal et al, 2007)

2.12.7. Pest management

Due to the unique environment within tunnels, growers may encounter different disease problems in the tunnel than in the field. This is because the tunnel excludes rainfall, the foliage tends to stay dry, resulting in fewer disease problems from pathogens that are spread by rain splash or require leaf-wetness for infection (Chibi et al., 2015). However, due to the limited movement of air in a tunnel, those diseases favoured by high humidity can increase in severity (Tumwine, 1999). Because of potential virus problems, bedding plants and other potted ornamentals should not be planted in the same greenhouse as tomatoes (Beilinski et al., 2013). Due to the irrigation needs of tunnel-grown tomatoes, blossom end rot, a calcium deficiency caused by irregular watering, can be a problem for some growers (Kaiser and Ernst, 2017).

Insect pests in tunnels differ from those in open fields. While the high tunnel presents a barrier to some insect pests (e.g. the sphinx moth), it is an ideal environment for others, particularly whiteflies and aphids (Annastancia et al., 2011). Typically, any insect pest that is a problem for greenhouses will be a problem in high tunnels. An insect exclusion screen can be placed over the sidewall and gable vents to prevent insect entry into the high tunnel (Gebber et al., 1988). Frequent scouting to monitor insect populations and disease incidence is essential due to the relatively high density of plants in tunnels, pests and diseases can spread very quickly (Foord, 2004).

2.13. Trellising

Crop support is very important in a high tunnel for many of the same reasons it is used in the field: better light penetration, improved air circulation, more plants per square foot, and fewer fruit in contact with the ground (Knapp, 2015). Options include cages, staking, stake and weave, and trellising; some methods are more labour intensive and/or costly than others (Maboko and Du Ploy, 2008). Trellising to the tunnel roof is not advisable unless the frame has been built to support the heavy weight of fruit-laden plants (Reiss et al., 2004). Most fresh market tomatoes are grown with a support system such as a metal pole or wooden stake commonly known as trellising (Birhanu and Tilahun, 2010). This support system allows for a higher quality product by keeping the fruit off the ground, increases yield, and allows harvest crews to enter the field for multiple picks without jeopardizing the integrity of the plant. In the warm summer months, open planting is the norm (Cox and Tilth, 2009).

2.14. Pruning and Training

Suckers (auxiliary shoots) should be pruned to hasten earliness and improve air circulation. It is recommended to prune only those shoots below the first flower cluster that are less than 4 inches long (Singh, 2004). Training the plants to two shoots or three shoots will not only facilitate easy trellising operation, but also permit closer planting, early ripening of fruits and get higher yields of larger sized fruits (SNV, 2014). Training methods vary with different growth habits of tomato cultivars and for different plant densities (Hochmuth and Hochmuth, 2014). Training the plant to two shoots or three shoots is generally practiced for indeterminate and semi-determinate cultivars in some foreign countries like Europe and Japan either in open field or glass house conditions (Maboko et al, 2011). In India there is no practice of training except removing of lower leaves and branches (Kaiser and Ernst, 2017).

2.12. Limitations for greenhouse production

Materials for construction and labour costs are some of the limitations to high tunnel production; however construction costs for high tunnels are far less than that of traditional greenhouses (Hunter, 2010). The cost of a high tunnel structure depends on the design. Galvanized steel high tunnel kits are available in a range of sizes. Steel-framed structures are generally more costly than PVC structures; however, steel structures have a longer life expectancy and may withstand high winds and large snow loads in extreme climates (Fidaros et al., 2008). Wind can tear plastic off of a high tunnel if it gets inside. Securing the plastic

tightly and keeping high tunnels closed during storms is a key step in preventing structural damage. Snow load will cause a PVC high tunnel to collapse under the weight unless there is some support inside; however, PVC that is not broken can return to shape after the snow is brushed off (Singh, 2017).

Based on Pedstock Investments design, a 12 m by 7m PVC high tunnel costs approximately USD3100 to build excluding labour whereas a similar sized steel structure would cost approximately USD9, 775 to build. The difference in price between the structures can make growing inside a PVC high tunnel more affordable to an individual grower. In addition to the cost of growing a crop, more labour hours are required for high tunnel production, including hours to construct the tunnel, maintain the structure, and manually ventilate the tunnel daily (Fidaros et al., 2008). When low tunnels are built within the high tunnel, daily ventilation will take approximately 20 minutes (Black et al., 2008).

Construction labour for a 12m by 7m PVC high tunnel is estimated to be 25 hours (Chibi et al., 2015). Maintenance labour will depend on the structure. Another limitation to high tunnel production is cropping space. Since high tunnels increase production costs, the crop grown inside should be valuable enough to offset the cost of construction. Space utilization using vertical structures has been explored for hydroponic systems in both the greenhouse and outdoor environments (Hochmuth et al., 1998; Jensen, 1991), and may be beneficial for high tunnels

2.15. Postharvest qualities of tomato

The term ‘quality’ is regarded as a complete and objective definition. For a consumer of horticultural produce, quality is a highly subjective judgment related to learned criteria (Singh 2017). Tomato fruit quality covers a number of different characteristics among which more attention has been paid to fruit grade.

Tomato quality components include appearance (colour, size, shape, freedom from defects and decay), firmness, flavour, and nutritional value (Freeman and Reimers, 2010). Colour, firmness, flavour, nutritive value, and safety of tomatoes are related to their composition at harvest and compositional changes during postharvest handling (Harold et al, 2007). Deterioration in quality can be caused by a variety of stress factors that may be grouped into four general but often inter-related categories: metabolic stress,

transpiration (water) stress, mechanical injury stress and microbial damage stress (Kaiser and Ernst, 2017).

Tomato fruits are often harvested at the mature green stage to minimize the damage during post-harvest handling (Michelle et al., 2011). The fruits may later ripen spontaneously or after treatment with ethylene before shipment to retailers. Losses often occur from excessive deterioration during holding and marketing of tomatoes. This problem is especially acute with tomatoes harvested when at the breaker or more advanced stages of ripeness (Jones, 2008). Apart from physical losses in quality, serious losses also occur in the essential nutrients, vitamins and minerals. Harvesting before physiological maturity, ripening conditions and lack of proper storage facilities cause a glut during the peak period of harvest and a large portion of fruits is sold at throw away prices (Radzevicius et al, 2009). The need to reduce post-harvest losses is of paramount importance as post-harvest losses can lead to yield losses of up to 40%. Suitable stages of fruit maturity and optimum ripening conditions that are crucial for preserving quality and longer storage of tomato has not yet been developed for developing countries (Naika et al., 2005).

2.15.1. Tomato fruit colour

Colour is an important component of visual appearance. Differentiation between individual fruits and vegetables by consumers is based primarily upon appearance, which often influences purchase (Singh et al., 2014). The analysis of colour is frequently an important consideration when determining the effectiveness of the variety for postharvest treatments (Eldin, 2009). The colour of tomatoes is a very important marketing factor that affects the consumer preference and is also a very important quality attribute for the processing industry (Erdal et al., 2007).

Colour change during ripening involves the conversion of chloroplasts to chromoplasts with the degradation of chlorophyll (Bellinski et al., 2013). During ripening, the chlorophylls gradually disappear and become undetectable 7 days after the breaker and/or turning stage. Tomato fruits change in colour from green, typical of chlorophylls, through pink-orange to bright red, owing to the development of carotenoids (Eldin, 2009). Different varieties have different pigmentations and the main pigments are β -carotene (yellow) and lycopene (red);

and so the tomato colour is considered to be the main function for fruit ripeness (Kumar et al., 2007).

Fruit colour change can be determined using tomato colour chart as demonstrated by Abdullah *et al.* (2004) in Fig 4 below.

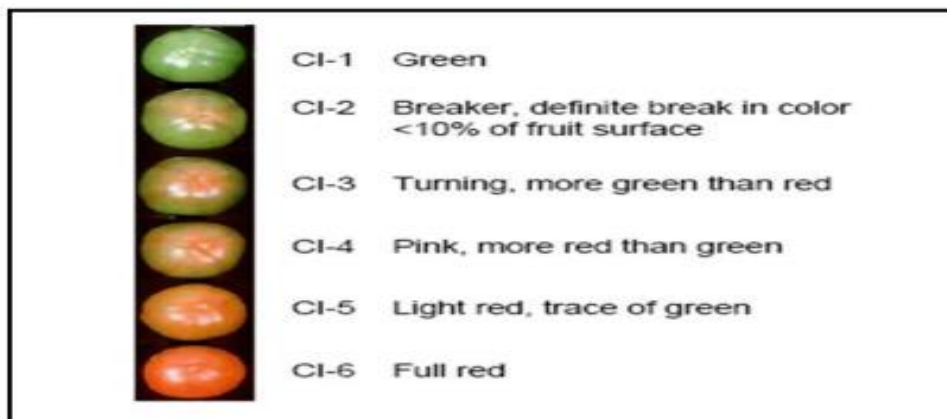


Figure 4: Tomato colour chart corresponding to stages of fruit ripeness

2.15.2. Tomato firmness

Firmness is an important factor to take into account since most, if not all, fruits exhibit a substantial change in firmness during the process of ripening. From the producers and the fruit processors' point of view, firmness can be an indication of the shelf life of the product (Anonymous, 2008).

Lycopene is the major carotenoid found in tomatoes and is responsible for their deep red colour (Goud, 1999). While lycopene may not achieve all the miraculous cures claimed for

Hepitine, it is a powerful antioxidant and several studies have shown that people who consume increased amounts of tomato products experience marked reductions in cancer risk (Giovannucci, 1999; Agarwal and Rao 2000). This research has spurred many breeders to produce tomatoes with high lycopene concentrations. Through this search breeders found that *L. esculentum's* wild cousin *L. pimpinelli* folium produces tiny fruit that have over 40 times more lycopene than domesticated tomatoes. Since these two are able to hybridize *L. pimpinelli* folium will prove indispensable in future programs aimed at increasing the lycopene content of tomato fruit (Cox and Tilth, 2009). A University of California Davis survey recently ranked the tomato as "the single most important fruit or vegetable of western diets in terms of overall source of vitamins and minerals" (Yue and Tong, 2009). All of these promised benefits have once again spurred marketers to encapsulate part of the tomato, lycopene. The importance of sourcing fresh produce on a local level is becoming a widespread consideration for people concerned with the character of their food (Dorais et al, 2007).

2.16. Summary

Tomato is also a very important off-season vegetable crop that fetches great remuneration to the farmers in Zimbabwe. It can be cultivated in open as well as in protected conditions but, its cultivation under open field conditions is not very profitable because of unfavourable weather and the use of low yielding varieties (Chibi et al., 2015). Thus, there is huge scope of tomato cultivation using higher yielding varieties under tunnel greenhouse conditions especially in Zimbabwe. At present there are a number of hybrid varieties that are being growing under the open field condition, but fewer varieties have been evaluated under the protected structures. There is a great possibilities of growing tomato under polyhouse to harvest the quality produce even in off season and export to other countries as a way to generate foreign currency. Production and yield potential of crop is much better under poly house(Singh, 2017).

At present, cultivation of tomato in open fields is a wide spread practice in Murehwa and Mtoko districts as well as Domboshava which supply the biggest markets in Harare (SNV, 2014). However, the tomato crop grown in open fields is exposed to various abiotic and biotic stresses and therefore, it is not possible to produce high quality tomato in terms of size, shape, and colour and, free from diseases and pests as compared to tomato

produced under protected environment(Mabengwa, 2013). Therefore, it makes imperative to take up tomato cultivation using high yielding hybrid indeterminate varieties under green house, particularly, when production of tomato is done for export purpose.

Tomato is also a very important off-season vegetable crop that fetches great remuneration to the farmers especially when grown in winter. At present there are number of hybrid varieties being growing under the open field condition, but fewer varieties have evaluated under the protected structures. There is a great possibilities of growing tomato under poly-house to harvest the quality produce even in off season. Production and yield potential of crop is much better under poly-house. High tunnels can contribute to the financial sustainability of a farm by providing a means to grow high quality produce at a time when a price premium can be obtained due to a shortage of the product.

Product diversification is a strategy that is implemented to decrease economic risk to the grower and reduce the negative environmental impacts of monoculture (Proctor, 2000). By having multiple crops in production, the income of the operation is not reliant on any one crop. An added benefit of a diversified operation includes the opportunity to capture profitable niche markets, and support of the local economy by growing crops that are otherwise imported. Markets and restaurants want to deal with suppliers who have a steady supply. Growers producing through the off season would have an advantage over growers who supply for a shorter season. A fresh marketing strategy might be necessary for expanding business; however, many growers with the potential to adopt a high tunnel system will already have an established market for their produce (Adam et al., 2007).

2.2 References

Abdel-Ghany, A.M, & Al-Helal, I.M. (2011).Solar energy utilization by a greenhouse: General relations. *Renewable Energy. World Applied Sciences Journal*.15(7): 765-791.

Abdel-Ghany, Ahmed M. (2011). Solar energy conversions in the greenhouses. *Sustainable Cities and Society. World Applied sciences Journal*. 17(4)964-975) .

- Abdelmageed, A. H. A., Gruda, N. and El-Balla, M. M. A. 2007. Performance of different tomato genotypes in the arid tropics of Sudan during the summer season. I. vegetative growth. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. 110: 137–145.
- Abdullah, A. A., Abdullah, A. M. and A. O. Mahmoud (2004). Effect of Plastic and Paper Packaging on Tomato Fruits Stored at Different Temperatures and High Relative Humidity. Paper Presentation: International Symposium on Greenhouses, Environmental Controls and In-house Mechanization for Crop Production in the Tropics and Sub-Tropics, Pahang, Malaysia *Journal of Applied Horticulture*.2(10):(568-628).
- Agarwal S, A. Rao (2000) Tomato lycopene and its role in human health and chronic diseases. Canadian Med Association.
- Anastacia, O., A. Masinde, Thomas, K. Kwambai, and N.H. Wambani. 2011. Evaluation of tomato (*Lycopersicon esculentum L.*) variety tolerance to foliar diseases at Kenya Agricultural Research Institute Centre-Kitale in North West Kenya. *African Journal of Plant Science*. 5(11):676-681.
- Aoun, B. A., Lechiheb, B., Leila, B. and Ferchichi, A. 2013. Evaluation of fruit quality traits of traditional varieties of tomato (*Solanum lycopersicum*) grown in Tunisia. *African Journals of Food Science*. 7 (10): 350-354.
- Arin, L. and S. Ankara. 2001. Effect of low-tunnel, mulch and pruning on the yield and earliness of tomato in unheated glasshouse. *Journal of Applied Horticulture*. 3(1):23-27.
- Arora, S. K, Bhatia, A. K, Malik, T. P, Batra, V. K, Yadav, S. P. S, Singh, V. P and Mehra, R. 2007. Studies on performance of different tomato hybrids (semi indeterminate) in off-season under greenhouse conditions in semiarid zone of Haryana. *Haryana Journal of Horticultural Sciences*. 36(1/2): 111-113.
- Arora, S. K, Bhatia, A. K, Singh, V. P and Yadav, S. P. S. 2006. Performance of indeterminate tomato hybrids under greenhouse conditions of north Indian plains. *Haryana Journal of Horticultural Sciences*. 35(3/4): 292-294.

- Benton, J. J. (2008). Tomato plant culture in the field, greenhouse and home garden. CRC Press, Taylor& Francis Group, 2nd ed., 399p.
- Bielinski S, E McAvoy, M Ozores-Hampton, G Vallad, P Dittmar, S Webb, Hugh Smith, Stephen Olson. "Chapter 12. Tomato Production." IFAS Extension University of Florida. IFAS Extension, 2013. Web. 26 Aug. 2014.
- Birhanu, K. and. Tilahun (2010). Fruit yield and quality of drip-irrigated tomato under deficit irrigation. African journal of food agriculture, Nutrition and Development 10 (102-109).
- Biswas, M., Sarkar, D. R., Asif, M. I., Sikder, R. K, Mehraj H. & Jamal Uddin, A. F. M. (2015). Comparison of Growth and Yield Characteristics of BARI Tomato Varieties. Journal of Bioscience and Agriculture Research 03(01), 01-07.
- Black, B., D. Drost, D. Rowley, and R. Heflebower. 2008. Constructing a low-cost high tunnel. Utah State Univ. Coop.
<http://extension.usu.edu/files/publications/publication/HG_High_Tunnels_2008-01photos.pdf>.
- Both, A. J., E. Reiss, J. F. Sudal, K. E. Holmstrom, C. A. Wyenandt, W. L. Kline, and S. A. Garrison. 2007. Evaluation of a manual energy curtain for tomato production in high tunnels. HortTech. 17(4): 467-472.
- Boulard, T. and Wang, S. 2002. Experimental and numerical studies on the heterogeneity of crop transpiration in a plastic tunnel. Computers and Electronics in Agriculture 5 (34-46).
- Bertelli, O., Macours, K. (2014). Food security and agriculture in developing countries: measurement and hypotheses for impact evaluations. *FOODSECURE Working Paper 21*, (21).
- Chapagain, T. R, Khatri, B. B and Mandal, J. L. 2011. Performance of tomato varieties during rainy season under plastic house conditions. Nepal Journal of Science and Technology. 12: 17-22.

- Chibi, F. I., Mushayabasa, T., & Magejo, E. (2015). Evaluation of hybrid indeterminate tomato (*Solanum lycopersicum L.*) varieties for commercial greenhouse production, 6(6), 65–68.
- Cox, B. and O. Tilth. (2009). Field production of organic tomatoes. January 22, 2009 Related resource areas: [http://www.extension.org/organic production](http://www.extension.org/organic%20production) (Accessed on 22/01/2009).
- Dalrymple, D. G. 1973. Controlled environment agriculture: A global review of greenhouse food production. U.S. Dept. Agr. Foreign Agr. Econ. Rpt. 89.
- Das, B., M.H. Hozarika and P.K. Das. 1998. Genetic variability and correlation in fruit character of tomato (*Lycopersicon esculentum Mill.*). Annual Agricultural Research, 19: 77 – 80.
- Diver, S. 2002. Root zone heating for greenhouse crops. ATTRA. 21 November 2010. <<http://attra.ncat.org/attra-pub/rootzone.html>>.
- Dorais, M., Papadopoulos, A. P. and Gosselin A., (2001). Greenhouse tomato fruit quality. Horticultural Review 26: 239-319.
- Edlin, D. J. (2009). Heirloom and Hybrid Tomato Yield and Quality in Organic and Conventional Production Systems.
- Emmert, E. M. 1956. Plastic row covering for producing extra-early vegetables outdoors. University of Kentucky Agriculture Extension. Serv. Leaflet 167.
- Erdal, I., ertek, A., Senyigit and M. A. Koyuncu (2007). Combined effects of irrigation and nitrogen on some qualities parameters of processing tomato. World Journal of Agricultural Sciences 3 (1): 57-62.
- FAOSTAT (2014). Global Tomato Production in 2012. Rome, FAO. Available at <http://faostat.fao.org/>. Accessed June 12, 2019.
- Food and Agricultural Organization of the United Nations (2011). The State of Food Insecurity in the World 2011: Addressing Food Insecurity in Protracted Crises (Food and Agricultural Organization of the United Nations, Rome).

- Fenny Dane, A., Gene Hunter and Oyette, L. 1991. Chambliss fruit set, pollen fertility, and combining ability of selected tomato genotypes under high temperature field conditions. *J. Amer. Soc. Hort. Sci.* 116: 906-910.
- Fidaros, D. K., Baxevanou, C., & Bartzanas, T. (2008). Thermal behaviour of a tunnel arc greenhouse during a solar day Thermal Behaviour of a Tunnel Arc Greenhouse during a Solar Day, (February 2014). <https://doi.org/10.17660/ActaHortic.2008.801.105>
- Foord, K. 2004. High tunnel marketing and economics. Regents of the University of Minnesota. <<http://www.extension.umn.edu/distribution/horticulture/M1218-12.pdf>>.
- Freeman, B.B., & Reimers, K. (2010). Tomato Consumption and Health: Emerging Benefits. *American Journal of Lifestyle Medicine*, 1559827610387488: 1-11.
- Gerber, J. M., I. Mohdkhir, and W. E. Splittstoesser. 1988. Row tunnel effects on growth, yield and fruit-quality of bell pepper. *Scientia Horticulturae* 36(3-4): 191-197.
- Giovannucci, E. (1999). "Tomatoes, Tomato-Based Products, Lycopene, and Cancer: Review of the Epidemiologic Literature." *Journal of the National Cancer Institute* 91(4): 317-331.
- Gosselin, A. and M. J. Trudel. 1985. Influence of root-zone temperature on growth, development and yield of cucumber plants cv. Toska. *Plant and Soil* 85: 327-336.
- Gould WA (1992) *Tomato Production and processing and Technology*, (3rdEdn.), CTI Publishers Baltimore.
- Hanna, H. Y. and Hernandez, T. P. 1980. A study of several characters related to heat tolerance in tomatoes. *Hort Science*. 15: 3,I, 281.
- Hanson, B. and D. May (2003). Drip irrigation increases tomato yields in salt-affected soil of San Joaquin Valley. *California Agriculture* 57 (4):132-137.
- Harold, C. P., Karapanos, I. C., Bebeli, P. J. and D. Savvas (2007). A review of recent research on tomato nutrition, Breeding and Postharvest Technology with reference to fruit quality. *The European Journal of Plant Science and Biotechnology* 1 (1): 1-21.

- Heidenreich, C., M. Pritts, M. J. Kelly, and K. Demchak. 2007. High tunnel raspberries and blackberries. Cornell Univ. Dept. Hort. No.47.
- “High Tunnel Tomatoes.” Cooperative Extension Service. University of Kentucky - College of Agriculture, 2012. Web. 26 Aug. 2014.
- Hobson, G. E., Adams, P and T. J. Dixon (1983). Assessing the colour of tomato fruit during the ripening, *Journal of Science of Food and Agriculture* 34: 286-292.
- Hochmuth .G.J and Hochmuth R.C., 2012. Production of Greenhouse Tomatoes-Florida Greenhouse Vegetable Production Handbook Vol 3: <http://edis.ifas.ufl.edu> Retrieved June, 2012.
- Hochmuth, G. and Hochmuth, R. “Production of Greenhouse Tomatoes – Florida Greenhouse Vegetable Production Handbook, Vol 3.” EDIS. University of Florida IFAS Extension, 1990. Web. 26 Aug. 2014.
- Hochmuth, R.C., Leon L.L, and Hochmuth G.J., 1997. Evaluation of several greenhouse cluster and beefsteak tomato cultivars in Florida. Univ. of Fla. Coop. Ext. Report Suwannee Valley REC 97-3 11pp.
- Hunter, B. L. (2010). Enhancing Out-of-Season Production of Tomatoes and Lettuce Using High Tunnels .
- Hussain, S. I., Khokhar, K. M., Mahmood, T., and Laghari, M. H. 2002. Varietal Differences in Tomato Crop Grown in Islamabad Conditions. *Asian Journal of Plant Sciences*. (569-572)
- Hussain, S. I., Khokhar, K. M., Mahmood, T., and Laghari, M. H. 2002. Varietal Differences in Tomato Crop Grown in Islamabad Conditions. *Asian Journal of Plant Sciences* [ime/magazine/article/0, 9171, 1595245, 00.html](http://www.ajps.com/ajps/issue/magazine/article/0,9171,1595245,00.html)>.
- Hussein, J. B., Usman M. A, and K. B. Filli, “Effect of Hybrid Solar Drying Method on the Functional and Sensory Properties of Tomato.” *American Journal of Food Science and Technology*, vol. 4, no. 5 (2016): 141-148. doi: 10.12691/ajfst-4-5-4.

- Hussein, J. B., & Filli, K. B. (2016). Effect of Hybrid Solar Drying Method on the Functional and Sensory Properties of Tomato, (January). <https://doi.org/10.12691/ajfst-4-5-4>.
- Ishwarappa, K, 2011. Performance of tomato (*Solanum lycopersicum* L.) hybrids under shade house condition. Doctoral dissertation, University of Agricultural Sciences. Dharwad, Karnataka (India).
- Jackson, J. E., Turner, A., and Matanda, M. 1997. Smallholder horticulture in Zimbabwe. University of Zimbabwe.
- Jawaharlal, M and Veeraragavathatham, D. 2003. Evaluation of parents and hybrids of tomato (*Lycopersicon esculentum* Mill) for plant growth, fruit yield and fruit characters. South Indian Horticulture. 51(1/6):25-29.
- Jayaprakashnarayan, R. P. 2007. Genetics of yield attributes, resistance to tomato leaf curl virus and bacterial wilt in tomato. Ph.D. Thesis, U.A.S. Bangalore.
- Jensen, M. H. 2004. Plasticulture in the global community - View of the past and future. American Society for Plasticulture
<http://www.plasticulture.org/history_global_community.htm>.June 2010.
- Jones, Jr., J.B. 2008. Tomato plant culture: In the field greenhouse and garden. 2nd ed. CRC Press, Boca Raton, FL.
- Kaiser, C. and M. Ernst, (2017). High Tunnel Tomatoes. CCD-CP-62. Lexington, KY: Center for Crop Diversification, University of Kentucky College of Agriculture, Food and Environment. USA.
- Knapp, M. (2015). Effect of Pruning and Trellising of Tomatoes on Red Spider Mite Incidence and Crop Yield in Zimbabwe, (April 2004).
<https://doi.org/10.4314/acsj.v11i4.27577>.
- Kumar, R. A, Vijayalatha, K. R, Alagesan, A and Veeraragavathatham, D. 2007. Performance of certain tomato (*Lycopersicon esculentum*) genotypes under greenhouse and open conditions in summer. Journal of Eco-biology. 19(2):105-112.

- Mabengwa, M. (2013). Growth Responses of Tomato (*Lycopersicon esculentum* Mill) to Different Growing Media under Greenhouse and Field Conditions.
- Maboko, M. M and Du Plooy, C. P. 2008. Effect of pruning on yield and quality of hydroponically grown cherry tomato (*Lycopersicon esculentum*). South African Journal of Plant and Soil. 25:178-181.
- Maboko, M. M., DU Plooy, C. P and Bertling, I. 2011. Comparative performance of tomato cultivar cultivated in two hydroponic systems. South African Journal of Plant and Soil. 28(2): 97-102.
- Mashego, D. C. 2001. The production of vegetable crops under protection for small-scale farming situations, MInst Agrar dissertation, University of Pretoria, Pretoria.
- Medina, T., Gabriela, S., Figueroa, A., Gustavo, J., & Cauih, D. (2017). Origin and evolution of tomato production *Lycopersicon esculentum* in México.
- Michelle Lestrage, Wayne Schrader, Timothy Hartz. "Fresh-Market Tomato Production in California." University California Agriculture and Natural Resources. UC Davis, 2000. Web. 26 Aug. 2014.
- Mishra B, Gowda A and Reddy SS. 2010. Impact of graded levels of N, P, K on yield, quality and nutrient uptake of three leaf curd resistant tomato varieties. Karnataka Journal of Agricultural Sciences 17: 28-32 Horticulture. 44(5-6): 132-134.
- Naika, S., J. Juede, M. Goffau, M. Hilmi, and B. Van Dam. 2005. Cultivation of tomato. Production, processing and marketing. In: B. Van Dam (ed.), Digigrafi, Wageningen, and the Netherlands.
- Olaniyi, J. O and Fagbayide, J. A. 1999. Journal of Agricultural Biotechnology and Environment. 1:4-10.
- Papadopoulos, A.P., 1991. Growing greenhouse tomatoes in soil and soilless media. Agriculture Canada publication, Ottawa, Canada.

- Parvej, M. R, Khan, M. A. H and Awal, M. A. 2010. Phenological development and production potentials of tomato under polyhouse climate. *Journal of Agricultural Sciences*. 5(1): 19-31.
- Pedro, A.M.K, Ferreira M.M.C (2007). Simultaneously calibrating solids, sugars and acidity of tomato products using PLS2 and NIR spectroscopy. *Analytica Chimica Acta* 595, 221.
- Perez, K., Gordon, J. S. F., Abdourhamane, I. K., Levasseur, V., Alfari, A. A., Mensah, A., Jahn, M. M. (2017). Connecting smallholder tomato producers to improved seed in West Africa. *Agriculture & Food Security*, 1–14. <https://doi.org/10.1186/s40066-017-0118-4>.
- Prasad, V.S.R.K.and D.P. Singh. 1994b. Genetic association and interrelationship between yield components in cucumber. *J. Maharashtra Agr. Univ.* 19; 147-148.
- Prema, G, Indires, K. M and Santhosha, H. M. 2011. Evaluation of cherry tomato (*Solanum lycopersicum* var. *Cerasiforme*) genotypes for growth, yield and quality traits. *Asian Journal of Horticulture*. 6(1): 181-184.
- Radzevičius A, Karklelienė R, Viškelis P, Bobinas Č, Bobinaitė R, Sakalauskienė S (2009). Tomato (*Lycopersicum esculentum* Mill.) fruit quality and physiological parameters at different ripening stages of; Lithuanian cultivars. *Agronomy Research*, 7 (Special issue II), 712–718.
- Razzak, H. A, Ibrahim, A, Wahb-Allah, M and Alsadon, A. 2013. Response of cherry Tomato (*Solanum lycopersicum* var. *cerasiforme*) to pruning systems and irrigation rates under greenhouse conditions. *Asian Journal of Crop Science*. 5(3): 275-285.
- Reiss, E., Both, A.J., Carrison, S, Kline, W. and Sudal, J. 2004. Season extension for tomato production using high tunnels. *Acta Horticulturae* 659: 153-160.
- Ros, J. R. (2013). MSc Thesis Presented for obtaining the Agris Mundus Master of Science Option : Water Management for Rural Development Specialisation : Irrigation and Water Management ; Resources , Agrarian Systems and Development (RESAD) Methodology for the Evaluation, 132p.

- Sam, O. and Iglesias, L. 1993. Flowering and fruiting of plants of five tomato (*Lycopersicon esculentum* Mill.) cultivars sown in two seasons. *Cultivos Tropicales*, 14: 64-70.
- Sima, R, Maniuțiu, D, Apahidean, A. S, Apahidean, M, Lazar, V, Sima, N and Ficior, D. 2011. The Evaluation of Yield Potential and Quality of Fruits at Tomato Hybrids Cultivated in Greenhouse. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture*. 68(1).
- Sharma, M. K, Kumar, R and Kumari. S. 2011. Identifying superior quality of F1 tomato hybrids for year round production under low cost plastic green houses in North-West Himalayas. *Vegetable science*. 38(1): 30-34.
- Shrestha, S., & Sah, R. (2015). Evaluation of Tomato Cultivars for Central Tarai of Nepal. *Nepal Journal of Science and Technology*, 15(2), 11-16.
<https://doi.org/10.3126/njst.v15i2.12105>.
- Sima, R, Maniuțiu, D, Apahidean, A. S, Apahidean, M, Lazar, V, Sima, N and Ficior, D. 2011. The Evaluation of Yield Potential and Quality of Fruits at Tomato Hybrids Cultivated in Greenhouse. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture*. 68(1).
- Singh, J.P., D.K Singh and G. Gulshanlal, 2000. Variability pattern in agro- Morphological characters in tomato (*Lycopersicon esculentum* L.) *Prog. Hort.*, 32(1):79-81.
- Singh, A.K and N. Raj. 2004. “Variability studies in tomato under cold arid condition of Ladakh.” *Hort.J.*, 17:67 – 72.
- Singh, J.K., J.P. Singh, S.K. Jain, J. Aradhana and A. Joshi. 2002. Studies on genetic variability and its importance in tomato (*Lycopersicon esculentum* Mill.). *Prog.Hort.*,34:77 – 79.
- Singh, R. (2017). (*Solanum lycopersicon* L.) Under protected condition. Department of plant physiology, Aromatic Plants College of Agriculture Raipur India Gandhi Krishi Vishwavidyalaya Raipur (Chhattisgarh) (*Solanum lycopersicon* L.) *Hort. Journal.*,42:102-104.

- Singh, T., Singh, N., Bahuguna, A., Nautiyal, M., and V.K. Sharma, 2014. Performance of Tomato (*Solanum lycopersicum* L.) Hybrids for growth, yield and quality inside polyhouse under Mid Hill condition of Uttarakhand. *American Journal of Drug Discovery and Development*, 4: 202-209.
- SNV, 2014. Rural agricultural revitalisation program. Horticultural sub-sector report. Harare, Zimbabwe.
- SNV, 2016. Smallholder horticultural production and business. Horticultural trainers manual. Harare, Zimbabwe.
- Sumathi, T, Suchindra, R, Narayanan, R. S and Nainar, P. 2013a. Studies on evaluation of tomato (*Solanum lycopersicum* mill) genotypes under polyhouse condition for yield attributing characters. *Plant Archives*. 13(2): 975-978.
- Thangam, M and Thamburaj, S. 2008. Comparative performance of tomato varieties and hybrids under shade and open conditions. *Indian Journal of Horticulture*. 65(4): 429-433.
- “Tomatoes.”The World’s Healthiest Food. The George Matelijan Foundation, 2014. Web. 26 Aug. 2014.
- Tumwine, J. 1999. Towards the development of integrated cultural control of tomato late blight (*Phytophthora infestans*) in Uganda. PhD Dissertation, Wageningen Agricultural University, Wageningen, Netherlands.
- Upadhyay, M., J.P. Singh., A. Singh and A. Joshi. 2005. Studies on genetic variability in tomato (*Lycopersicon esculentum* Mill.). *Prog. Hort.* 37(2): 463 – 64.
- Veershetty, V. 2004. Studies on variability, character association and genetic diversity in tomato (*Lycopersicon esculentum* Mill). M.Sc. (Agric.) Thesis, University of Agricultural Science, Dharwad (India). 465.
- Yue, C. and C Tong. 2009. Organic or local? Investigating consumer preference for fresh produce using a choice experiment with real economic incentives. *Horticultural Science*. 44:366- 371.

CHAPTER 3

MATERIALS AND METHODS

This chapter deal with the description of the material used and various techniques or methods adopted throughout the course of investigation entitled “ growth and yield component of tomato (*Solanum lycopersicon L.*) under protected conditions.” This research was carried out at Pedstock Investments Pvt Ltd in Harare Zimbabwe (17° 45' 25" South, 31°4' 28" East) from August 2018 to April 2019.

3.1 Experimental site

This experiment was carried out during the year 2018-19 at Pedstock Investments which is located in Harare, Zimbabwe under protected cultivation in a tunnel greenhouse. Six hybrid indeterminate tomato varieties bred by Haaretz seeds in Israel and Italy were used. Pedstock Investments is located in Natural region IIA and its geographical coordinates are 17° 45' 25" South, 31°4' 28" East. The climate of Harare is characterized as dry sub-humid agro-climatic region. The rainfall ranges from 750 to 1 000 mmyear⁻¹. It is fairly reliable, falling from November to March/April which is the summer season in Zimbabwe. The Natural Region IIA is also characterised by mean maximum temperature range of 19-23 °C, mean minimum temperature range of 10-13 °C and mean annual temperature of 16-19 °C.

3.2 Experimental design

Tomato varieties namely: 3295, 3297, 3298, 29202, 29412 and Daniella (control). All six varieties were bred by Hazera Seeds and Daniella has been grown in Zimbabwe for the past

six years. The experiment was laid out as a randomized complete block design (RCBD) with six treatments (Table .1) replicated three times. Slope was used as the blocking factor.

Table 1: Design of RCBD as with treatments replicated in blocks

Treatment number	Variety	Origin	Description	Breeding company	Determinate/indeterminate
1	3295	Israel	Vining	Haaretz	Indeterminate
2	29412	Italy	Vining	Haaretz	Indeterminate
3	Daniella	Israel	Vining	Haaretz	Indeterminate
4	29202	Italy	Vining	Haaretz	Indeterminate
5	3297	Israel	Vining	Haaretz	Indeterminate
6	3298	Israel	Vining	Haaretz	Indeterminate

3.5 Details of Tunnel greenhouse used for the experiment

The tunnel greenhouse used was (280 m²) and it already existed at Pedstock Investments in Harare. It is a conventional tunnel greenhouse with plastic sheeting and steel frames. Drip liners 8mm in size were laid one meter apart having emitting points at every 30 cm interval with discharge rate of 1 litre ha⁻¹. One month before transplanting the tomato seedlings, the tunnel greenhouse was cleaned in preparation for the new crop. Cleaning involved removing the old plants and disinfesting the house and growing surfaces. Plants were removed from the tunnel greenhouse and buried in deep compost in a distant area to avoid reintroduction of insects and disease organisms. Surfaces were wiped clean of dust and insect honeydew. The sump tank was flushed and cleaned using 10% chlorination to clean out bacteria.

3.5.1 Seedbed

The seeds of the six hybrids were sown in plastic containers by using soilless media having a mixture of peat and vermiculite, inside a convectional greenhouse to get healthy and disease free seedlings of tomato. The seedlings were ready for transplanting after four weeks of sowing and were subsequently transplanted inside the tunnel greenhouse equipped with a drip irrigation system.

3.5.2 Transplanting of seedlings

Hardening of seedling was done at 20days after germination through total withdrawal of water for one week and subsequently on day 28 seedlings were transplanted into the naturally ventilated tunnel green house in labelled blocks at spacing of 100cm by 30cm intervals as shown on Figure 5 below.



Fig. 4: Newly transplanted tomatoes in the tunnel greenhouse

3.5.6 Crop maintenance

The needed agronomic (irrigation, weeding, fertigation, trellising and de-suckering) and plant protection procedures were done to maintain healthy plants as tomatoes are very vulnerable to pest and disease problem. Fertilizer application was applied at a rate of 30g of compound C per plant station at transplanting as a once off application (Book et al., 2006) Mono Ammonium phosphate (MAP) was applied at a rate of 1, 5gplant⁻¹ once a week for five

weeks. From week 7 until last harvest, Calcium Nitrate was applied at a rate of 0, 5gplant⁻¹ once a week. At week 10 Potassium Sulphate was applied at a rate of 2 g plant⁻¹ weekly up to last harvest. All these fertilisers are water soluble and they were given through fertigation during the entire crop growth period. Each plant had an emitter/drip/irrigation point next to it. This fertigation regime was done to encourage continuous flowering as well as prevent abortion of flowers and fruits. **3.5.7 Pest and Disease Control**

Scouting was done on a daily basis where preventative sprays with Abamectin, were done against red spider mites twice. Mancozeb 75% WP was applied as a preventative measure at a rate 2.1 glitre⁻¹ against early and late blight on the sixth week. In rotation Copper Oxychloride another preventative spray against fungal infections was applied at a rate of 3glitre⁻¹. These preventative sprays were applied as full cover sprays one week after

transplanting. Weeding was done by hand hoeing throughout and spraying of chemicals was done using battery powered knack sack sprayer. Below is table 3 showing chemicals that were used for pest and disease control for the experiment.

Table 2: List of chemicals used to control pest and diseases.

Pest/Disease	Casual Organism	Chemical Sprayed	Dosage
White Fly	<i>Bemisa Tabaci</i>	Dishwashing soap	5ml/15L
		Actara	6,4g/15L
		Cabandazim	8ml/15L
		Mancozeb	32g/15L
		Azostrobin	12ml/15L
Red Spider Mite		Abamectin	14ml/15L
		Imidacloprid	8ml/15L
Early/ Late Blight	<i>Alternaria solani</i>	Cabendazim	8ml/15L
		Mancozeb	32g/15L
		Dithane M45	32g/15
Leaf Miner	<i>Tuta Absoluta</i>	Cartap	64g/15L
		Belt	4ml/15L
		Methomyl	8g/15L

3.5.8 Irrigation Management

Tomato plants had ample water without overwatering, to avoid leaching of nutrients into the soil profile beyond the reach of plant. Irrigation was done two to three times a day at a rate of 1litre/hour using 8mm dripline everyday according to requirement.

3.5.9 Trellising

Tomatoes varieties were trellised with stakes and twine, in high tunnels three weeks after transplanting. The plants were pruned to two leaders and attached to vertically suspended twine with plastic clips. Small spools allowed lowering of the twine as plants grow (Picture 1). Since all the varieties were indeterminate plants they continued to grow upward and required trellising throughout the season.



Fig 6: Picture of trellised hybrid indeterminate variety 29202 in the tunnel greenhouse experiment site.

Lowering of plants and De-leafing

The plants were lowered periodically, to maintain the plants at workable heights. Provisions were made to have an extra length of plastic twine so that the plants were lowered to required length. Lowering was performed at 20-30 days interval starting from 70- 80 days after transplanting. De-leafing of older leaves was done periodically starting from 70 days

after transplanting and at least 50cm of stems from growing point had leaves at any given point of time.

Termination of crop

About 40 to 45 days prior to termination date, the plants were topped by cutting the plant top off at the trellis cable. Pollination could stop but fertilizer solution application was maintained. Fruits on the vine continued to ripen and the last ones were harvested by the projected termination date.

3.6 Data collection and methods used

Each plot had ten plants of the same variety and the middle four plants were tagged, and it was from these tagged plants that data for yield and yield components was obtained. Each plot with the same variety was replicated three times in the tunnel greenhouse. For total yield, the tagged plants in a plot were used only. Growth and yield components recorded from the four tagged plants in a plot included : plant height, fruit number per cluster, number of clusters per plant, weight of fruits per cluster, weight of fruits per plant, single fruit weight, flower numbers per cluster. Another yield component such as days to 50 percent flowering was recorded from all plants in the whole plot.

Plant height was measured at first harvesting and it consisted of the average height of the middle four plants replicated three times from each plot. The plant height was measured from the soil surface to the last growth point at 120days after transplanting. Leaf area was measured from the four tagged plants that were selected randomly from each plot where leaf area was measured using grid paper where each leaf was laid out and traced. The number of grid boxes covered was then counted to obtain the area of the leaf. The distance between clusters was measured using a tape measure on the tagged plants. This activity was repeated on all the replicated plots. The number of flowers per cluster was counted physically through observation and recorded at 60 days, 90 days and 120 days after transplanting to obtain the average number of flowers. The top cluster was the one selected on each plant at the various stages to obtain the number of flowers. Number of days was counted by visual observation in each plot to obtain days to first flowering. Days to first inflorescence of first observed flowers at the time of appearance of first inflorescence.

Days to fruit initiation were observed at the time of appearance of first fruit. Fruit initiation was recorded at the time of appearance. Fruits from four tagged plants in each plot were randomly selected at each picking and their length (cm) was measured between two polar ends with the help of vernier calliper. Days to first fruit picking was recorded at time of fruit ripening at the first break. The fresh weight of five fruits was randomly selected from tagged plants per replication and the mean was computed and expressed in grams. Individual fruits were from the four tagged plants in each plot were weighed using a scale. The fruit yield per plant was calculated by adding the weight of total picking and the average yield per plant was worked out and expressed in tonnes.

3.6 Data collection and methods used

3.6.1 Morphological and phenological parameters

Each plot had ten plants of the same variety and the middle four plants were tagged, and it was from these tagged plants that data for yield and yield components was obtained. Each plot with the same variety was replicated three times in the tunnel greenhouse. For total yield, the tagged plants in a plot were used only. Growth and yield components recorded from the four tagged plants in a plot included : plant height, fruit number per cluster, number of clusters per plant, weight of fruits per cluster, weight of fruits per plant, single fruit weight, flower numbers per cluster. Another yield component such as days to 50% flowering was recorded from all plants in the whole plot.

3.6.1.1 Plant height (cm)

Plant height was measured at first harvesting and it consisted of the average height of the middle four plants replicated three times from each plot. The plant height was measured from the soil surface to the last growth point.

3.6.1.2 Leaf area (cm²)

Leaf area was measured from the four tagged plants that were selected randomly from each plot where leaf area was measured using grid paper where each leaf was laid out and traced. The number of grid boxes covered was then counted to obtain the area of the leaf.

3.6.1.3 Distance between clusters (cm)

The distance between clusters was measured using a tape measure on the tagged plants. This activity was repeated on all the replicated plots.

3.6.1.4 Number of flowers per cluster

The number of flowers per cluster was counted physically through observation and recorded at 60 days, 90 days and 120 days after transplanting to obtain the average number of flowers. The top cluster was the one selected on each plant at the various stages to obtain the number of flowers.

3.6.1.5 Days to 50% flowering

Number of days was counted by visual observation in each plot to obtain days to 50% flowering.

3.6.1.6 Node to first inflorescence

Days to first inflorescence of first observed at the time of appearance of first inflorescence.

3.6.1.7 Days to fruit set

Days to fruit initiation were observed at the time of appearance of first fruit. Fruit initiation was recorded at the time of appearance.

3.6.1.8 Fruit diameter (cm)

Fruits from four tagged plants in each plot were randomly selected at each picking and their length (cm) was measured between two polar ends with the help of vernier calliper.

3.6.1.9 Days to first fruit picking

Days to first fruit picking was recorded at time of fruit ripening at the first break.

3.6.1.10 Fruit weight

The fresh weight of five fruits was randomly selected from tagged plants per replication and the mean was computed and expressed in grams. Individual fruits were from the four tagged plants in each plot were weighed using a scale

3.6.1.11 Yield per plant

The fruit yield per plant was calculated by adding the weight of total picking and the average yield per plant was worked out and expressed in tonnes.

3.7 Statistical analysis

The data was analysed using Genstat version 14 and where there were significant differences the means were separated using the least significant differences at 0.05 probability levels. The data pertaining to vegetative, reproductive, quality and yield parameters of different varieties of tomato were tabulated according to treatment, block as well as replications done. The data was subjected to statistical analysis as per the methods using the mean values of random plants in each replication from all the treatments to find out the significance of treatment effect.

CHAPTER 4

Growth and yield characteristics of indeterminate tomato hybrid varieties under tunnel greenhouse production.

Abstract

Hybrid indeterminate tomato varieties are a suitable option for Zimbabwe which has recorded low yields of up to 7tha⁻¹ in comparison to world averages of up 37tha⁻¹ due to the use of

recycled seed as well as field production conditions that are not conducive. The objective of the study was to assess growth and yield attributes of new hybrid indeterminate tomato (*Solanum lycopersicum* L.) varieties bred by Haaretz . The experiment was laid in a Randomized Complete Block Design with six treatments replicated three times. Treatments consisted of varieties (3295, 29412, 29202, 3297 and 3298) and Daniella as a control. Data were analysed using GenStat 14th edition and means were separated using Least Significant Difference (LSD) at 5% level of significance. Variety 29202 had the highest plant height (521.70cm) and was significantly different from other varieties whilst variety 3298 had the lowest plant height (418.20cm). Leaf area was highest in variety 29202 (204.55cm²) while 3298(141.10 cm²) recorded minimum leaf area. Significant difference for days to flowering were noticed where 29412 was the earliest hybrid to flower in 17.25days while 3298 was last to flower in 24.667 days. Daniella recorded the highest average fruit weight of 218.30 g whereas lowest average fruit weight was observed in 3298 (120.70 g). Highest yield per hectare was recorded for variety 29202 (142.80tonsha⁻¹) while 3298 achieved the lowest yield of (80.23 tonsha⁻¹). Growers are thus recommended to grow 29202 based on the higher yields obtained as well as utilise tunnel greenhouses however further research is recommended for pest and disease resistance.

Keyword: Tunnel greenhouse production, growth and yield traits, F1 hybrids

4.1 Introduction

The tomato (*Solanum lycopersicon* E.) is a horticultural crop of economic importance globally and in the Zimbabwean context. Tomatoes are a part of every meal in Zimbabwe as a rich source of Vitamin C, and a source of income for rural communities to supplement staple food production (Maboko and Du Ploy, 2008). Improvements in tomato breeding programs have resulted in the development of F1 hybrid indeterminate varieties which have a

prolonged harvesting period as well as being higher yielding (Jawaharlal and Veeraragavathatham, 2003).

The use of F₁ hybrids provides some advantages to growers and consumers, particularly increased yield, earliness, greater fruit uniformity, improved standardization and fruit quality, enhanced pest and disease resistance or tolerance, extended keeping qualities, and reduced seed cost per area unit (Singh et al., 2002). In general, simple hybrid schemes are used to obtain hybrid seeds of self-pollinated species, such as tomato, since homozygous species do not lose their vigour, thus not affecting seed production.

Tomato breeding programs have traditionally focused on developing hybrids with improved yield performance particularly traits related to yield and fruit quality. For that reason, expanding knowledge about the nature and magnitude of correlations between traits of interest is of utmost importance. Selection for a particular trait may either increase or reduce the expression of another trait, depending on the genetic correlation between them (Olanayi, 1999).

If two characters exhibit high genetic correlation, it is possible to obtain a gain in one of them through indirect selection of the other trait (Das et al., 1998). This is advantageous when a character of high economic value has low heritability, when compared to the associated trait. This implies that selection may be based on either the character having high heritability or the one that is more easily evaluated, with the objective of co-inheriting the associated trait. Fruit yield is a complex trait with polygenic inheritance, and correlation studies provide information that selection for one character results in progress for all positively correlated characters (Biswas et al., 2015). Correlation studies in tomato breeding programs are useful when highly heritable traits are associated with an important trait like yield. This chapter deals with experimental findings and discussion obtained during the course of Investigation entitled “ Evaluation of growth and yield characteristics of hybrid indeterminate tomato varieties (*Solanum lycopersicon E.*) under tunnel greenhouse environment in Zimbabwe”. The field experiment was conducted during summer (2018-19) at Pedstock Investments in Harare Zimbabwe.

4.2 Material and Methods

Six indeterminate tomato varieties (treatments) were evaluated under a tunnel greenhouse with 8mm drip liners. The treatments were bred by Haaretz Seeds namely 3295, 3297, 3298, 29412, 29202 and Daniella which was the control as explained in chapter 3. The evaluated growth and yield components were plant height per plant (PH), fruit yield per hectare (FP), leaf area per plant (LA), days to 50% flowering (DF), average fruit weight (FW), polar diameter of fruit (PD), cluster number per plant (CN) and distance between fruit clusters (CD). These traits were evaluated when fruits of the plants of each plot were fully ripe, and a total of five harvests were made in a period of 58 days.

4.2.1 Description of study area

This research was carried out at Pedstock Investments Pvt Ltd which is a trial centre for Haaretz Seeds, representing Southern Africa located in Zimbabwe Harare.

4.2.2 Research Design

The experiment was laid out as a completely randomised block design where each plot had three varieties (treatments). Each treatment was then replicated three times using gradient as the blocking factor. Each plot had ten plants of the same treatment.

4.2.3 Sampling procedure

Three tomato plants were tagged in each plot and the middle three were selected for tagging. This meant that for each variety a total of eighteen plants were sampled for data collection.

4.2.4 Data collection procedure

Data was collected through routine recordings from date of planting, date of transplanting, agronomic procedures done, as well as growth and yield factors namely plant height, leaf area, number of clusters per plant, distance between clusters, days to flowering, plant fruit yield as well as fruit diameter. Two research assistants assisted with crop management as well as data collection.

4.2.4 Data analysis procedure

Data was analysed using GENSTAT 14 and where there are significant differences the means will be separated using the Least Significant Differences at 0, 05 probability levels as well as correlation at 95%. Means were separated using Fisher LSD. Simple correlation analyses were done to find out traits that are positively correlated to yield. A stepwise multiple regression was done to determine the

contribution of the various traits to yield, then a path coefficient analysis was also carried out to estimate the direct and indirect effects of components identified by stepwise multiple regression on yield

4.2.5 Challenges encountered during data collect

Equipment for chemical analysis was not available and analytical laboratories required payments in USD thus limiting chemical analysis of fruit quality. The research site did not have a scale that could measure small weights because of the way it had been calibrated and therefore a suitable scale had to be outsourced to measure fruit weight. Equipment like veneer callipers was also not available and these were outsourced from other research institute.

4.3 Results and Discussion

4.3.1 Plant Height

The different hybrids differed significantly among themselves for the trait plant height at 120 days after transplanting at 5% level of significance. Plant height ranged from 418.20 cm (3298) to 521.70 cm (29202) with an average mean of 474.4 cm (Fig 7 below). The highest plant height was achieved by tomato variety 29202 achieving a height of 521, 70 cm in 120days after transplanting whereas the least was recorded for 3298 (418.20 cm). The grand mean for all varieties was 476.28cm.

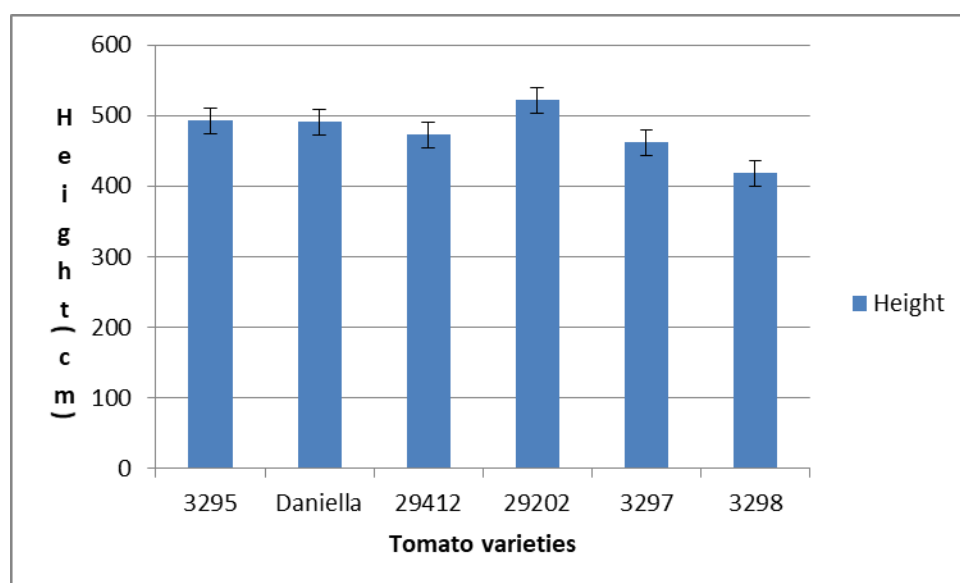


Fig 7: Plant height of different tomato varieties

Previous research indicated that plant height was positively correlated with number of fruit clusters plant⁻¹ and fruit yield plant⁻¹. Chibi et al.(2015) reported similar results of increase in plant height due to partial modification of natural environment and favourable micro climate condition in the commercial greenhouse. The increased temperature and humidity in tunnel greenhouses stimulates accelerated growth in plants (Benton, 2008).

4.3.2 Tomato leaf area

Significant differences were observed for leaf area at $p < 0.005$ with highest leaf area in 29202 (204.55 cm²), while 3298(141.10 cm²) recorded minimum leaf area (Fig 8 below). The average mean leaf area was 176.09 cm.

Leaves play an important role in absorption of light radiation and using it in photosynthesis process, leaf size is influenced by light moisture and nutrients, hence yield depends on leaf area of crop. Similar results were found by Singh (2017) and Sumathi (2013). Leaves enable photosynthesis to occur whereby photosynthesis is the process by which leaves absorb light and carbon dioxide to produce carbohydrate (food) for plants to grow. Having a large surface area is one of the ways in which leaves are adapted to their function of absorbing sunlight (Kumar, 2010).

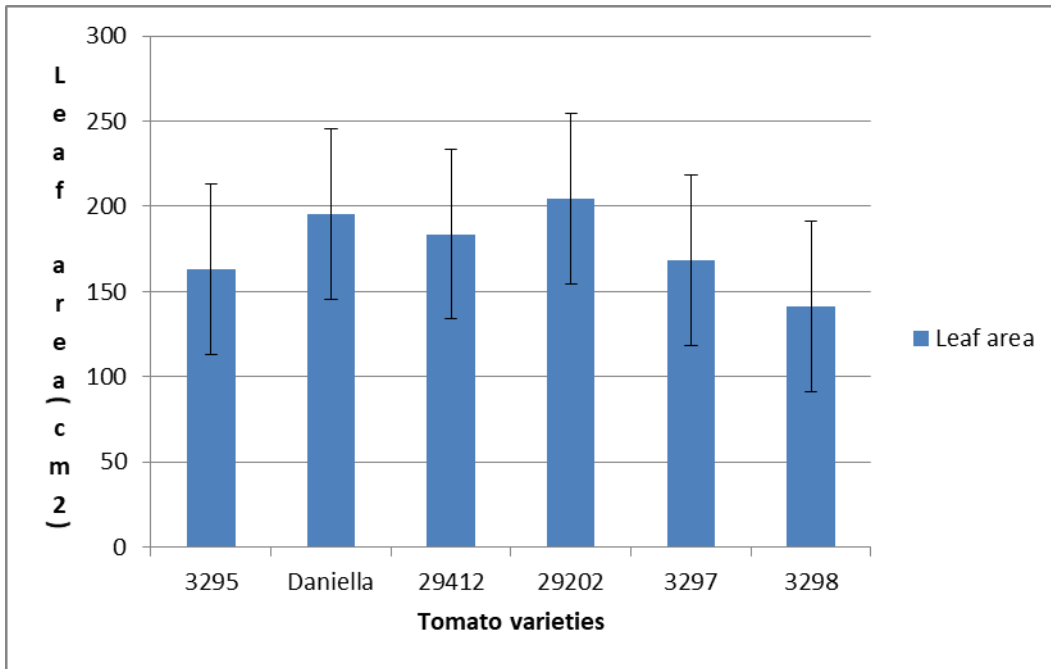


Fig. 8.The leaf area of different tomato varieties in the tunnel greenhouse

4.3.3 Days to flowering

There was significant difference among the hybrids indeterminate tomatoes studied for days to flowering where 29412 was the earliest hybrid to flower followed by 3295 (18.250days), while 3298 was last to flower in 24.667 days.

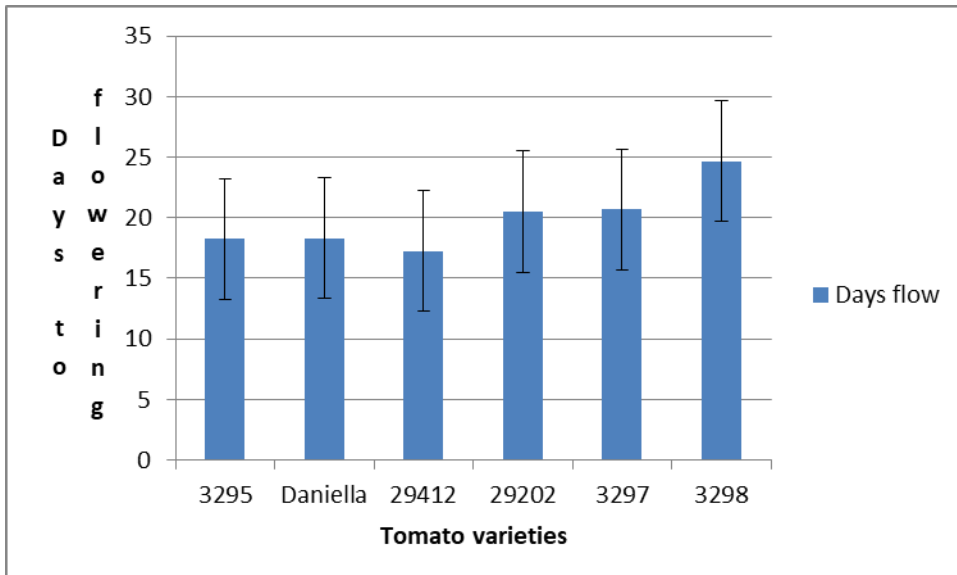


Fig. 9: Days to flowering in relation to the six tomato varieties

Early flowering is an indication of early fruit formation and consequently helps in getting early and high yields. The early flower initiation in 29412 might be due to higher capacity of this variety to make available assimilates to the reproductive site during sensitive phase before flower initiation and conducive micro climate inside the tunnel greenhouse. Similar results of significant differences for days to first flower among genotypes and potential use of these growing conditions for assimilation of photosynthates for early flower initiation was also reported by Arora (2007), Ishwarappa (2011).

4.3.4 Number of fruit cluster per plant

The difference among the hybrids with respect to number of fruit clusters per plant was significant at $p < 0.05$ level of significance (Table 4.4 & Fig 10). Highest number of fruit clusters were observed from 29202 (23.67 clusters) and the lowest number of fruit clusters per plant was recorded in 3298 (14.42 clusters) with an average mean of 19.08 clusters.

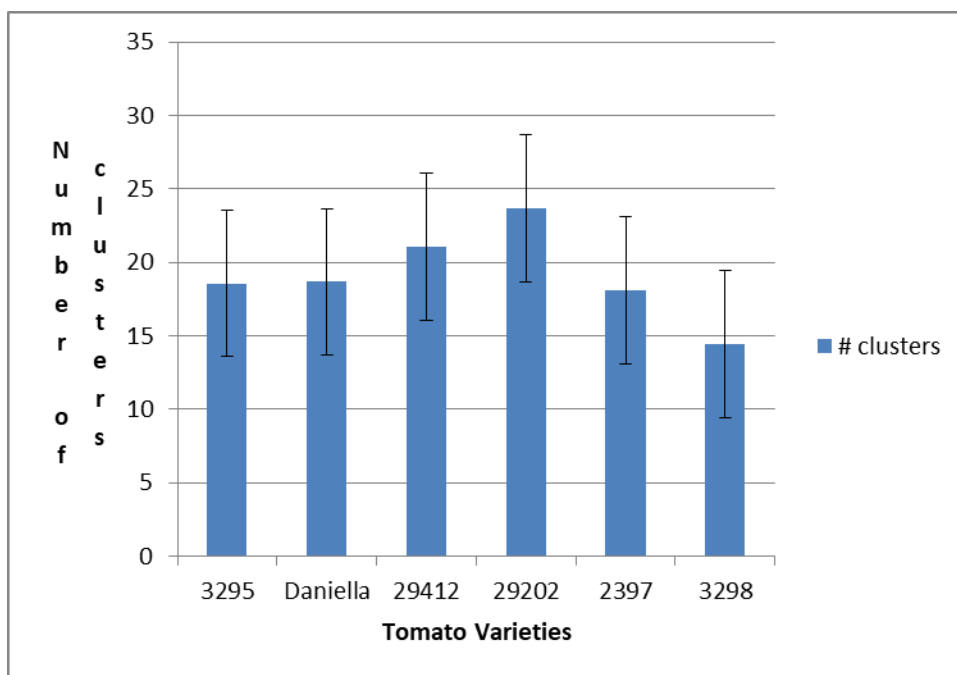


Fig 10: Number of fruit clusters in relation to tomato variety.

Prema *et al.* (2011) observed positive and significant genotypic and phenotypic correlation of average fruit yield per plant with fruit clusters per plant. Singh *et al.* (2004) and Fenny *et al.*

(1991) also observed positive and significant phenotypic and genotypic correlation between tomato yield traits with emphasis on fruit yield and fruit clusters per plant.

4.3.5 Distance between fruit clusters per plant

Distance between fruit clusters per plant of the different plant varieties differed significantly recording highest distance in 3298 (35.29 cm), while 29412 recorded minimum distance between clusters (20.86 cm) (Table 4.5 and figure 11) with an average mean of 29.23 cm. The shorter the distance between clusters the greater the number of fruit clusters per plant. Similar results were observed by Arora, (1982) and Prema et al., 2011).

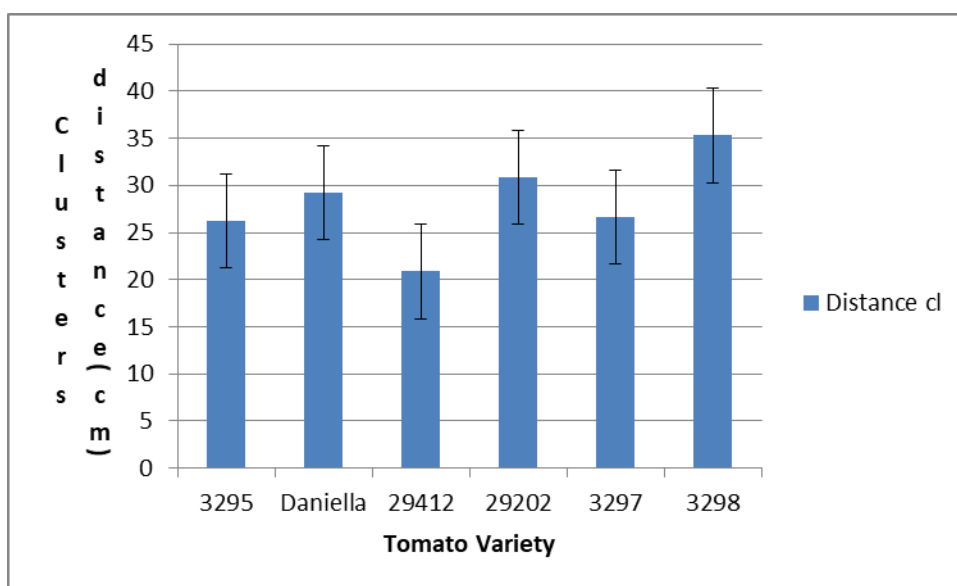


Fig 11: showing Distance between fruit clusters

4.3.6 Average fruit weight

The data pertaining to fruit weight among the varieties is highly significant and presented in (Table 4.6 and fig 12). The hybrid indeterminate 29202 recorded the highest average fruit weight of 218.30g whereas lowest average fruit weight was observed in 3298 (120.70 g).

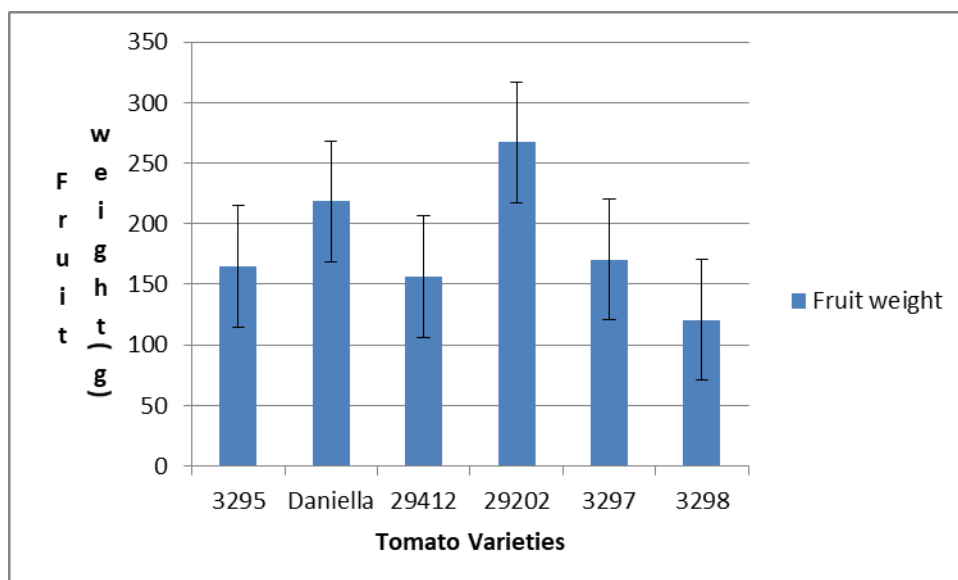


Fig 12: Fruit weight of different tomato varieties under tunnel greenhouse production

Fruit weight is influenced by fertilizers response of cultivars and nutritional status of soil. The highest fruit weight in variety 29202 is attributed to better vegetative growth in terms of leaf area as well as plant height. This may be due to the inherent ability of the hybrids and their better response to tunnel greenhouse conditions. Similar reports of better performance of hybrids due to genetic makeup have been reported by Munshi and Kumar (2000), Singh et al. (2001), Arora et al. (2007) and Razzak et al. (2013) in tomato.

4.3.7 Polar diameter of the fruit

There were no significant differences in the polar diameter of fruits as shown in (table 4.7 and fig 12) below. Highest fruit length of variety 3298, might be due to their genetic character and the response of these varieties to acclimatize to the tunnel greenhouse conditions. Shortest fruit diameter observed in 3297 mainly due to the flattened and round nature of fruits. Similar results of significant variation in fruit diameter of tomato were obtained by Oum (1995).

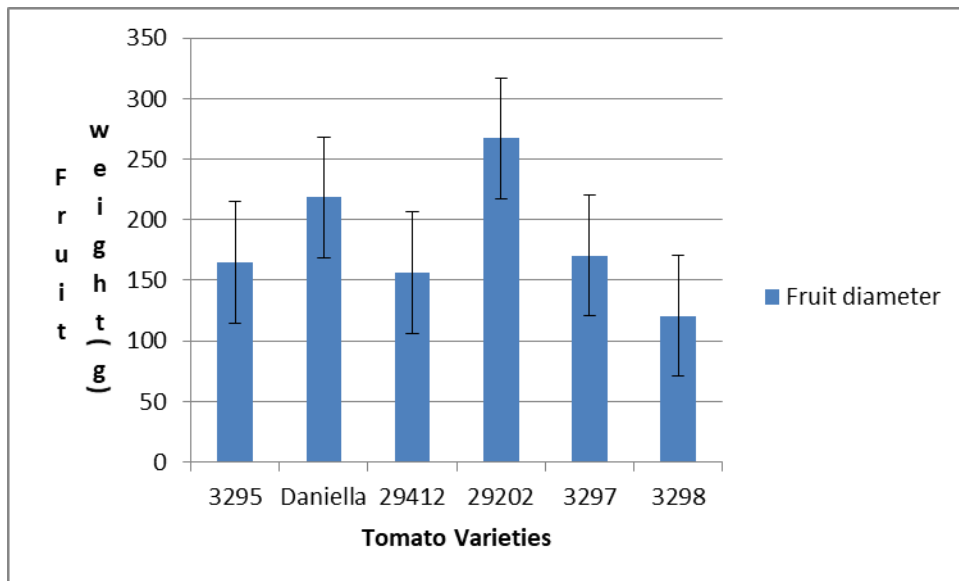


Fig 13: Fruit diameter of different tomato varieties under tunnel greenhouse production

Days to first fruit picking differed significantly among the tomato varieties at $p < 0.005$ level of significance (fig 13). The variety 3295 (62.00 days) took shortest period from transplanting to first fruit picking while, 3298 took maximum number of days (73.33 days) for first fruit picking. Earliness plays important role on fetching higher price and more income. Therefore early varieties are generally preferred for cultivation on commercial scale. Early harvest in this experiment might be due to the varietal response to the congenial growing environment in tunnel greenhouse and early flowering whereas, delayed fruit ripening was due to late flowering. Similar results obtained by Agguire, (2012) in tomato growing in poly house and Prema et al. (2011) in cherry tomato.

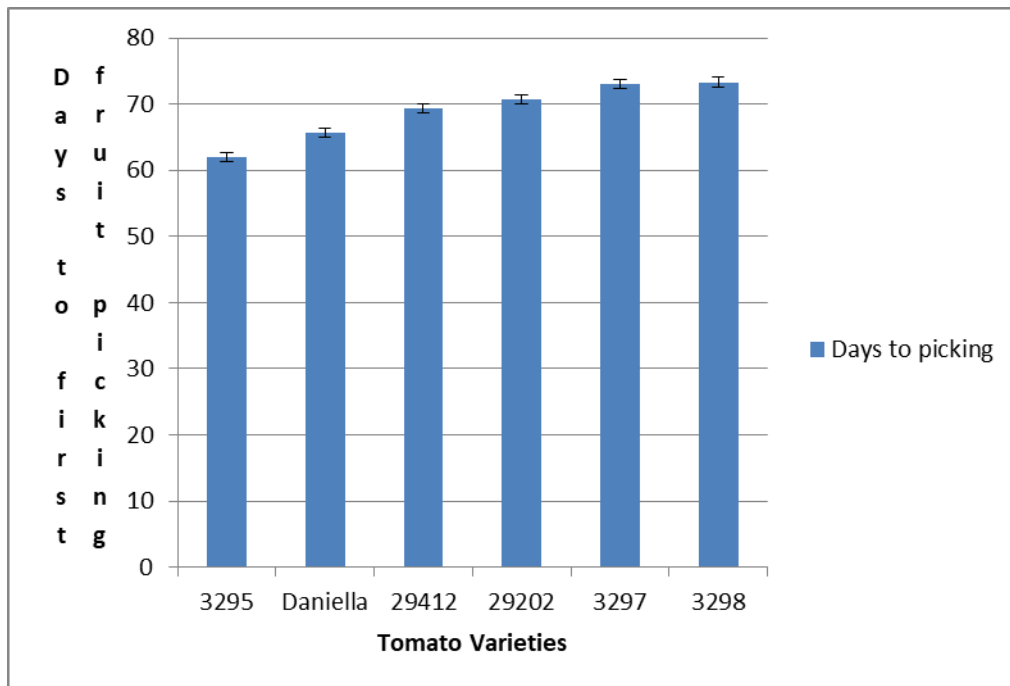


Fig: Days to first fruit picking.

4.3.9 Yield per hectare

The differences among hybrids for yield per hectare were significant at $p < 0.05$ level of significance (Fig 14) where the highest yield per plant was recorded for variety 29202 (142.80 tons/ha) while 3298 achieved a yield of (80.23 tons/ha).

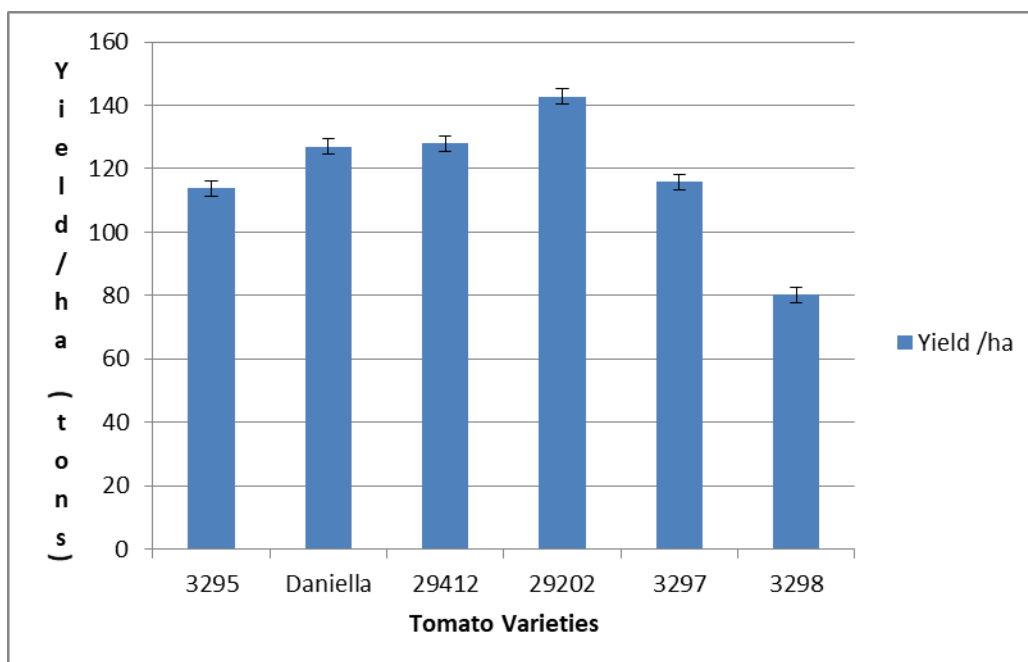


Fig 14: Yield/ha in tonnes for the tomato varieties

The highest fruit yield per hectare for variety 29202 is attributed to better vegetative growth, early flowering, more number of cluster per plant, high average fruit weight, higher fruit set percentage and taller plants over the other variety (Swaroop, K. and Suryanarayana ,2005). This may be due to the inherent ability of the hybrids and their better response to greenhouse conditions. Similar reports of better performance of hybrids due to genetic makeup have been reported by Munshi and Kumar (2000), Singh et al. (2001), Arora et al. (2007) and Razzak et al. (2013) in tomato.

4.4 Recommendations

The experimental results and conclusions are indicative of better findings hence it is recommended that this experiment should be repeated at least for one more year.

1. Growers in Zimbabwe are recommended to grow variety 29202 under tunnel greenhouse which exhibited the highest yield of 142tonsha⁻¹.
2. Variety 3295 exhibited green shoulder amongst the other traits and therefore this is an undesirable trait for tomato production. Growers are therefore encouraged to select varieties that do not exhibit this trait.
3. Environmental factors play an important role in plant growth and development. Weekly harvest was conducted for a period of seven months under tunnel greenhouse conditions and therefore growers are recommended to produce tomatoes under tunnel greenhouse conditions.

4.5 Conclusion

This research showed that there was a relationship between tomato variety leaf area, plant height, fruit weight, number of clusters as well as distance between clusters with the yield per hectare. Hybrid indeterminate variety 29202 showed significantly higher yields of up to 142.80tons ha⁻¹ under tunnel greenhouse conditions compared to the other five tomato varieties including Daniella the control. Tomato variety 29202 therefore has potential to replace Daniella on the market. Considering that the indeterminate hybrids continued to produce fruit for up to eight months under tunnel greenhouse conditions the results show the relationship between environment and length of period of production. Tunnel greenhouses are

therefore efficient in environmental modification despite outside weather conditions Daniella also proved to be a high yielding variety that still has great potential faring second after 29202 as it yielded 127.97tons/ha.

4.6 References

- Ahmad, F., Obedullah, K., Sarwar, S., Hussain, A. and Ahmad, S. (2007). Evaluation of tomato cultivars at high altitude. *Sharad J. Agriculture* 23: 312-14.
- Arora, S. K, Bhatia, A. K, Malik, T. P, Batra, V. K, Yadav, S. P. S, Singh, V. Pand Mehra, R. 2007. Studies on performance of different tomato hybrids (semi indeterminate) in off-season under greenhouse conditions in semiarid zone of Haryana. *Haryana Journal of Horticultural Sciences*. 36(1/2): 111-113
- Aguirre, N. C and Cabrera, F. A. V. 2012. Evaluating the fruit production and quality of cherry tomato (*Solanum lycopersicum var. cerasiforme*). *Revista Facultad Nacional de Agronomia Medellin*. 65(2): 6593-6604.
- Biswas, M., Sarkar, D. R., Asif, M. I., Sikder, R. K, Mehraj H. & Jamal Uddin, A. F. M. (2015). Comparison of Growth and Yield Characteristics of BARI Tomato Varieties. *Journal of Bioscience and Agriculture Research* 03(01), 01-07.
- Olaniyi, J. O., Akanbi, W. B., Adejumo, T. A. and Akande, O. G. (2010). Growth, fruit yield and nutritional quality of tomato varieties. *African J. of Food Sci.* 4(6): 398-402.
- Fayaz, A., Khan, O., Sarwar, S., Hussain, A. and Sher, A. (2007). Performance Evaluation of Tomato Cultivars at High Altitude. *Sarhad J. Agric.* 23(3): 581-585.
- Munshi, A. D and Kumar. R. 2000. Evaluation of tomato varieties under plastic greenhouse during off season. National Seminar on Hi- Tech Horticulture, Bangalore, June. pp 45-49.

- Nahiyan, A. S. M., Momena, K., Mehraj, H., Shiam, I. H., Jamal Uddin, A. F. M. and Rahman, L. (2014). Genetic Diversity of Sixteen Tomato Varieties Grown at Sher-e-Bangla Agricultural University. *Int. J. Bus. Soc. Sci. Res.* 2(1): 39-44.
- Ramesh, K. S and Arumugam, T. 2010. Performance of vegetables under naturally ventilated polyhouse condition. *Mysore Journal of Agricultural Sciences.* 44(4): 770-776.
- Ranganna. S. 2001. Handbook of Analysis of Quality Control for Fruit and Vegetable Products, 2 nd Edition, Tata Mc. Graw Hill.
- Swaroop, K. and Suryanarayana, M. A. (2005). Evaluation of tomato varieties and lines for growth, yield, quality and bacterial wilt resistance under coastal tropical condition of the Andaman Islands. *Tropical Agriculture.* 82: 294-299.

CHAPTER 5

Characterization of the physical traits and shelf life of the indeterminate tomato fruit varieties grown under tunnel greenhouse production.

Abstract

Hybrid indeterminate tomato varieties are a suitable option for Zimbabwe which has recorded low yields of up to 7tha⁻¹ in comparison to world averages of up to 37tha⁻¹ due to the use of recycled seed as well as field production conditions that are not conducive. The objective of the study was to characterise the physical traits and shelf life of hybrid indeterminate tomato (*Solanum lycopersicum* L.) varieties bred by Haaretz as well as characterise the physical traits of the varieties under Zimbabwe conditions. The experiment was laid in a Randomized Complete Block Design with six treatments replicated three times. Treatments consisted of varieties (3295, 29412, 29202, 3297 and 3298) and Daniella as a control. Data were analysed using GenStat 14th edition and means were separated using Least Significant Difference (LSD) at 5% level of significance. Highest shelf life was observed in 3297 (33.75 days) followed while variety 29412 had the shortest shelf life (18.67 days). Presence of green shoulder was observed in variety 3295 only and this is an undesirable fruit quality. Growers that do not have cooling facilities in very hot regions are recommended to grow variety 3297 which had a long shelf life of 33.75 days however yielding 120tha⁻¹ though further research is recommended in terms of disease tolerance and other quality parameters for the two varieties.

Keyword: Tunnel greenhouse production, growth and yield traits, F1 hybrids

5.1 Introduction

Modern food production has placed much emphasis on evolving new varieties in tomato production for increasing productivity as well as quality with respect to shelf life, processing, TSS and lycopene (Chibi et al, 2015). In Zimbabwe, the testing and release of new varieties ultimately leading to their identification and notification is undertaken through a coordinated varietal evaluation trial, generated data on yield, quality, reaction to diseases and pests under field conditions and artificial epiphytes and to assess performance under different agronomic zones (Jackson et al, 1997). Zimbabwe imports the bulk of horticultural seed from other countries as there has been minimum varietal release in the country in the last decade. Different varieties perform differently in different microclimates (SNV, 2016). Tomatoes are highly perishable and therefore shelf life is an important trait as most growers in Africa do not have cold chains to prolong shelf life and reduce huge postharvest losses.

Haaretz seeds are a leading seed producer in the world and seed breeding is done in Italy and Israel mainly for export to other markets. Various methods are followed for varietal identification depending upon the utility of the method, purpose and economics. Considering the importance of varietal identification, Jones (2008) outlined the ideal features of the various methods which include limited environmental influences, capacity for high throughput, less amenable to personal bias and convenience to provide statistically significant results. In order to ensure the rights of the breeders/breeding institutions, protection of genotypes is essential (Veershetty, 2004). For this purpose, it is imperative that these genotypes are fully characterized on the basis of distinct fruit morphological markers. The present research was designed to characterize the physical traits and shelf life of the indeterminate tomato fruit varieties grown under tunnel greenhouse production with particular reference to the fruit.

5.2 Materials and methods

This experiment was carried out in a tunnel greenhouse under drip irrigation where six hybrid indeterminate tomato varieties namely 3295, 3297, 29412, 29202, 3298 and Daniella were grown from seed. After 3 weeks the seedlings were transplanted into planting stations 30cm apart for in-row spacing and 100cm apart inter-row spacing. All agronomic processes were

observed as explained in Chapter 3 until fruits were harvested at weekly intervals at least from 60 days after transplanting.

5.2.1 Description of study area

This research was carried out at Pedstock Investments Pvt Ltd located in Harare as explained in chapter 3. Pedstock has a quality control room where the bulk of postharvest measurements as well as observations were carried out with the assistance from research assistants.

5.2.2 Research Design

This experiment was carried out as a completely randomized block design where gradient was used as a blocking factor as explained in Chapter 3. Six selected plants of the same variety in each block were tagged for data collection.

5.2.3 Sampling procedure

Harvested fruits from the tagged plants were transported to the storage shed according to plant variety on a weekly basis in a wooden crate that was labelled. The fruits were weighed and subsequently graded based on fruit size, colour, bruising as well as shape. Out of each variety five fruits were selected randomly and it is out of these selected fruits that measurements and observations were made. At least five fruits from each variety made a sample.

5.2.4 Data collection

To measure pericarp thickness harvested fruits were cut at the equatorial plain and the pericarp thickness was measured with the use of vernier callipers and expressed in centimetres. Five fruits per plant from one of the tagged plants were used for recording the observation. Shelf life of the different tomato varieties was observed where harvested fruits at red ripe stage were kept in room temperature and observed for days till the consumption stage was over and shelf-life in days was recorded.

Exterior colour of immature fruit was also recorded on 5 tagged plants of each hybrid indeterminate tomato before maturity and grouped into four major groups namely.

- 1 Greenish-white
- 2 Light green
- 3 Green
- 4 Dark green
- 5 Very dark green

Presence of green shoulder on fruit-It was recorded on 5 plants of each hybrid before maturity and grouped into the following groups:

0 Absent (uniform ripening)

1 Present (shoulders on the upper part of the fruit, around calyx - are green while pistil area of the fruit is red)

Fruit homogeneity within a plant -Ripe fruits were harvested from individual plant at maturity, observed visually for homogeneity and grouped into:

1 Low

2 Intermediate

3 High

Exterior colour of mature fruit- Five fruits were harvested at maturity from five plants from each hybrid and observed the colour under constant white light and grouped into:

1 Green

2 Yellow

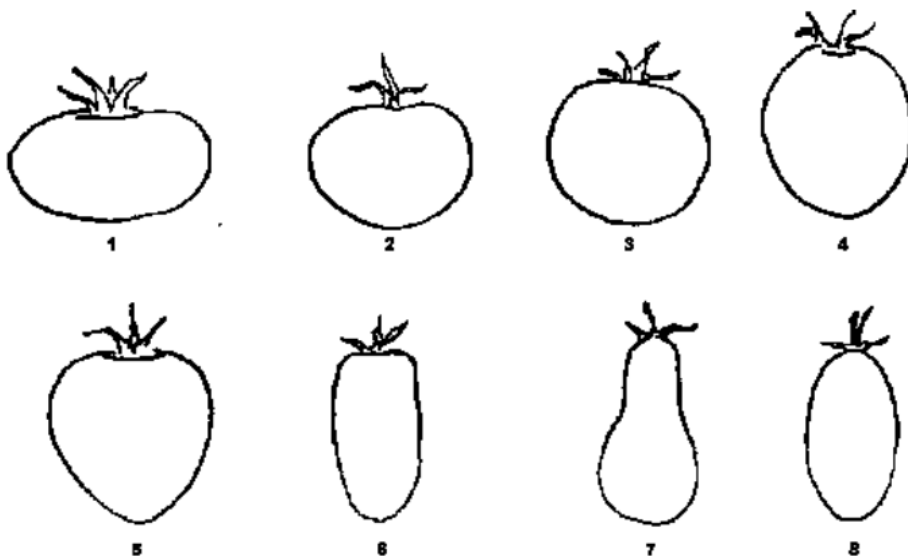
3 Orange

4 Red

5 Pink

6 Other

Fruit shape was also determined based on the below diagrams:



1) Flattened (oblate)

2) Slightly flattened

3) Rounded

4) Highly rounded

5) Heart shaped

6) Cylindrical

7) Pyriform

8) Ellipsoid (plum shaped)

5.2.5 Challenges encountered during Data collection

At 50 days after transplanting Tuta Absoluta infestation was spotted which affected the quality of fruits as some had been bored into. However, chemicals were imported from Zambia and within a week the pest was under control. Restricted entry was also implemented to prevent transfer of diseases from other greenhouses into the experimental tunnel greenhouse.

5.3 Results

5.3.1 Shelf life

Significant difference in shelf life or keeping quality was observed under room temperature (from red ripe to softening stage) at $p < 0.005$ level of significance. The fruit of hybrid 3297 (33.75) had the longest shelf life while the shelf life was shortest for 29412 (18.67 days).

The variation in keeping quality was mainly due to their pericarp thickness and firmness. This is an agreement with (Kumar, 2010) who reported that the pear shaped tomato cultivars are preferred over round shaped, because of longer keeping quality and are therefore better suited for canning and processing purposes. They further reported that pericarp thickness and firmness were important characters that give ideal storage behaviour of the fruits (Biswas et al., 2015). The difference among the varieties in pericarp thickness of fruits might be due to the genetic constitution of the varieties. These results are in good agreement with the finding of Swaroop and Suryanarayana (2005) and Ahmed et al. (2007).

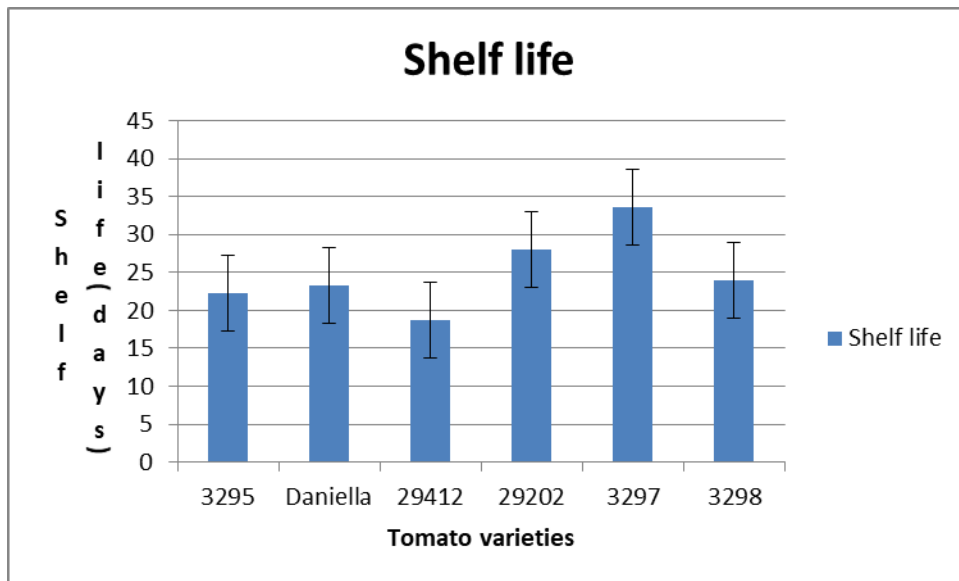


Fig. 15: Shelf life of different tomato varieties

5.3.2 Fruit pericarp thickness (cm)

Pericarp thickness was highest in 3297 (0.98 cm) whereas the lowest was observed in 29412 (0.81 cm) as shown in (Fig 16). Fruit firmness and pericarp thickness are related to the genotype. Similar results were observed by Singh (2017). Higher pericarp thickness and firmness also improves shelf life (Olaniyi et al., 2010). Pericarp thickness should be more than 6 mm for transportation and canning (Kumar, 2010). Haaretz varieties are bred for long shelf life as they are targeted for export as well as have to endure long periods of transportation to foreign markets (www.haaretz.com).

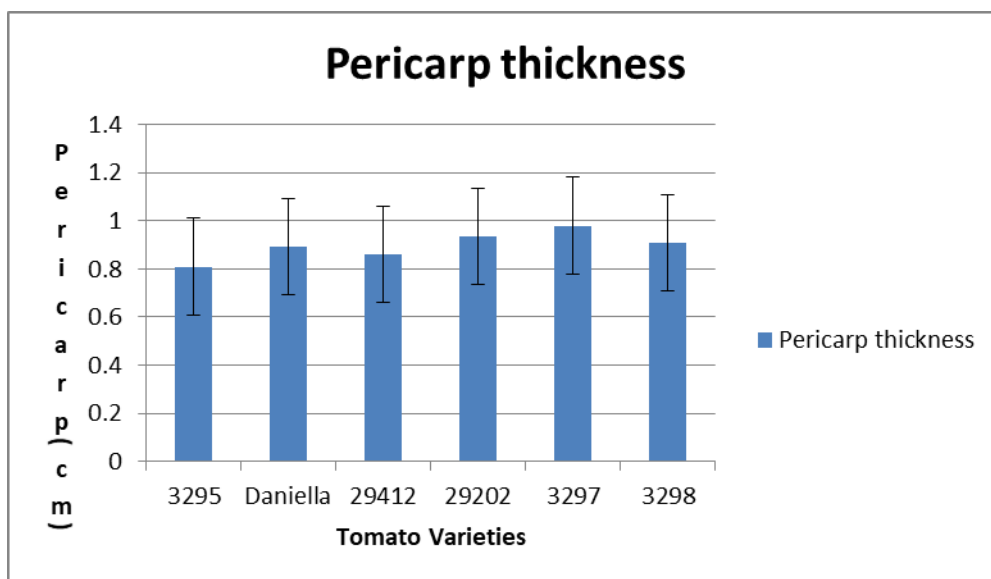


Fig. 16: Fig Pericarp thickness of tomato varieties

5.3.4 Presence of green shoulder on the fruit

Hybrid indeterminate variety 29412 showed presence of green shoulder (greenback) while, other hybrids showed uniform ripening (Fig 17). The presence of green shoulder is an undesirable quality as it usually affects palatability of fresh fruits, marketability as well as cooking quality of soups and in most instances the green patches need to be removed before consumption. Certain varieties are not prone to this phenomenon whereas other varieties are resistant to green shoulder. Typically green shoulder is common in field grown tomatoes that are exposed to excess sunlight, high temperatures and insufficient feeding during maturation and ripening (Ahmed, 2010). Generally greenhouse tomatoes are more prone to greenback.

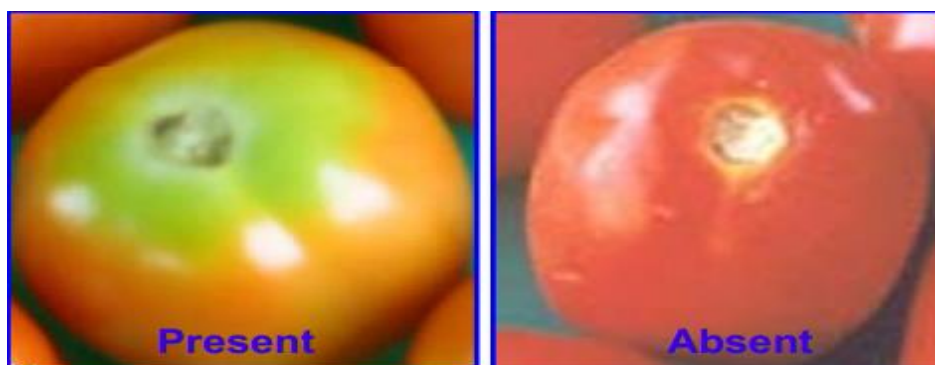


Fig. 17: Pictures showing presence and absence of green shoulder on fruit (Biswas et al, 2015).

5.3.5 Exterior colour of immature fruit

Grouping of hybrids based on exterior colour of immature fruit was also observed for all plant varieties based on Fig 18 below. Daniella, 3298, 3297, 29202, 3295 were distinct by their dark green colour while, 29412 had a green colour. This character can be employed to identify these hybrids before maturity (Ahmed et al, 2007).



Fig.18 Exterior colour of immature fruit (Biswas et al, 2015)

5.3.6 Exterior colour of ripened fruit

Observations were also made for the exterior fruit colour as based on colour indicators shown on Fig 19 below at the full ripe stage. Tomato variety 3295 and 29412 indicated intermediate colour at ripening whereas varieties Daniella, 29202, 3297 and 3298 indicated a dark red colour. The colour of the tomato at full ripe stage is essential for the end use of the tomatoes. Dark red colours are well suited for processing as well as making soups and sauces according to Ferreira et al., (2004).



Fig.18. Exterior colour of ripe tomato fruit and how it was graded.

Results of the experiment showed that variety 3295 and 29412 had intermediate exterior colour as shown on the table 5.1 below however varieties Daniella, 29202, 3297 as well as 3298 exhibited a dark red colour at full ripe stage.

Table 5.1: Exterior colour of tomatoes at full ripe stage.

Light	Intermediate	Dark
	3295	Daniella
	29412	29202
		3297
		3298

5.3.7 Predominant fruit shape

There was variation observed among hybrids with reference to fruit shape. Hybrids were grouped into nine groups based on predominant fruit shape. Results of the study showed variation in fruit shape among the hybrids. 3295 was slightly flattened whereas 3297 and 3298 were heart shaped, and Daniella, 29412, 29202 were all rounded. Consumer preference depends on fruit shape and size. It is also important for transportation purpose. Fruit shape is the most promising character which can be visualized by naked eye and can be utilized for identification of tomato cultivars during field inspection as well as marketing purposes. The round character is promising as it is stable and not influenced by biotic and abiotic stresses and more useful in cultivar differentiation as shown by Yue and Tong, (2009) in tomato, Arya and Saini (1976). However, differences were not very apparent between secondary fruit shape and primary fruit shape and were almost same.

5.3.8 Fruit size homogeneity

Fruit size homogeneity is a characteristic observed on size of fruit from first harvest up to the last harvest and below is the table 5.2 showing homogeneity for the tomato varieties studied.

Table 5.2: Homogeneity of fruits

Low	Intermediate	High
3295		29412

	3298	
Daniella		
29202	3297	

5.5 Recommendations

1. It is recommended that growers who are concerned with green shoulder should not grow 3295 variety.
2. Further it is recommended that for growers that are interested in long shelf life they should grow 3295 which had the longest shelf life as well as biggest pericarp thickness.

5.6 Discussion

Consumers of products are interested in the quality of the product they consume and the producers are worried more about yield (Medina et al, 2017). In marketing of products perception is a powerful tool for establishing and maintaining brand loyalty as well as ensuring increase in volumes consumed. The quality of a product, especially food is about appearance, shelf life, smell, taste as well as palatability (Yue and Tong, 2009). Tomato varieties that do not have a green shoulder are more appealing to customers and all varieties except 3295 did not have this trait. Fruit shape affects shelf life as well as use of the tomatoes (Das et al, 2008).

There will always be a need for increased productivity because of increasing world population. The world's population is projected to reach 9 billion people by 2050 and as such one of the first steps in increasing productivity is availability of high quality seed, which should be genetically pure, high yielding, and disease free, produce rapid uniform seedlings, adapted to existing climates and should confirm to varietal identity after establishment (Bertelli and Macours 2014)Perez et al. Dietary preferences continue to change over the years with increasing incomes, health awareness as well as the development of the internet and e-

commerce that has turned the world into a global village and this has positively influenced consumption of tomatoes.

5.7 References

- Aoun, B. A., Lechiheb, B., Leila, B. and Ferchichi, A. 2013. Evaluation of fruit quality traits of traditional varieties of tomato (*Solanum lycopersicum*) grown in Tunisia. African Journals of Food Science. 7 (10): 350-354.
- Arora, S. K, Bhatia, A. K, Malik, T. P, Batra, V. K, Yadav, S. P. S, Singh, V. P and Mehra, R. 2007. Studies on performance of different tomato hybrids (semi indeterminate) in off-season under greenhouse conditions in semiarid zone of Haryana. Haryana Journal of Horticultural Sciences. 36(1/2): 111-113.
- Dorais, M, Papadopoulos, A. P and Gossein, A, 2001. Green house tomato fruit quality. Horticulture Reviews. 26: 239-270.
- Ferreira, S. M. R.; Freitas, R. J. S.; Lazzari, E. N. Identity and quality standards of tomatoes (*Lycopersicon esculentum* Mill.) for fresh consumption. Ciência Rural, v.34, p.329-335. 2004.
- Kaiser, C. and M. Ernst.(2017). High Tunnel Tomatoes. CCD-CP-62. Lexington, KY: Center for Crop Diversification, University of Kentucky College of Agriculture, Food and Environment. Available: <http://www.uky.edu/ccd/sites/www.uky.edu/ccd/files/hightunneltomatoes.pdf>.
- Kiya,M., Mataa, M., and Nguz, K., 2007. Influence of the stage of maturity at harvesting on quality and shelf-life of tomato (*Lycopersicon esculentum* Mill.).University of Swaziland. Research journal of Agriculture science and technology, Volume 10: 93-98.

- Kumar, R. A, Vijayalatha, K. R, Alagesan, A and Veeraragavathatham, D. 2007. Performance of certain tomato (*Lycopersicon esculentum*) genotypes under greenhouse and open conditions in summer. *Journal of Ecobiology*. 19(2):105-112.
- Kumar, S. R, and Arumugam, T. 2010. Performance of vegetables under naturally ventilated polyhouse condition. *Mysore Journal of Agricultural Sciences*. 44(4): 770-776.
- Maboko, M. M., DU Plooy, C. P and Bertling, I. 2011. Comparative performance of tomato cultivar cultivated in two hydroponic systems. *South African Journal of Plant and Soil Sciences*. 28(2): 97-102.
- Maboko, M. M and Du plooy, C. P. 2008. Effect of pruning on yield and quality of hydroponically grown cherry tomato (*Lycopersicon esculentum*). *South African Journal of Plant and Soil Sciences*. 25:178-181.
- Swaroop, K. and Suryanarayana, M. A. (2005). Evaluation of tomato varieties and lines for growth, yield, quality and bacterial wilt resistance under coastal tropical condition of the Andaman Islands. *Tropical Agriculture*. 82: 294-299.
- Upadhyay, M., J.P. Singh., A. Singh and A. Joshi. 2005. Studies on genetic variability in tomato (*Lycopersicon esculentum* Mill.). *Prog. Hort.* 37(2): 463 – 468.

CHAPTER 6

6.1 Introduction

Tomato (*Solanum Lycopersicum* L) is a crop of both nutritional and economic importance in Zimbabwe where they are a part of every meal as well as a source of livelihood for many small scale farmers dotted across the country. Worldwide the tomato fruit is used as a fresh salad vegetable, popular ingredient in soup, stews, and sauces, various other dishes and has become a major source of several plant nutrients providing important nutritional value to the human diet (Singh et al., 2017). Tomatoes are widely cultivated in tropical, sub-tropical and temperate climates through environmental manipulation to achieve higher yields and quality

as well as prolonging the production season thus assuring a consistent supply to the market. Hybrid tomato varieties can either be determinate or indeterminate in their genetic makeup however, F1 hybrids are renowned for their consistency as well as stability in terms of production. This research was carried out to evaluate the performance of hybrid indeterminate varieties (Radzevicius et al. 2009).

6.2 Summary

The investigation entitled “Evaluation of growth and yield characteristics of hybrid indeterminate tomato (*Solanum Lycopersicum L.*) varieties under tunnel greenhouse production in Zimbabwe” was conducted at Pedstock Investments Pvt Ltd located in Harare, Zimbabwe from August 2018- May 2019. The experiment was laid out in a completely randomized design with three replications and six treatments consisting of varieties, 3295, 29214, 29202, 3297, 3298 and Daniella which was the control. The significant findings of the study at $p < 0.05$ level of significance summarized below:

- 1) Among the tomato varieties studied, the maximum plant height was recorded by tomato variety 29202 achieving a height of 521, 70 cm in 120 days after transplanting, and the least was (418.20 cm). The grand mean for all varieties was 476.28 cm. Significantly highest leaf area was recorded in 29202 (204.55 cm²) whereas 3298 (141.10 cm²) recorded minimum leaf area. There was significant difference among the hybrids indeterminate tomatoes studied for days to flowering however the general trend was that all the varieties flowered within a 7 day period where 29412 (17.25 days) was the earliest hybrid to flower while 3298 was last to flower in 24.667 days.

Significant differences among the hybrids with respect to number of fruit clusters per plant were recorded where highest number of fruit clusters was observed from 29202 (23.67) and the lowest number of fruit clusters per plant was recorded in 3298 (14.42). Distance between fruit clusters per plant of the different plant varieties differed significantly recording maximum distance in 3298 (35.29 cm), while 29412 recorded minimum distance between clusters (20.86 cm). Significant differences

were noted on data pertaining to average fruit weight were hybrid indeterminate Daniella recorded the highest average fruit weight of 218.30 g, whereas lowest average fruit weight was observed in 3298 (120.70 g).

The mean number of days taken for first fruit picking differed significantly where variety 3295 (62.00 days) registered shortest period from transplanting to first fruit while, 3298 took maximum number of days (73.33 days) for first fruit harvest. Significant differences among hybrids for yield per hectare varied where the highest yield per hectare was recorded for variety 29202 (142.80 tons/ha) while 3298 achieved a yield of (80.23 tons/ha).

- 2) Significant difference in shelf life or keeping quality was observed under room temperature (from red ripe to softening stage) among the varieties with an average mean of 25.00 days. The fruit of hybrid 3297 (33.75) had the longest shelf life followed by 29202 (28.00 days), while the shelf life was shortest for 29412 (18.67 days). Pericarp thickness was highest in 3297 (0.98 cm) whereas it was lowest for 29412 (0.81 cm). Presence of green shoulder was only observed in variety 3295

6.3 Conclusion

- The results clearly indicated that growth and yield characteristics of experimented six tomato varieties varied despite similar environmental and cultural conditions among the varieties of tomato tested 29202 performed better than the other five varieties however closely following was Daniella and therefore farmers can grow 29202 preferably.
- Growing indeterminate hybrid tomatoes under tunnel greenhouse conditions showed very high yields under Zimbabwean conditions as such, the use of these tomato varieties is greatly encouraged over use of convectional seed and determinate varieties. The practice should be readily adopted especially by commercial growers as well as suitable for export because of the long shelf life.
- Days to first fruit set, days to first flowering, number of clusters, distance between clusters, fruit weight, plant height as well as leaf area were found to be significantly higher in varieties that had higher yields per hectare.

- Shelf life of fruit and pericarp thickness were closely linked such that varieties with greater pericarp thickness had a longer shelf life.

6.4 Policy implication and recommendations

- All new varieties especially of imported seed should be tested for at least three successive years for varietal consistency as well as stability before they are sold on the market for growers to access.
- There is need for promotion of hybrid indeterminate tomato variety for export under controlled environments in order to secure foreign markets as well as improve tomato yields in the country.

6.5 Suggestions for future research work

The experimental conclusions are indicative of better findings hence it is suggested that this experiment should be repeated/replicated and scaled up at least for another two seasons.

1. The varieties should be tested under field condition to finally verify the stability of varieties.
2. Environmental factors play an important role in plant growth and development. The genotypic traits should be repeated in different natural regions of the country under the same conditions during the same period to obtain conclusive results.
3. The tomato varieties should be screened for their response to different doses of nutrients applied through fertigation so that their nutrient uptake ability and utilization can be better assessed.
4. Experiment should be conducted to study the effect of controlled environment on biochemical aspects namely Total Soluble Solids, acidity, ascorbic acid, lycopene content, starch content, reducing sugar, total sugar and chlorophyll content.

6.6 Appendices

APPENDIX 1: ANOVA TABLE FOR PLANT HEIGHT AT 120 DAYS AFTER TRANSPLANTING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	44.8	22.4	0.05	
Variety	5	17734.5	3546.9	7.17	0.004
Error	10	4950.1	495.0		
Total	17	22729.4			

APPENDIX 2: ANOVA TABLE FOR LEAF AREA FOR THE DIFFERENT VARIETIES

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	1.175	0.587	0.07	
Variety	5	8101.218	1620.244	185.03	<.001
Error	10	87.567	8.757		
Total	17	8189.959			

APPENDIX 3: ANOVA TABLE FOR DAYS TO FIRST FLOWERING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	0.2986	0.1493	1.24	
Variety	5	104.3611	20.8722	173.73	<.001
Error	10	1.2014	0.1201		
Total	17	105.8611			

APPENDIX 4: ANOVA TABLE FOR NUMBER OF FRUIT CLUSTERS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	0.3333	0.1667	0.39	
Variety	5	144.6250	28.9250	67.40	<.001
Error	10	4.2917	0.4292		

Total	17	149.2500
-------	----	----------

APPENDIX 5: ANOVA TABLE FOR DISTANCE BETWEEN FRUIT CLUSTERS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	0.0858	0.0429	0.17	
Variety	5	356.8621	71.3724	275.08	<.001
Error	10	2.5946	0.2595		
Total	17	359.5425			

APPENDIX 6: ANOVA TABLE FOR DAYS TO FIRST FRUIT PICKING

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.0000	0.5000	0.65	
Variety	5	293.3333	58.6667	76.52	<.001
Error	10	7.6667	0.7667		
Total	17	302.0000			

APPENDIX 7: ANOVA TABLE FOR DISTANCE FRUIT DIAMETER

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	7.8958	3.9479	5.31	
Variety	5	2.3229	0.4646	0.62	0.685
Error	10	7.4375	0.7438		
Total	17	17.6563			

APPENDIX 8: ANOVA TABLE FOR FRUIT WEIGHT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	0.7400	0.3700	0.83	
Variety	5	401.9888	80.3978	181.01	<.001
Error	10	4.4416	0.4442		
Total	17	407.1704			

APPENDIX 9: ANOVA TABLE FOR YIELD PER HACTARE IN TONS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	11.242	5.621	0.60	
Variety	5	6733.392	1346.678	144.31	<.001
Error	10	93.321	9.332		
Total	17	6837.955			

APPENDIX 10: ANOVA TABLE FOR SHELF LIFE IN DAYS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replications	2	8.3333	4.1667	9.62	
Variety	5	405.3333	81.0667	187.08	<.001
Error	10	4.3333	0.4333		
Total	17	418.0000			

APPENDIX 11: ANOVA TABLE FOR FRUIT PERICARP THICKNESS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0003444	0.0001722	0.72	
Variety	5	0.0519778	0.0103956	43.52	<.001
Error	10	0.0023889	0.0002389		
Total	17	0.0547111			
