# Growth Responses of Tomato (*Lycopersicon esculentum* Mill) to Different Growing Media under Greenhouse and Field Conditions

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DEPARTMENT OF PLANT SCIENCES

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I, Mutumpike Mabengwa, declare that this thesis represents my own work and that it has not been previously submitted at this or any other University.

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# APPROVAL

This dissertation of Mutumpike Mabengwa is approved as fulfilling the requirements for the award of the degree of Master of Science in Agronomy by the University of Zambia

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## ABSTRACT

Green houses provide opportunity for year round crop production. Although tomatoes are an option for utilizing greenhouse space, performance of tomato under these conditions has potential limitations which may include root restriction and its attendant impacts such as artificial media effects on varietal characteristics. Decline in profitability of rose production for which greenhouses in Zambia were used has left excess capacity. Tomatoes provide a profitable option for farmers. A study was conducted was to evaluate growth responses of tomato grown in different growing media under controlled environment (greenhouse) and Field conditions of three tomato varieties (Star 9030, Tengeru and Rodade) under different growing media (Peat in sleeve, Coccus in sleeve, Coccus in trough, Soil in sleeve and Soil bed). The experiment was conducted at the Natural Resources Development College in Lusaka between May to October 2011. Two experiments were carried out; the first one was a Greenhouse study under an open sided naturally ventilated Plastic greenhouse. The experimental design adopted was a Split plot design where, varieties were assigned to the main plots and the media to subplots. The field experiment involved the same varieties planted directly into the soil but used a Randomized Complete Block Design. The parameters measured included vegetative variates i.e. plant height and root/ canopy ratio; reproductive variates were; total fruit number per plant and total yield. Fruits were harvested at breaker stage when the skin colour was 30% pink red. Fruit quality parameters including shape (indicated by the ratio of fruit diameter to height) and Brix (Total soluble solutes content). The results from the study showed that: In the greenhouse Star 9030 grown in soil bed grew taller than the other 2 varieties. The trend of these results was significant from 4 weeks after transplanting. The total fruit number and weight of Star 9030 grown in soil bed (29 and 19.5t/ha) was significantly higher than Rodade (14 and 8t/ha) and Tengeru (24 and

15t/ha) compared to other media ($p \leq 0.001$), whilst the root: shoot ratio was not significant different among the cultivars and media. The total soluble solid content expressed as Brix was significantly different between varieties, Tengeru with 5.0 was highest followed by Star 9030 with 4.0, Rodade with 3.5. ). Fruit diameter: height ratio was not different between Rodade and Tengeru but significantly lower than Star 9030 whilst the effect of media showed no significant differences. In comparison to the greenhouse results, the field experiment performance was as follows; the mean fruit weight was; Star 9030 (12 t/ha), Rodade (5 t/ha) and Tengeru (10 t/ha) whilst total soluble content at 4.7 for Star 9030, 3.5 for Rodade and 3.7 for Tengeru was not significantly different among the different varieties .

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## DEDICATION

I dedicate this work to my wife Annie, and my children Chileshe, Musonda, Kasonde and Mapalo.

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**Chapter 1**

# 1. INTRODUCTION

Agriculture is an important and growing sector of the Zambian economy (National Agricultural Policy, 2003). Within the agricultural sector, horticultural production has experienced significant growth recently (GRZ, Fifth National Development Plan, 2006). Despite the recognition by many growers of the value of vegetable production, the majority of the small holders are however often discouraged by among many reasons the low yields attained with most vegetable crops. The choices in Zambia that constitute the main vegetable commodities include the following major vegetable crops (Hichaambwa et al 2009) with their potential tonnages; Tomato-*Lycopersicon esculentum* (25-50 tons/ha), Cabbage-*Brassica oleraceae* (30-70 tons/ha), Rape-*Brassica napus* (20 tons/ha), Onion-*Allium cepa* (25-30 tons/ha), Beans-*Phaseolus vulgaris* (5-10 tons/ha), Lettuce-*Lactuca sativa* (15 tons/ha), Carrots-*Daucas carota* (30-40 tons/ha) and the Melons-*Citrullus lanatus* (20-35 tons/ha) (Mingochi, 2000). Maintaining optimum temperature, plant nutrition, water, humidity, solar radiation, Light and Day-length are among some factors that affect the growth of these vegetable crops in specific ways (Johns 2007). Due to these factors, variation is often observed in the performance of different crops, and even between cultivars within the same crop, with respect to rate of growth, vulnerability to pests/diseases, as well as yield and quality of the produce (Mingochi, 2000). Knowledge of how these factors interact with the crop is necessary for making correct management decisions in situations where corrective measures are required. Therefore controlled production systems such as under greenhouses would provide opportunities for year- round agricultural production. The cultivation of greenhouse crops is the most intensive form of production (Johns, 2007). In Zambia like other emerging agricultural based economies, investment in greenhouse production for high value commodities like roses (*Rosa* spp) and other flower commodities was preferred. However, high freight charges and an initial rapid appreciation of the national currency impacted negatively on this sub sector (Mataa and Munguzwe, 2011). The decline in profitability of rose production forced growers to move out of flower production and this situation has left excess capacity of greenhouse utilization in Zambia. Possibly, investment in other commodities such as tomato may provide a profitable option for using greenhouses as the greenhouse environment optimize crop production environment thereby providing optional use of high capital investment and boosts farmer income (Johns, 2007). For instance, the production per cultivated unit area of greenhouse tomatoes can be in excess of 50 $kg/m^2$ which are 10 times superior to that of field crops (Canadian encyclopedia, 2010). Tomato is a popular fruit vegetable in many parts of the world. It is particularly rich in pigments and secondary metabolites like lycopene (red pigment in tomato fruit) - a strong anti carcinogen, and Vitamin C (Sams et al, 2011). It is widely grown although consumption and preparation methods differ in various countries. In Zambia tomatoes are cooked as a relish, on its own or stewed with onions or are used as a condiment of almost all relishes (Unicef, 2006) In Zambia, much of the tomato is produced for the fresh market and consumed as a component of relishes (Mubita, 1997) and is an important vegetable grown by both commercial and small scale farmers (Luchen, 1997) in open fields. The physical and chemical characteristics of the soil or artificial media, the greenhouse internal environment and the nature of the plant (cultivar selection) determine the most critical productivity parameters for plant growth (Johns, 2007).

Tomato is a herbaceous annual with a creeping stem covered with single hairs. The plants are characterized either as indeterminate or determinate types based on plant habit and vigor (Papadopoulos, 1995). The determinate types eventually form a flower cluster at the terminal growing point, causing the plant to stop growing in height (Papadopoulos, 1995). Determinate tomatoes are bushy and usually stop growing at about 1.5 m (Anon 2011). The leaves are compound and alternate. 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 (Unicef, 2006).

In Zambia some of the common varieties grown include Rodade, Heinz, Money maker, Star 9030 and Tengeru (Ayres, 1998 and AVRDC, 1990). Rodade is semi-determinate, bearing very firm, medium sized fruit, have long bearing period and are resistant to Bacterial wilt as well as Verticillium and Fusarium (Ayres, 1998). Heinz is medium-sized, medium firm fruit, borne on plants providing good cover and resistant to cracking (Ayres, 1998). Star 9030 is an indeterminate tomato hybrid with vigorous growth for winter production. It has good resistance against disease for summer production and has above average fruit size (Ayres, 1998). Tengeru has a long growth period up to over 12 months and take 3 months from planting to harvest. They grow up to 2.5 meters tall and yields between 25 and 50 tons/ha (Mingochi, 2000).

Under high intensity precision horticultural production systems, artificial media is used instead of direct soil planting because plants grow well in media that will hold water as evenly as possible and provide sufficient nutrient holding capacities. Un even uptake of water can cause many problems including damping off, flower drop, fruit splitting and blossom end rot (Gardener, 2011). Greenhouses provide environmental control that includes both the soil and above ground micro environment.

The main objective of the study was to evaluate growth responses of tomato grown in different growing media under controlled environment (greenhouse) and Field conditions.

Specifically the study:

i. Determined how different growing media impact on growth and development of tomato varieties;

ii. Compared responses among tomato varities in the greenhouse controlled environment and those grown in open field conditions.

Chapter 2

# 2. LITERATURE REVIEW

## 2.1. Plant Development and 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 Mohr and Schorpe, 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 (Manuel 2012).

Developmental homeostasis describes a phenomenon that an organism is able to *maintain* a structured development precisely *regulated* in time and space and *independent* of specific environment influences. Implicit here is the fact that important organism functions are constant.

Development can be looked at from an analytical framework.

*i. Growth*

Generally considered to be an increase in a growth trait. Growth can be looked at two perspectives; need for essential factors (preconditions for growth) and actual regulating factors-growth regulators and light. Growth proceeds as an *irreversible* increase in growth traits and or system enlargement.

Growth involves the following: - increase in length, diameter, cell number, fresh matter, dry matter, total protein or amount of DNA. However a number have to occur together if growth is assumed to be taking place. Any quantitative change in any of these parameters can be used to measure growth. Therefore, plant growth is the process by which a plant increases in the number and size of leaves and stems. This is achieved through process where chlorophyll the green pigment in the plant's leaf absorbs energy from sunlight and using this energy, water and carbon dioxide, produces oxygen and simple sugars. It has commonly been observed and modelled that an increase in $CO_2$ concentrations from 400 µmol.mol$^{-}$ to 800 µmol.mol$^{-}$ results in large (15% to 50%) increase in growth, photosynthesis and yield in $C_3$ species (Thornley and Johnson, 2000). Root growth is determined by the plant's actively photosynthesizing leaf area since the roots being heterotrophic tissues depend on energy captured by the leaves- autotrophs (Rayburn, 1993). The plant then uses these sugars to make more complex sugars and starches for storage, cellulose and hemicelluloses for cell walls and proteins for more tissue (Rayburn, 1993). According to Papadopoulos, (1991) the vegetative growth continues in the form of a side shoot growing from the axil of the last leaf, a process known as sympodial growth.

*ii. Differentiation*

Parts of the plant or cells in this process become different. Therefore differentiation can be considered as a process of functional and structural changes of cells and tissues/ organs in the development multicellular systems. It is important to note that these cells (daughter cells) are originally derived from one mother cell- the zygote but acquire different phenotypes. To differentiate cells require specific type and strength of environment stimulus. When cells have acquired specific functional phenotype they are considered to have acquired *determination*. Cell *commitment* on other hand describes stable dedication to a specific specialized fate.

The bases of differentiation may be due to differential DNA replication (gene amplification); differential RNA synthesis (gene transcription) or differential protein synthesis (gene translation). It is important also to consider different cellular functions (the essential functions such as metabolic processes and formation of ATP i.e. activities not related to growth.

*iii. Pattern formation*

Cells and other elements acquire a non- random arrangement. Two critical process have to be distinguished- pattern design and pattern expression. The former is strictly and endogenously regulated (developmental homeostasis) whereas the latter is subject to environment.

*iv. Morphogenesis*

There is development of specific form or shape as defined specific character of the species. The critical stages of development are vegetative, bud, flowering, fruit setting and fruit ripening (Rayburn, 1993). The foliage of mature tomato plants typically consists of leaves that are initiated from the apical meristem ( referred to as main or “ true” leaves) or from Axillary leaves or “suckers” (Decoteau, 1990). A large number of Axillary leaves during the vegetative growth phase often delays initiation of the reproductive phase. In addition, the resulting fruits are smaller than those produced from Tomato plants that had many of their Axillary leaves removed (Decoteau, 1990).

To remain competitive in national and international markets, technologies which contribute to increasing the production per cultivated unit area should include use of high performance culture that fulfills the root needs of the plants (Johns, 2007) which play a major role in the growth and development of the crop.

Tomatoes are classified as determinate or indeterminate depending on their growth characteristics. Determinate cultivars eventually form a flower cluster at the terminal growing point, causing the plant to stop growing in height. Plants that do not set terminal flower clusters, but only lateral ones and continue indefinitely to grow taller are called indeterminate (http://urbanext.illinois.ed/veggies/tomato.cfm). The notable characteristics observed for these two classes are; growth period, planting to harvest period, plant height, bearing period and yields (Amiran, 2000).

### 2.2. Environment and its relationship to plant development

Plants in their natural environment have lived, with almost without exception, in association with soil, an association known as the soil-plant relationship. Crop growth and development is dependant on factors internal and external to the plant. The effect of nutrient on root morphology has been widely studied in artificial soils or solution cultures. However, the effect of this experimental procedure has never been assessed by comparing plant response in artificial and natural soils ( Manuel, 2012).The general heading “Environmental response” has been used to describe the factors affecting crop growth and development such as temperature, water and nutrient requirements and, in some instances; day length and light intensity (Tindall, 1983). These components may be used as a general guide to both aerial and root environment conditions which affect tomato growth and development, although cultivar variation in response to climatic factors should also be taken into consideration. The root environment provides four basic needs of plants: water, nutrients, oxygen, and support. With the advancement of science and technology, humans have provided for these needs in an artificial way and have successfully grown plants without soil (Papadopoulos, 1991). All the various methods and techniques developed for growing plants without soil are collectively called soilless methods of plant culture. These methods include a great diversity of systems, from the purely hydroponic, which are based on water and nutrients only (e.g., nutrient film technique, (NFT), to those based on artificial mixes that contain various amounts of soil. In between these extremes lie a great number of soilless methods that make use of some sort of growing medium, either inert (e.g., rock wool slabs, polyurethane chunks, and perlite or not inert (e.g., gravel culture, sand culture, and peat bags) (Papadopoulos, 1991). This is partly related to the maintenance of an adequate Carbohydrate/Nitrogen balance (Tindall, 1983).

**2.3 Tomato improvement**

One of the major achievements in tomato improvement is the result of the work of the Asian Vegetable Research and Development Center (AVRDC) and research and development programmes done independently by the United States Universities and the Department of Agriculture in Productivity, Adaptability, Reliability, Quality and Special traits. The World Vegetable Center, previously known as the Asian Vegetable Research and Development Center (AVRDC) is the leading international center for vegetable research and development worldwide. It aims at working towards reducing malnutrition and alleviating poverty in developing countries through improved production and consumption of safe vegetables (http://www.globalhort.org/partners/avrdc/. By operating sustainably Universities and the US Department of Agriculture identify sub-optimal performances by developing a science based strategy and boost the overall production efficiency (http://www.heinz.com/data/pdf_files/tomato_sustainability_report.pdf. Currently successful improvements in Tomato growing include actively sourcing and developing new, improved varieties out of the most sophisticated and specialized breeding programmes as well as amendments of the growing environments (Ayres, 1998) making it one of the most rewarding greenhouse crops of the world (htt://www.greenhousegrowing.co.uk © 2010) and one of the most important cultivated and cash crops in the world (Zhou et al., 2011). Worldwide production statistics show 63,988,000 metric tons whose important production regions and tonnage are China-5,474,000mt, Southeast Asia-404,000mt, South Asia-899,000mt, Near east-13,154,000mt, Southern Africa-814,000mt, Developing Africa-2,844,000mt and Latin America-6,677,000mt (FAO, 1988). These figures are the total production figures from the open and protected culture systems.

*i. Tomato production systems- open and protected culture*

Tomatoes are conventionally grown in open- field conditions. However, they are also grown in greenhouses under soil or soil less conditions, a practice referred to as protected culture (Papadopoulos, 1995). Green house cultivation as well as other modes of controlled environmental cultivation have been evolved to create favourable micro-climates, which favour the crop production all through the year or part of the year required and its orientation should permit shadow of the gutter across the greenhouse covered with a transparent plastic film for admitting natural light (Agrictech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation.html) for plant growth.

In the unmodified state, field soils are generally unsatisfactory for the production of plants in containers primarily because soils do not provide the aeration, drainage and water holding capacity required. To improve this situation, peat, bagasse, coconut fiber (Cocus), straw, sawdust, calcine clays, rice hulls and leaf molds have been used (Wilkerson et al., 1994). Soilless growing media is usually used in greenhouses for the production of tomatoes. The growing media though, must be amended to provide the appropriate physical and chemical properties necessary for plant growth. Many commercially important qualities of container grown plants are a function of nutrients and water availability during production (Scagel et al., 2012).

*ii. Detailed environmental requirements*

According to Frantz, (2011), to achieve rapid growth and productivity growers potentially have to control watering and fertility (root environment), $CO_2$ supply, light and temperature (aerial environment). The crop has a high water requirement throughout the growing period, until fruiting occurs. Uneven levels of water application may lead to physiological disorders such as cracking and splitting of the fruit skin. Low temperature retards the growth and, absorption of minerals may be affected. A diurnal variation of at least 5-6$^0$C, within the range of 21-27$^0$C, is considered necessary for optimum growth and development.

*iii. Parameters that influence suitability of a variety for green house culture.*

The parameters that influence suitability of a variety for green house culture should be both vegetatively and reproductively vigorous to achieve high productivity. The yield parameters include Plant height, Fruit number per truss, Number of pickings, Fruit number per plant and Total Fruit weight per plant.

### 2.4 Planting media

Commercially available materials like Peat, Coccus, Vermiculite, Perlite and locally available materials like Sand, Manure and Compost can be used in different proportions to grow greenhouse crops (Agrictech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation.html). They should however be free from Toxic elements, Pests and Diseases.

*Cocus media*

Cocus is a waste bi-product of the Coconut industry. It is sourced from Coconut fibre. It may be composted to produce a material which can increase the aeration and drainage properties of container media. However these do not constitute major commercial sources of organic amendments. The main reason for the Zambian situation is that coccus is an imported material therefore availability is scarce due to sourcing and importation impediments involved.

*Peat + vermiculite*

Peat moss is formed by the accumulation of plant materials in temperate regions under poorly drained environment. It is light in weight and has the ability to absorb 10- 20 times its weight in water. This is attributed to the large groups of water holding cells. The type of plant material and degree of decomposition largely determine its value for use in a growing medium. Vermiculite is produced by heating micacious mineral to approximately 745 $^{\circ}$C. The expanded, plate-like particles which are formed have a very high water holding capacity and aid in aeration and drainage. Vermiculite has excellent exchange and buffering capacities as well as the ability to supply potassium and magnesium.

*Soil*

Soil mixes used for greenhouse production of potted plants are highly modified mixtures of soil, organic and inorganic materials generally combined to improve the water holding capacity and aeration of the potting soil.

## 2.5 Biomass partitioning

Since 90 % of a plant's dry matter is the result of photosynthesis, biomass partitioning seems to be a logical, predictable relationship between net photosynthesis and dry matter content of the whole plant (Moorby 1981). A high investment in the leaves may increase the plants photosynthetic leaf area but this will decrease the relative investment in root biomass and thus decrease the nutrient uptake capacity (Poorter 1991). Plants growing with a low root: shoot ratio have a lower capacity for water and solute uptake than those grown at a higher root: shoot ratio (Abbas, 1983). As the shoot grows larger, it needs more water and nutrients; and the roots usually grow in proportion to such a need ((AVRDC, 1990) implying a proportional investment of assimilates in the roots and foliage.

## 2.6 Yields

Yield is defined as a measurement of the amount of crop that was harvested per unit of land area (Chastain 2000) and the components of yield in the case of tomato) include land area, number of fruits and the weight of fruits. The yield components and the inherent physiological activities involved in their formation interact with the crop growth environment and management practices to affect Yield (Chastain 2000).

Determinate tomato plants grow to a predetermined size and set all their fruit at once. You can expect to harvest 4.5 – 6.8 kg of tomatoes per plant. Indeterminate varieties can produce up to 9 kg per plant (http://www.gotomatogardening.com/2008/12/08/the-average-yield-f).

Tomato breeders release few varieties each year, and knowledge about their performance is extracted from the description released by the company. Many growers, particularly new ones, depend on communication with established growers to choose a variety (Hanna, 2010).

### 2.7 Zambian tomato production

Tomatoes are grown for home consumption in the backyard gardens of almost every homestead across sub-Saharan Africa. It is a cash crop for both smallholders and medium-scale commercial farmers (Varela et al, 2003). In Zambia tomatoes are grown throughout the country all year round for their fruits (Mingochi, 2000). The fruit parameters which determine how good the product is include total soluble solutes expressed as brix, fruit colour shape and flavour. The country's subtropical climate permits production of a wide range of tomato varieties throughout the year and when produced timely, they can provide a reliable and regular source of income to the producer. The low yields would be indicative of a tomato crop grown outside favourable growing conditions (rainy or cold seasons) that attract high weed management requirements, frequent pest and disease outbreaks or retarded growth. Hence the ability of a farmer to control their production environment, such as greenhouse, in those unfavourable seasons, boosts crop productivity and avoids supply shocks (Mwiinga, 2009). Horticultural products, whose production is affected by weather is often associated with

fluctuations in product output related to the season of the year. Between December and April the weather is hot and wet; from May to August it is cooler and dry; between September and November conditions are hot and dry. Average temperatures during the hot wet and hot dry seasons range between 25°C to 35°C, while in cool dry season the range is 6 °C to 24 °C (http://www.worldtravels.com/Travelguide/Countries/Zambia/Climate/). In the hot wet season, disease prevalence, pest and weed infestation are high and therefore during this season, crop management requirements for diseases, pests and weeds are high. In the cooler dry season, temperatures are unseasonably low thereby inflicting cold stress, injury and subsequent retarded growth. Mwiinga (2009) showed that tomatoes are one of the most consumed fresh fruit and vegetable items among urban areas of Zambia namely Lusaka, Kasama, Mansa and Kitwe accounting for over 18% of the fresh fruits and vegetables. Among all fresh fruits and vegetables, tomatoes have the largest share in both production and consumption, following rape (FSRP UCS data, 2007) rendering it to be one of the most widely grown.

### 2.8 Harvesting tomatoes

Tomatoes are ready to be harvested when their colour is even and texture is soft but resilient. They ripen from the bottom or “blossom end” to their tops or “shoulders” where they are attached to the stem (Renee, 2011).

The colour stage description for ripening tomatoes (U.S.D.A, 1991) helps to harvest at the desired time;

i. Green mature-no external colour change from green,
ii. Breaker-not more than 10% colour change from green to red,
iii. Turning-more than 10% but less than 30% colour change from green to red,
iv. Pink- more than 30% but less than 60% colour change from green to red and
v. Red-more than 90% colour change to red.

Source: Standards for Grade of Fresh Tomatoes (7 CFR 51), US. Department of Agriculture.

Fruit at the breaker stage, which have some inter locular gel and a pinkish red colour on the outside, are sure to be mature. The best quality is ensured when vine-ripened tomatoes are harvested at breaker stage (http://www.indiagronet.com/tomato/resources/2/2centre.htm).

The crops grown in open field were exposed to vivid environmental conditions, attack of insects and pests, whereas greenhouse provided a more stable environment. However it is important to consider both the economic as well as cultural optimums. In many cases innumerable amendments can produce growing media with favourable characteristics for desired plant growth.

**Chapter 3**

# 3. MATERIALS AND METHODS

## 3.1. Experimental site

The research was conducted at the Natural Resources Development College (NRDC). The college is located 12 kilometers from the city center on the great east road, latitude 15$^{o}$ 25$^{'}$ S and longitude 28$^{o}$ 17$^{'}$E. The College has a demonstration farm and greenhouses for commercial production. For the purpose of this study, one of the greenhouses and the open field were used. The study location has three distinct seasons: a cool, dry season (April – August); hot, dry season (September – October) and a hot and wet rainy season (November – March).

## 3.2. Agronomic Practices

### 3.2.1. Green house

In order to manipulate temperature, controlled environment in greenhouse was used. Generally however, $CO_2$ supply, light and temperature controls are considered more expensive because their manipulation depends on features such as structure design involving materials, orientation, capacity for supplemental lighting and the geographical location. Based on the type of structure and environmental control, the greenhouse used was curved roof type with environmental control polyhouse which had frames of inflated structure covered with transparent plastic film in which tomato was grown. The structure design of the greenhouse was open sided with plastic covers estimated to have light transmission quality of 300 µmolm$^{-2}$s$^{-1}$ and ambient $CO_2$ levels. The inside temperature was increased when all sidewalls were covered with plastic film providing favourable conditions for tomato growth. It was constructed with timber. Monthly atmospheric temperatures were recorded for the open field (Meteorological data) and greenhouse environments (In-built thermometer readings) refer to Figure 1.The primary environmental parameters controlled were temperature and nature of growing media.

*Media preparation and Transplanting*

Polyethylene sleeves, 45cm high and 30cm in diameter were used (source: Polyethylene Ltd-Lusaka). Growing media was stuffed in 144 sleeves; 48 for each variety. Then a trough with cocus and a soil bed were prepared. According to Tindall, 1983, the nutrient demands of the crop for potash, phosphate and nitrogen are high and fertilizers containing these nutrients should be applied. Trace elements such as boron, zinc and copper have to be added, otherwise deficiencies are likely to affect crop development. The sleeves were arranged in rows. The crop was transplanted in these media on 7$^{th}$ May, 2011, and grown for 5 months. Setting of these transplants was done at 1.5 m inter-row x 0.4 m inter-plant spacing. The plants were trellised at 2 weeks after transplanting to tie the plants for support so that the plants remained erect. At 15 days after setting, pruning (de-suckering) was carried out, leaving a single stem up to 26$^{th}$ July, 2011 when the first harvesting was done.

i. *Source of planting material*

The seedlings were obtained from Sunshine seedlings, Chisamba- Zambia. At transplanting the seedlings were about 10 cm tall and were vigorous without signs of diseases or pests.

ii. *Irrigation*

The crop was under drip irrigation. Water used for irrigation was drawn from a reservoir that was supplied with fertilizers, from boreholes. Ten minutes of irrigation at 3 - 4 days was sufficient to meet the irrigation schedule required. This period was during the cool dry season.

iii. *Fertilization*

A chemical analysis of the media was done to establish the nutrient status, then the nutrient feeding program was adjusted (using a standard case where 1litre of stock solution was diluted in 100litres, then irrigated), refer to Table 1 and 2.

Fertilizers supplying the nutrient feed targets as described in Table 2 were applied through the drip irrigation system.

*iv. Plant protection practices*

Insects and diseases were controlled with preventive foliar pesticide applications. Routine sprays (Thiokill, Cypermethrine, Mancozeb and Copper-oxychloride) against aphids, white flies, red spider mites and fungal diseases were carried out. Weeds were regularly removed.

*v. Harvesting*

Harvesting was done by hand picking for ripened tomatoes every after four days and in the morning. Fruits were harvested, counted and weighed, and the fruit height: diameter ratio calculated for each plant.

The cultivation practices used in terms of Transplanting, Irrigation, Fertilization, Plant protection and Harvesting practices were adopted as recommended by Mathai (1984).

**Table 1** A chemical analysis of the soil and media used in the study

| Nutrient | Chemical constitution of the different media (mg/Kg) | | |
|---|---|---|---|
| | Soil | Cocus | Peat |
| Nitrogen | 0.7 | 0.55 | 1.03 |
| Phosphorus | 40.43 | 266.70 | 250 |
| Potassium | 8.3 | 15.1 | 8.9 |
| Calcium | 18.01 | 5.99 | 10.1 |
| Magnesium | 7.14 | 11.56 | 16.0 |
| Iron | 30.20 | 14.52 | 20.5 |
| Manganese | 1.40 | 10.02 | 6.7 |
| Copper | 8.32 | 1.00 | 16.2 |
| Zinc | 0.33 | 4.76 | 9.6 |
| E.C[z] | 0.2 | 0.592 | 1.62 |
| pH CaCl | 6.6 | 5.8 | 6.5 |

[Z] Measured as mS/cm

**Table 2.** Nutrient content of solution supplied indicating targeted rates and actual amounts in the irrigation water.

| Nutrient | Chemical content of irrigated solution (mg/L) | Target feed content (mg/L) |
|---|---|---|
| Nitrogen | 200.00 | 200.00 |
| Phosphorus | 50.00 | 55.00 |
| Potassium | 400.00 | 300.00 |
| Calcium | 127.00 | 200.00 |
| Magnesium | 50.00 | 55.00 |
| Iron | 8.00 | 3.00 |
| Manganese | 2.00 | 0.50 |
| Copper | 0.07 | 0.12 |
| Zinc | 0.07 | 0.20 |
| $pH_{CaCl}$ | 6.83 | 5.80 |

### 3.3 Experimental design and data analysis

In the greenhouse a Split–plot design with four replications was used (Gomez and Gomez, 1984). Comparatively more sensitivity in media effect and its interaction with variety was required compared to single varietal effect (Cochran and Cox, 1987). Therefore, the main plots were assigned to tomato variety and the split plots were the media. Data were analysed by Superanova computer program (Abacus Concepts, 1984). Mean separation was done by Duncan's new multiple range tests (Cochran and Cox, 1987). A control experiment was conducted adjacent to the greenhouse in the open field. All the three tomato varieties were planted directly into soil and at the same time as for the greenhouse in a Randomised Complete Block Design. Data were analysed just as for the green house experiment.

Measurements taken included plant height at predetermined intervals, number of fruits harvested per plant, fruit weight at ripening – Breaker stage (10% pink red colour), fresh fruit weights, Brix and Biomass partitioning. Other measurements taken were atmospheric temperature, Growing media Physical and Chemical analysis, and dates of flower set.

### 3.4 Field experiment

*Land preparation*

The raised beds were prepared to a fine tilth with a bed centre of 1.5 m and 28 m long. The soil amendments of manuring used were the same with the bed treatment in the greenhouse because predominantly these soils were silty clay soils.

*Planting*

Planting or setting was done on the same day as that of the greenhouse on the 7$^{th}$ of May, 2011. Intra-row spacing was pegged at 0.4 m between plants with a bed centre of 1.5 m. Un-usually cold weather prevailed from setting to about 3 months old ( Figure 1) resulting in poor plant establishment and subsequently few fruits.

*Irrigation and Fertilization*

Nutrition was supplied by the drip irrigation with the source as that for the greenhouses.

*Plant protection*

Routine sprays (Thiokill, Cypermethrine, Mancozeb and Copper-oxychloride) against aphids, white flies, red spider mites and fungal diseases were carried out. Weeds were regularly removed.

*Harvesting*

Harvesting was done by hand picking ripened tomatoes every four days and in the morning. Fruits were harvested, counted and weighed, and the fruit height: diameter ratio calculated for each plant just as for the greenhouse experiment.

### 3.5 Plant materials and planting media

Tomato was planted as three (3) treatments arising from tomato varieties (Rodade, Tengeru and Star 9030).The tomato was established by planting seedlings. The varieties used in the study were selected on the basis of popularity by growers and consumers arising out of the high yield and good quality (Farmer interactions and workshops). Tengeru is a product of the breeding efforts of the Asian Vegetable Research Development Center (AVRDC) in Tanzania and Rodade is an established variety in Zambia that was a product of the American tomato crop improvement. Star 9030 was developed from a high performance testing programme by Starke Ayres (PTY) Limited, a member of the PANNAR group of companies based in Cape Town, South Africa. In the greenhouse the planting media used were Peat in sleeve, Coccus in sleeve, Coccus in trough, Soil in sleeve and Soil bed. The soil used in the sleeves was taken from the site where the field experiment was conducted. In the open field all the three varieties were planted in soil beds. The varieties were all hybrids and popular among local growers, Rodade however is an old variety. The varieties opted had higher yield potential and favorable fruit quality (Kiya et al, 2009).

### 3.4 Temperature

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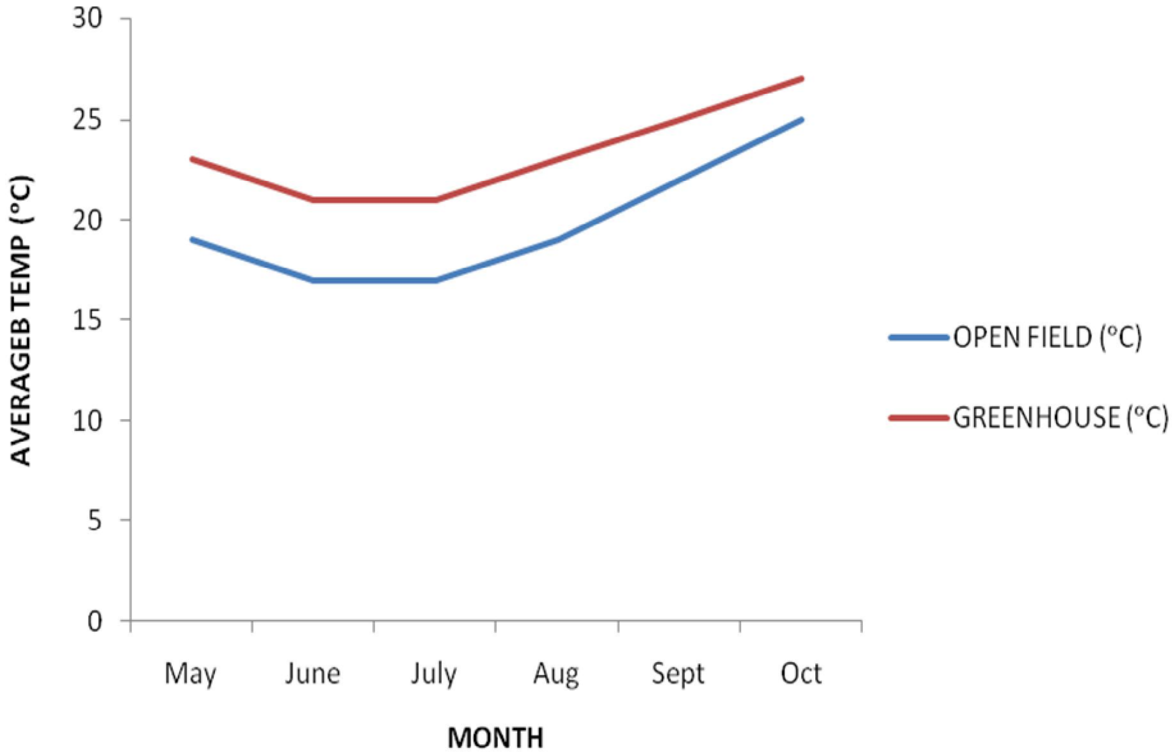


**Figure 1.** Monthly atmospheric temperatures as determined for the open field and greenhouse environments from May to October, 2011.

Temperature readings were recorded as monthly averages for both the ambient open field temperatures and greenhouse using the minimum and maximum temperatures for the period under study.

Chapter 4

# 4. RESULTS

## 4.1. Effects of variety and media on vegetative growth stages in greenhouse grown tomato at 4 and 6 weeks after planting

In the vegetative growth stages of greenhouse grown tomato, there were significant differences among varieties at $p \leq 0.001$ (Table 3). The data revealed that Star 9030 was the tallest at both 4 and 6 weeks after planting. It was 80.1 cm and 100.0 cm respectively, followed by Tengeru at 64.5 cm and 89.3 cm respectively, and then Rodade at 59.2 cm and 82.7 cm respectively. There was a variation in the performance of variety in the different media indicating that there were significant differences among the media. Rodade was tallest planted in direct soil at 71 cm and 85.2 cm respectively, but lowest planted in Soil sleeve at 43.5 cm and 68.6 cm respectively. Tengeru was tallest planted in Direct Soil at 79.0cm and 97.4cm respectively, but lowest planted in Soil sleeve at 51.8 cm and Peat sleeve 85.2 cm respectively. Star 9030 was tallest planted in Direct Soil at 88.1 cm and 114.5 cm respectively, but lowest planted in Peat sleeve at 70.0 cm and 94.6 cm respectively.

Analysis of variance (ANOVA) for Plant height in centimeters at 4 weeks of growth

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 1.8 | 0.6 | 0.5 | 6.9 |
| Media | 4 | 5797.9 | 1449.5 | 877.7*** | 0.001 |
| Rep x Media | 12 | 19.8 | 1.6 | 1.4 | 1.9 |
| Variety | 2 | 9426.0 | 4713.0 | 3958.0*** | 0.001 |
| Var x Media | 8 | 2088.5 | 261.1 | 219.2 *** | 0.001 |
| Residual | 90 | 107.2 | 1.2 | | |

*** Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Plant height in centimeters at 6 weeks of growth.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 12.2 | 4.0 | 1.9 | 1.3 |
| Media | 4 | 1443.5 | 360.9 | 155.8*** | 0.001 |
| Rep x Media | 12 | 27.8 | 2.3 | 1.1 | 3.7 |
| Variety | 2 | 6406.9 | 3203.4 | 1514.1*** | 0.001 |
| Var x Media | 8 | 1027.9 | 128.5 | 60.7 *** | 0.001 |
| Residual | 90 | 190.4 | 2.1 | | |

* * * Highly significant ($p \leq 0.001$)

**Table 3.** Effects of variety and media on vegetative growth stages of greenhouse grown tomato at 4 and 6 weeks after planting.

| Variety (Main plot) | Planting media (sub plot) | Plant height (cm) at different vegetative growth stages after planting 4weeks | 6weeks |
|---|---|---|---|
| Rodade | Direct soil | 71.0d | 85.2d |
| | Soil sleeve | 43.5a | 68.6a |
| | Peat sleeve | 63.3b | 80.1b |
| | Coccus sleeve | 57.5b | 79.4b |
| | Coccus trough | 60.6c | 83.2c |
| | Variety mean | 59.2A | 79.3 A |
| Tengeru | Direct soil | 79.0d | 97.4 d |
| | Soil sleeve | 51.8a | 85.3b |
| | Peat sleeve | 66.2b | 85.2a |
| | Coccus sleeve | 61.2b | 89.2c |
| | Coccus trough | 64.4c | 89.2c |
| | Variety mean | 64.5B | 89.1B |
| Star 9030 | Direct soil | 88.1d | 114.5d |
| | Soil sleeve | 78.4b | 96.1b |
| | Peat sleeve | 70.0a | 94.6a |
| | Coccus sleeve | 79.5b | 98.4b |
| | Coccus trough | 84.4c | 98.5c |
| | Variety mean | 80.1C | 100.0C |

### 4.2 Effects of variety and media on growth reproductive stages of greenhouse grown tomato at 8 and 10 weeks after planting.

In the reproductive growth stages of greenhouse grown tomato, there were significant differences among varieties at $p \leq 0.001$ (Table 4). The mean separation according to the Duncan New Multiple Range test, revealed that Star 9030 grew the tallest at both 8 and 10 weeks after planting(128.1 cm and 147.3 cm respectively), followed by Tengeru(115.0 cm and 134.9 cm respectively), and then Rodade (100.4 cm and 114.2 cm respectively). There was a variation in the performance of variety in the different media indicating that there were significant differences among media used in this study. Rodade was tallest planted in Direct soil at116 cm and 126.6 cm respectively, but shortest in Peat sleeve or Coccus sleeve at 92.4 cm and 99.5 cm respectively. Tengeru was tallest planted in the Soil sleeve 125.0 cm and 140.7 cm respectively, but shortest in Peat or Coccus sleeve at103.2 cm and 126.2 cm respectively. Star 9030 was tallest planted in the Soil sleeve at133.0 cm and 154.4 cm respectively, but shortest planted in Peat or Coccus sleeve at122.8 cm and 134.2 cm respectively. This reproductive growth period was recorded between 18$^{th}$ June, 2011 and 16$^{th}$ July, 2011 owing to the determinate cultivar that had the terminal bud into flowering. Flowering was observed to have started 15 days after transplanting (DAT) for Rodade, 21 DAT for Star 9030 and 27 DAT for Tengeru.

Analysis of variance (ANOVA) for Plant height in centimeters at 8 weeks of growth.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 5.8 | 1.9 | 0.6 | 6.0 |
| Media | 4 | 3775.0 | 943.7 | 184.9*** | 0.001 |
| Rep x Media | 12 | 61.2 | 5.1 | 1.6 | 0.9 |
| Variety | 2 | 15337.9 | 7669.0 | 2471.6*** | 0.001 |
| Var x Media | 8 | 1572.5 | 196.5 | 63.3 *** | 0.001 |
| Residual | 90 | 279.2 | 3.1 | | |

* * * Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Plant height in centimeters at 10 weeks of growth.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 7.5 | 2.5 | 1.3 | 2.7 |
| Media | 4 | 5622.4 | 1405.6 | 1598.8*** | 0.001 |
| Rep x Media | 12 | 10.5 | 0.9 | 0.5 | 9.3 |
| Variety | 2 | 22288.9 | 11144.4 | 5949.6*** | 0.001 |
| Var x Media | 8 | 2082.0 | 260.2 | 138.9 *** | 0.001 |
| Residual | 90 | 168.6 | 1.9 | | |

* * * Highly significant ($p \leq 0.001$)

**Table 4.** Effects of variety and media on reproductive growth stages of greenhouse grown tomato at 8 and 10 weeks after planting.

| Variety (Main plot) | Planting media (sub plot) | Plant height (cm) at different reproductive growth stages after planting 8weeks | 10weeks |
|---|---|---|---|
| Rodade | Direct soil | 111.6c | 126.6c |
| | Soil sleeve | 102.6d | 116.1d |
| | Peat sleeve | 92.4a | 111.1b |
| | Coccus sleeve | 91.1b | 99.5a |
| | Coccus trough | 104.4cd | 115.7cd |
| | Variety mean | 100.4A | 113.8A |
| Tengeru | Direct soil | 117.1c | 130.9c |
| | Soil sleeve | 125.0d | 140.7d |
| | Peat sleeve | 103.2a | 131.5b |
| | Coccus sleeve | 110.4b | 126.2a |
| | Coccus trough | 119.3cd | 140.0cd |
| | Variety mean | 115.0B | 133.9B |
| Star 9030 | Direct soil | 124.8c | 142.6c |
| | Soil sleeve | 133.0d | 154.4d |
| | Peat sleeve | 122.8a | 148.5b |
| | Coccus sleeve | 127.4b | 134.2a |
| | Coccus trough | 132.6cd | 150.9cd |
| | Variety mean | 128.1C | 146.1C |

## 4.3 Variety and Production media effect on reproductive and fruit quality variates of greenhouse grown tomato

*Total Number of fruits Harvested per plant*

The total number of fruits harvested for greenhouse grown tomato showed significant differences among varieties at $p \leq 0.001$ (Table 5). Star 9030 had the highest number of fruits per plant (21) followed by Tengeru (18), and then Rodade (12). The Total fruit numbers for these varieties were highest in Direct soil with (29), (24), and (14) respectively and lowest in Peat sleeve with (15), (13) and (11) respectively.

*Fresh fruit weight*

The Fresh Fruit weights in tons/ha were significantly different at $p \leq 0.001$between varieties and the media (Table 5). The dimensions used for the experimental plots were 4 $m^2$ and extrapolated the fresh fruit weights as; Rodade 6.5 tons/ha, Star 9030 14.0 tons/ha and Tengeru 11.2 tons/ha. These varieties were highest in Direct soil with (8 t/ha), (19.5 t/ha), and (15.2 t/ha) respectively and lowest in Coccus and Peat sleeve with (5.2 t/ha), (10.2 t/ha) and (8.0t/ha) respectively.

*Fruit diameter: height ratio*

The fruit size (which was indicted through the Fruit diameter: height ratio in this study) between Tengeru (0.8) and Rodade (0.8) was not significant but different from Star 9030 (0.9) whilst the media was non- significant among each other (Table 5), being denoted by the same letter (a).

*Brix*

The Brix showed significant differences depending on variety; Rodade (3.5), Star 9030 (4.0) and Tengeru (5.0), (Table 5). Tengeru was highest in Cocus and Soil (5.1) followed by star (4.0) then Rodade (3.7).

Analysis of variance (ANOVA) for total number of fruits harvested per plant

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 0.958 | 0.319 | 0.887 | 4.511 |
| Media | 4 | 1373.550 | 343.387 | 1267.892*** | 0.001 |
| Rep x Media | 12 | 3.250 | 0.271 | 0.752 | 6.972 |
| Variety | 2 | 2071.017 | 1035.508 | 2874.933*** | 0.001 |
| Var x Media | 8 | 306.400 | 38.300 | 106.334 *** | 0.001 |
| Residual | 90 | 32.417 | 0.360 | | |

* * * Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Fresh fruit weight.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 204862.692 | 68287.564 | 1.414 | 2.438 |
| Media | 4 | 94971117.800 | 2374277.945 | 1139.699*** | 0.001 |
| Rep x Media | 12 | 249989.933 | 20832.494 | 0.431 | 9.469 |
| Variety | 2 | 20731277.645 | 1036564.108 | 2146.714*** | 0.001 |
| Var x Media | 8 | 24272479.050 | 3034059.881 | 62.835 *** | 0,001 |
| Residual | 90 | 4345747.000 | 48286.078 | | |

* * *Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Fruit diameter: height ratio

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 0.115 | 0.038 | 1.405 | 2.465 |
| Media | 4 | 0.147 | 0.037 | 0.928 ns | 4.796 |
| Rep x Media | 12 | 0.476 | 0.040 | 1.454 | 1.570 |
| Variety | 2 | 0.0398 | 0.199 | 7.300 ** | 0.012 |
| Var x Media | 8 | 0.960 | 0.120 | 4.404 ** | 0.002 |
| Residual | 90 | 2.453 | 0.027 | | |

* *Significant ($p \leq 0.001$)

ns Not significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Brix (Total soluble solutes).

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 2.447 | 0.816 | 2.123 | 1.029 |
| Media | 4 | 3.065 | 0.766 | 0.840 ns | 5.257 |
| Rep x Media | 12 | 10.943 | 0.912 | 2.373 | 0.105 |
| Variety | 2 | 21.859 | 10.929 | 28.445 ** | 0.001 |
| Var x Media | 8 | 9.021 | 1.128 | 2.935 ** | 0.058 |
| Residual | 90 | 34.580 | 0.384 | | |

* *Significant ($p \leq 0.001$)

ns Not significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Biomass partitioning.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Replication | 3 | 0.103 | 0.034 | 1.259 | 2.465 |
| Media | 4 | 0.023 | 0.006 | 0.222[ns] | 7.656 |
| Rep x Media | 12 | 0.163 | 0.014 | 0.519 | 0.001 |
| Variety | 2 | 0.004 | 0.002 | 0.074 [ns] | 5.566 |
| Var x Media | 8 | 0.021 | 0.003 | 0.111 | 1.978 |
| Residual | 90 | 2.453 | 0.027 | | |

[ns]Not significant ($p \leq 0.001$)

**Table 5.** Variety and Production media effect on reproductive and fruit quality variates.

| Variety (main plot) | Production media (sub plot) | ᶻFruit number per plant | ʸFruit wt (t/ha) | ˣFruit shape | Brix | ʷRoot: canopy ratio |
|---|---|---|---|---|---|---|
| Rodade | Cocus sleeve | 10b | 5.2a | 0.8a | 3.7a | 0.2a |
| | Cocus trough | 12d | 6.8d | 0.8a | 3.7a | 0.2a |
| | Peat sleeve | 11a | 6.3b | 0.8a | 3.4a | 0.2a |
| | Direct soil | 14e | 8e | 0.8a | 3.6a | 0.2a |
| | Soil sleeve | 11c | 6.3c | 0.8a | 3.4a | 0.2a |
| | Rodade average | 12A | 6.5A | 0.8A | 3.6A | 0.2A |
| Star 9030 | Cocus sleeve | 18b | 12.2b | 1.0a | 4.0b | 0.2a |
| | Cocus trough | 24d | 13.8d | 1.0a | 3.9b | 0.2a |
| | Peat sleeve | 15a | 10.2a | 1.0a | 4.0b | 0.2a |
| | Direct soil | 29e | 19.5e | 0.8a | 4.0b | 0.2a |
| | Soil sleeve | 20c | 14.2c | 0.9a | 4.0b | 0.2a |
| | Star average | 21C | 14.0C | 0.9B | 4.0B | 0.2A |
| Tengeru | Cocus sleeve | 15b | 9.0b | 0.8a | 5.0c | 0.2a |
| | Cocus trough | 21d | 13.5d | 0.8a | 5.1c | 0.2a |
| | Peat sleeve | 13a | 8.0a | 0.8a | 4.9c | 0.2a |
| | Direct soil | 24e | 15.2e | 0.8a | 5.1c | 0.2a |
| | Soil sleeve | 17c | 10.2c | 0.8a | 4.9c | 0.2a |
| | Tengeru average | 18B | 11.2B | 0.8A | 5.0C | 0.2A |

[z] Total number of marketable fruit at harvest.
[y] Total weight of marketable fruit at harvest..
[x] Calculated as ratio of diameter to height ratio determined at harvest.
[w] Ratio of fresh weight canopy to root ratio as determined at maturity.

Figures followed by same letter within columns were not significantly different at $p \leq 0.001$

## 4.4 THE FIELD TRIAL

The field trial was laid down as a single factor experiment replicated four (4) times in a randomized complete block design. All other practices were the same as in the greenhouse. The trial revealed that the height in centimeters of all the varieties were significantly different at $p \leq 0.001$ and the tallest was Rodade followed by star 9030, then Tengeru at 4 , 8 and 10 weeks of growth (Figure 2). These results gave a comparative study to those of the greenhouse and clearly, there were significant differences in vegetative growth stages observed. The results in figure 2 show a very slow growth rate to about 6 weeks after setting. From the observations made, the compensation growth that followed in the latter weeks was not very vigorous though, despite the rise in the temperatures experienced. Therefore the growth pattern from 4 to 10 weeks of growth was similar. The dimensions of the experimental plots used were the same as those in the greenhouse.

Analysis of variance (ANOVA) for Plant height (in centimeters) at 4 weeks of growth.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 801.583 | 400.792 | 91.734** | 0.001 |
| Residual | 21 | 91.750 | 4.369 | | |

* *Significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for Plant height (in centimeters) at 6 weeks of growth.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 360.583 | 180.292 | 22.093** | 0.001 |
| Residual | 21 | 171.375 | 8.161 | | |

* * Significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for plant height (in centimeters) at 8 weeks of growth

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 265.750 | 132.875 | 38.621** | 0.001 |
| Residual | 21 | 72.250 | 3.440 | | |

* * Significant ($p \leq 0.001$)

Analysis of variance (ANOVA) for plant height (in centimeters) at 10 weeks of growth

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 294.333 | 147.167 | 50.252** | 0.001 |
| Residual | 21 | 61.500 | 2.929 | | |

* * Significant ($p \leq 0.001$)

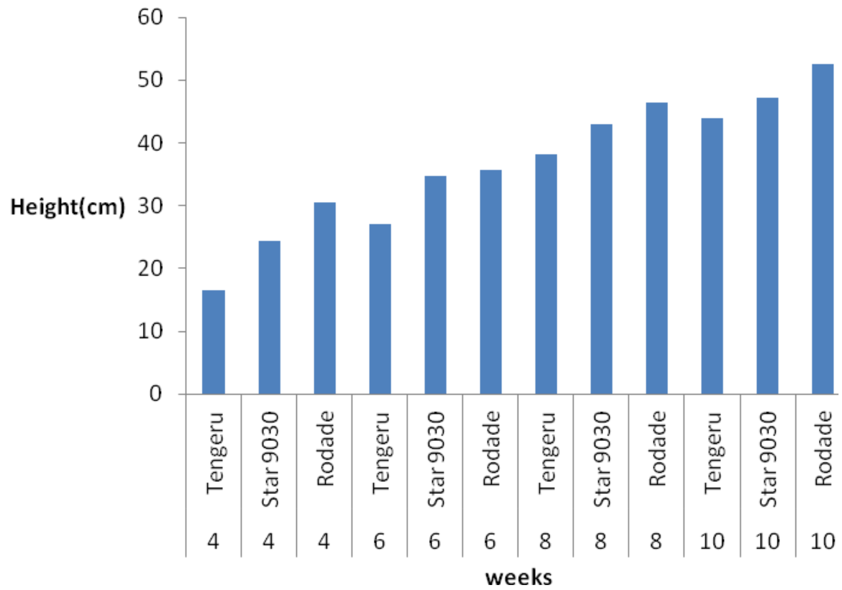


**Figure 2.** Effect of tomato variety on shoot growth in the open field. Plant height is expressed in cm and was collected at 4, 6, 8 and 10 weeks of after planting in the field.

### 4.4.1 Effect of Variety and Production media on reproductive and fruit quality variates of field grown tomato;

*Total Number of fruits Harvested per plant*

The total number of fruits harvested for open-field grown tomato showed significant differences among varieties at $p \leq 0.001$ (Table 6). The mean separation according to the, revealed that Star 9030 had the highest number of fruits per plant (12) followed by Tengeru (10), and then Rodade (5).

*Fresh fruit weight*

The Fresh Fruit weights in tons/ha were significantly different at $p \leq 0.001$ between varieties (Table 6). The dimensions used for the experimental plots were $4m^2$ and extrapolated the fresh fruit weights as; Rodade 3.8tons/ha, Star 9030 8.5tons/ha and Tengeru 6.2tons/ha.

*Brix*

The Brix showed significant differences depending on variety; Rodade (3.5), Star 9030 (4.7) and Tengeru (3.7), Table 6. Star was (1.0) higher than Tengeru and (1.2) higher than Rodade when all were grown in soil.

Analysis of variance (ANOVA) for Total Number of fruits harvested per plant.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 216.083 | 108.042 | 386.191*** | 0.001 |
| Residual | 21 | 5.875 | 0.280 | | |

* * * Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA); for Total Fresh fruit weight.

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 14079805.083 | 7039902.542 | 621.916*** | 0.001 |
| Residual | 21 | 237713.875 | 11319.708 | | |

* * *Highly significant ($p \leq 0.001$)

Analysis of variance (ANOVA); for Brix (Total soluble solutes).

| Source of variance | Degree of freedom | Sum of squares | Mean squares | F-value | P-value |
|---|---|---|---|---|---|
| Variety | 2 | 7.006 | 3.503 | 143.183*** | 0.001 |
| Residual | 21 | 0.514 | 0.24 | | |

* * *Highly significant ($p \leq 0.001$)

**Table 6.** Variety and Production media effect on reproductive and fruit quality variates in tomato grown under field conditions.

| Variety (main plot) | Production media | Fruit number per plant | Fruit weight (t/ha) | Brix |
|---|---|---|---|---|
| Rodade | Soil | $5^{av}$ | $3.8^{a}$ | $3.5^{a}$ |
| Tengeru | Soil | $10^{b}$ | $6.2^{b}$ | $3.7^{b}$ |
| Star 9030 | Soil | $12^{c}$ | $8.5^{c}$ | $4.7^{c}$ |

$^{v}$ Means within same row and column for each variety with different superscripts are significantly different according to Duncan multiple range test ($p \leq 0.001$).

Chapter 5

## 5.0 DISCUSSION

In the greenhouse experiment, plants were submitted to five levels of media supply. In four artificial media made of coccus in sleeve, peat in sleeve, soil in sleeve and cocus in trough and one natural soil. Deep differences in plant homeostasis, growth and development were observed in the sub-plots.

The results showed that the growth of the tomato varieties in all the media started slowly from setting to 6 weeks after setting and so demanded minimum use of nutrients and waste of available photosynthates (Marschner, 1986). After several leaves had formed, the growing point changed from vegetative to reproductive phases, and a cluster of flowers were formed that ultimately developed into the first fruits or trusses. The sympodial growth was faster in varieties grown in the greenhouse than those in the open field and more so for star 9030 in the soil bags probably owing to the Tomato being a warm season crop (Mathai, 1984) and that some varieties are determinate, others indeterminate (Papadopoulos 1991). The pre-harvest and harvest period between May and September during which the crop was grown was unseasonably cold, resulting into a large amount of slow establishment and subsequent growth retardation of indeterminate varieties that had more growing points being damaged in the Open field. The crop plant could get damaged due to metabolic toxicity, membrane disorganization, inhibition of photosynthesis, and altered nutrient acquisition (Ismail and Hall, 1999). Plant growth was not maintained in the greenhouse artificial media and the open field; however it was maintained in the greenhouse natural soil where the plants grew faster and differently. A few multifactor environmental studies have been conducted on a handful of greenhouse crops. Krizek et al, (1974) evaluated cucumber (*Cucumis sativa* L.), tomato (*Solanum Lycopersicon* L.) and Lettuce (*Latuca sativa* L.) seedling growth in various combinations of light, temperature and $CO_2$ concentrations. The influence of each environmental parameter depended largely on the species. In this study temperature was a key factor determining optimal growth and productivity of the varieties. According to Zhou et al, (2011), significant inhibition of photosynthesis occurs at temperatures only a few degrees above or below the optimum range, resulting in a considerable loss of potential productivity. Thus pot-experiment in the greenhouse aimed to compare crop response towards uniform treatments of different growing media (Cottenie, 1980) giving a screening method to select for significant responses towards a given treatment. After having stated the probability of positive responses by means of greenhouse experiment, the field study indicated a way to verify the effectiveness of the varieties.

Failure to maintain a good balance between vegetative and reproductive growth during the first 2-3 months of growth in the open field resulted in plants that grew very slowly. The plants had thinner stems  possibly an indication of assimilate deficits leading to slow growth and ultimately low productivity. A complicating factor of these slow growth rates was that individual plants differed considerably. In practice growers can boost productivity by choosing less expensive crop improvement controls. Hence in the present study, results show that tomato crop improvement could be enhanced by growers having a choice between ‘media x variety’. This study has revealed that Star 9030, grown in direct soil treatment grew faster and yielded higher than the other varieties during this period of study under greenhouse conditions.  However, all the 3 varieties performed best in direct soil (Table 4 and 5). Longer and warmer days that occurred later in the season did not appear to compensate for low growth early production in the open field.

Temperatures in the greenhouse were above $21^{\circ}C$ (Fig1) and probably favoured higher productivity than those temperatures in the open field. The air temperature in this study was therefore attributed as the main environmental component influencing vegetative growth, cluster development, fruit setting and subsequent fruit development and ripening. This agrees with the ecology of tomato according to UNICEF, 2006 which states that tomato thrives well in temperatures between 21 °C and 28 °C, preferring deep, friable soils rich in organic matter.

The yield and yield components as described by Monamodi, 2011 (Plant height, Fruit number per truss, Number of pickings, Fruit number per plant and Fruit weight) showed significant differences among the different media and between the varieties (Tables 5). This can be attributed to the differences owing to the media's water and nutrient holding capacity. In soil the roots and root hairs are in intimate contact with the soil colloidal surfaces giving it a better media for cation exchange and nutrient absorption than peat or coccus therefore as shown by the results Star 9030's in the soil bed had the highest number of fruits harvested per plant (29) and a mean yield in tons/ha of (19.5) followed by Tengeru (24) and (15.2), then Rodade with (14) and (8) respectively as indicated in Table 5, qualifying Star 9030 in the soil bed for optional treatment. Yields varying from 5-15t/ha were obtained; these can be exceeded if the management of the crop is of a high standard and the environmental conditions are favourable to growth and fruiting (Tindall, 1983). The results of this experiment seemed to fall within this range. Previous research (Togo, 2011) who did a study on yield responses to irrigation and nitrogen fertilizer rates on Artichoke has demonstrated that there are strong interactions for yield and yield components. It would therefore, be expected that there was better crop nutrient use efficiency. During commercial production, the ability to control crop growth and yield by manipulating the environment is desirable. Rodade in the open field grew the tallest but star 9030 yielded the best (Fig 2 and Table 6). This type of polyhouse helped or permitted off-season production by way of controlling temperature and nature of root medium. It allows growers to schedule and improve crop productivity (Blanchard and Runckle, 2008).

Plants grown with a low root: shoot ratio have a lower capacity for water and solute uptake than those grown at higher root: shoot ratio (Abbas, 1983). In this study the root: shoot ratio did not appear to depend on the varieties since none were significant. Since 90% of a plant's dry matter is the result of photosynthesis, biomass partitioning seems to be a logical, predictable relationship between net photosynthesis and dry matter content of the whole plant (Moorby, 1981). Therefore a low investment in the leaves may have decreased the plant's photosynthates thereby decreasing the relative investment in root biomass and thus decreasing the nutrient uptake capacity. In this study, the different 'variety x media' interactions show that for soil x Star 9030, there was a shift of biomass to below ground tissues prompting the productivity to be higher.

The media did not have any effect on the fruit size and shape as indicated from the fruit diameter: height ratio.  Brix was significantly different between Rodade, Star 9030 and Tengeru indicating that Brix was influenced by variety.

Chapter 6

## 6.0 CONCLUSION AND RECOMMENDATIONS

The greenhouse environment affected crop productivity and quality. There were significant differences in performance amongst varieties (Rodade, Tengeru and Star 9030) grown under different environments. Vegetative growth and development depended on to the capacity of the media for retention and maintenance of nutrients and water. Possibly different types of media held moisture and nutrients in varying amounts for use by the growing plants thereby affecting the growth and development of the cultivars studied differently. Plant responses to different media included differences in the growth of shoots and differences in the reproductive variates of plant development. Further this study indicated differences among varieties. The results from the study showed that: In the greenhouse Star 9030 grown in soil bed grew taller than the other 2 varieties. The trend of these results was significant from 4 weeks after transplanting. The total fruit number and weight of Star 9030 grown in soil bed (29 and 19.5t/ha) was significantly higher than Rodade (14 and 8t/ha) and Tengeru (24 and 15t/ha) compared to other media ($p \leq 0.001$), whilst the root: shoot ratio was not significant among the cultivars and media. The total soluble solid content expressed as Brix was significantly different between varieties, Tengeru with 5.0 was highest followed by Star 9030 with 4.0, Rodade with 3.5. ). Fruit diameter: height ratio was not different between Rodade and Tengeru but significantly lower than Star 9030 whilst the effect of media showed no significant differences.

In comparison to the greenhouse results, the field experiment performance was as follows; the mean fruit weight was; Star 9030 (12 t/ha), Rodade (5 t/ha) and Tengeru (10 t/ha) whilst total soluble content at 4.7 for Star 9030, , 3.5 for Rodade and 3.7 for Tengeru was not significantly different among the different varieties .

According to this study, to achieve optional greenhouse use for tomato production in Zambia conventional cropping in soil with star 9030 gives better growth response than Rodade or Tengeru. The soil should be well-aerated with a high water holding capacity, rich in nutrients and free from pathogens, classified as loams, sandy loams or silty loams, all with high organic matter content.

This study indicated that Star 9030 probably grown directly into the soil beds offer appropriate alternatives for tomato production in Zambia. The importance of the study was that, since the performance of tomatoes was higher in soil media, it was therefore not necessary as a country to be importing an expensive media such as cocus for tomatoes production and possibly other horticultural crops when its performance was not superior to soil. Performance could still be enhanced by mixing local media.

Although Tomatoes may be an option for utilizing greenhouse space, further research for modifications to recommended mixtures of growing media against seasons and varieties should be conducted. However, greenhouse soil that has good texture and structure is a valuable asset as a growing medium.

Chapter 7

## 7.0 LITERATURE CITED

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**APPENDIX**

**Appendix A.** Plate showing tomato grown under greenhouse in the study.

**Appendix B.** Plate showing tomato grown under greenhouse in the study.